The Effect of Different Checkerboard Sizes on Steady State Visually Evoked Potentials

Randy R. Deng
Science Research Program Ridgefield High School
Contact: randyrdeng@gmail.com

Research was conducted at Old Dominion University
University in Norfolk, Virginia
Mentor: Professor Dean Krusienski

Abstract

A major challenge since the invention of the steady-state visually evoked potential (SSVEP)-based Brain-Computer Interface (BCI) has been improving accuracy and signal recognition. Although SSVEPs have exhibited high accuracy rates with subjects with minimal BCI exposure, to be reliable for everyday use, BCIs must achieve high, if not 100% accuracy. In this study, we examine the effect of altering the size of the checkerboard pattern on the SSVEP signal at 6Hz and 10Hz. The size of the pattern was evaluated on a continuum from a large pattern, which is equivalent to a solid flashing stimulus, to a bounded single pixel checkerboard (256x256 pixels) with the same boundary. The boundary was a 256x256 pixel square. The number of checkerboard tiles quadrupled with each increase (the number of checkerboard tiles in each side was doubled), resulting in the following checkerboard sizes: 1x1, 2x2, 4x4, 8x8, 16x16, 32x32, 64x64, 128x128, and 256x256 (pixel size). A Fast Fourier Transform was done to graphically display the power spectral density (PSD) of the SSVEP signals and a paired t-test was done between the increasing checkerboard and solid stimuli with their respective frequencies to see if there was any significant power difference. Results indicate that 2x2 and 4x4 stimuli generally create the most distinct SSVEP signal, which becomes less noticeable as the checkerboard stimuli size became smaller.

1.0 Introduction

In the world today, people are suffering from neuromuscular disorders such as amyotrophic lateral sclerosis (ALS), also known as Lou Gehrig's disease, brain stem stroke, and spinal cord injury. These people lack the means to communicate and interact with the world through conventional methods, Therefore, brain-computer interfaces (BCI) have been invented to help transform brain generated electrical signals into commands, thereby bypassing the regular path of the nervous system [1]. However, BCIs are not limited to medical purposes. Applications in gaming, computer and robot control, and more are currently being explored by researchers [13]. Though the past few decades have shown significant advancements in BCI technology, BCIs are far from perfect and require many improvements in accuracy, speed, and efficiency [2].

Steady-state visually evoked potential (SSVEP) based BCIs are a viable solution as they require very little training and tend to obtain high accuracy, making them a reliable alternative to other input signals. Many studies and surveys on SSVEP signal detection have concluded that SSVEP signals are affected by color, frequency, and texture of the stimuli [8, 9]. The two most common types of SSVEP stimuli are the solid color and pattern reversal (often in a checkerboard pattern) [8]. Although there is still some debate on whether the solid black and white flashing stimulus is better than the inverting checkerboard flashing stimulus, there have not been any studies done on which checkerboard size is optimal for SSVEP detection.

In this study, we examined the effect of altering the size of the checkerboard pattern on the SSVEP signal at 6Hz and 10Hz. The size of the pattern was evaluated on a continuum from a large pattern, which is the equivalent to a solid flashing stimulus, to a bounded single pixel checkerboard (256x256 pixels) with the same boundary. The boundary was a 256x256 pixel square. The size of the checkerboard sides were divided in half each time, resulting in the following checkerboard sizes: 1x1, 2x2, 4x4, 8x8, 16x16, 32x32, 64x64, 128x128, and 256x256 (pixel size).

2.0 Methodology

2.1 Experimental Setup

A total of 18 different SSVEP stimuli were tested. There were 9 different checkerboard sizes (1x1, 2x2, 4x4, 8x8, 16x16, 32x32, 64x64, 128x128, and 256x256 pixel size) and 2 different frequencies (6 Hz and 10 Hz). The 1x1 solid SSVEP stimuli acted as a control for the experiment due to its high usage in several studies [3, 4, 5, 6, 8]. The size of each stimuli was a 256x256 pixel square. Each stimuli was tested twice for each subject during the study. Subjects were to look at each of the SSVEP stimuli and the data recorded would indicate which checkerboard size is optimal for signal detection.

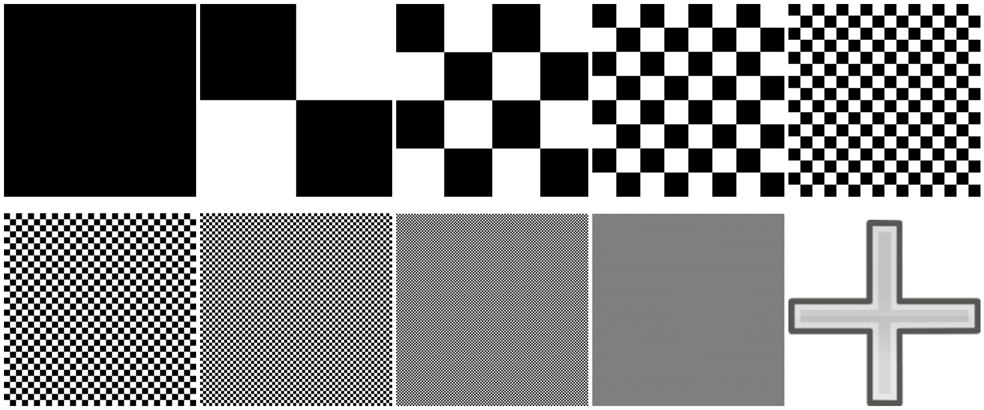

Figure 1.These images show the 9 different checkerboard sizes used, ranging from a 1x1 solid SSVEP stimulus to a 256x256 pixel sized SSVEP stimulus. As seen, as the checkerboard size increases, the checkerboard looks more and more gray. The final image shows a zoomed in cross, which was placed in the center of each of the SSVEP stimuli as a focus target for subjects. The cross was 50x50 pixels on the screen.

During the course of the experiment, 5 subjects (3 males and 2 females), from ages 18-30, were used. Subjects were seated 60 centimeters away from a Samsung TV screen. The TV screen was connected to a laptop, which was used by the experimenter to monitor the subjects' status. C Sharp was used to create the SSVEP stimuli and time the length of the stimulus while BCI2000 was used to set up the experiment and record raw data.

Subjects were instructed to look at the black cross on the center of the SSVEP stimuli square. The black cross was 50x50 pixels and did not disrupt the flashing stimulus. The experiment had an initial 10 second rest period in which the screen did not flash. Afterwards, each stimuli was presented for 30 seconds with a 5 second rest period in between each stimuli. There were a total of 36 stimuli to account for the 9 different checkerboard sizes and the 2 different frequencies used (6 Hz and 10 Hz). Each stimuli was presented twice. The order in which the stimuli were displayed was randomized and the experiment for each subject was completed in a single sitting. Since each stimuli was tested twice, the length of the experiment was 21 minutes and 10 seconds (1270 seconds).

2.2 Feature and Feature Analysis

A 16 channel EEG cap with active electrodes was used for the study. A reference electrode was placed on the mastoid, a ground electrode was placed on the ear, and a wrist electrode was attached to monitor any movement. The EEG cap electrodes were attached to a gGamma system preamplifier which was connected to a Bioamplifier made by gTech.

Signals were sampled at a rate of 256 Hz and a chebyshev type 2 filter was used to filter out any signals outside the 1-30 Hz frequency range. A 50 Hz notch filter was used to remove any electrical noise in the room. MATLAB was used to analyze the EEG raw data. MATLAB was also used to filter out the data from when the checkerboard stimulus was not flashing. The remaining data was reorganized and compiled in order from the largest checkerboard size (1x1) to the smallest checkerboard size (256x256). A Fast Fourier Transform (FFT) with a hamming window of length 256 samples with 50% overlap was used to create a power spectral density (PSD) graph in frequency domain. After completing the FFT, the average power was computed by averaging a 2 Hz frequency bin around the stimulus frequency to mitigate the effects of any errors created by the SSVEP stimulus flash and alpha noise. For the 6 Hz signal, signals within 4-8 Hz had their powers averaged and for the 10 Hz signal, signals within 8-12 Hz had their powers averaged.

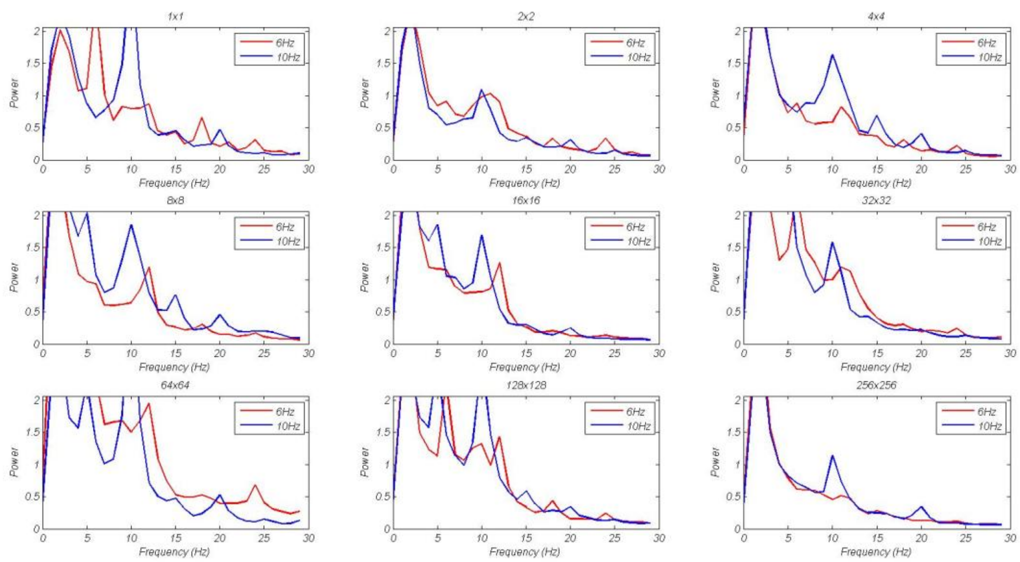

Figure 2. The subplots for subject GDJ001 are displayed above. The 6 Hz and 10 Hz non-averaged powers were plotted on the same graph for each of the 9 checkerboard conditions. Peaks can be seen at 6 Hz and 10 Hz, as well as their corresponding harmonics, 12 Hz and 20 Hz. Because some of the frequencies seemed slightly off, frequencies within 2 Hz of the stimulus frequency were averaged to mitigate any effect it may have had.

The 6 Hz and 10 Hz non-averaged powers were graphed together on 9 different subplots, each corresponding to 1 checkerboard size. A scatter plot with a power regression line and bar graph showing the averaged powers was also created. Lastly, a paired t-test was done to see if the power in different checkerboard sizes differed from the solid SSVEP stimuli. If there was a statistically significant difference ($p<0.05$), then a second paired t-test was done to see if the average power in the different checkerboard sizes was significantly larger ($p<0.05$) than the solid SSVEP stimuli power.

2.3 Safety

In accordance with Old Dominion University's IRB approval, only healthy individuals were used. Individuals with any sort of severe medical condition, physical disability, or epilepsy were not permitted to undergo experimentation. Prior to experimentation, subjects were given an informed consent form to read and sign, verifying that they understand the implications of this study and agree to participate in the study. During the experiment, an experimenter was always in the room with the subject in case there was an emergency.

3.0 Results and Conclusions

Figures 3 and 4 show a scatter plot and bar graph of the average (PSD) for the 6 Hz and 10 Hz SSVEP stimuli of subject GDJ001. The numbers 1-9 labeled on the x-axis denote the 9 different checkerboard sizes used. The numbers indicate the checkerboard size in descending order where 1 corresponds to a 1x1 checkerboard and 9 corresponds to a 256x256 checkerboard. The 2 graphs indicate that the average bin power decreased on checkerboard sizes 2, 3, and 4, but increased to a peak at 7 before decreasing again. As seen, there does not seem to be a significant difference between checkerboard size 1 and checkerboard sizes 6-8 PSDs. Checkerboard size 9 (pixel size), shows a significant drop in average bin power. The reason for these two observations may due to the fact that although the checkerboard is increasing, the actual checkerboard size is becoming smaller. At a certain point, perhaps around checkerboard sizes 6-8, the smaller checkerboard sizes may seem to look more like a solid color stimuli, which is why the average bin power is very similar. The reason there is a significant drop at the pixel sized checkerboard is because the SSVEP stimuli was not very noticeable. In figure 1, the pixel sized checkerboard looked essentially gray, which is due to the fact that the checkerboards were so small, the black and white colors to the human eye would appear gray. Therefore, when this stimulus was flashing, the SSVEP signal would not be very noticeable. Since SSVEP signals rely on the human eye to notice visual stimuli, if no stimuli is detected, there will not be a noticeable SSVEP signal. Instead of there being a noticeable color change between black and white, checkerboard size 9 would only appear to the human eye as a gray flicker.

These graphs only show the results of a single subject because the power spectral density may vary from person to person. Though the general trend of the graphs may be similar, the PSD numerical values may fluctuate. Therefore, averaging the bin power of each subject is not a viable option as it would not properly generalize the whole population. Moreover, there have been several cases of "BCI illiteracy," a condition where subjects obtain accuracy levels of below 70%, that may skew the averaged data. The reason for this is unknown and is still being explored by researchers. Data all of the subjects can be found in the appendix.

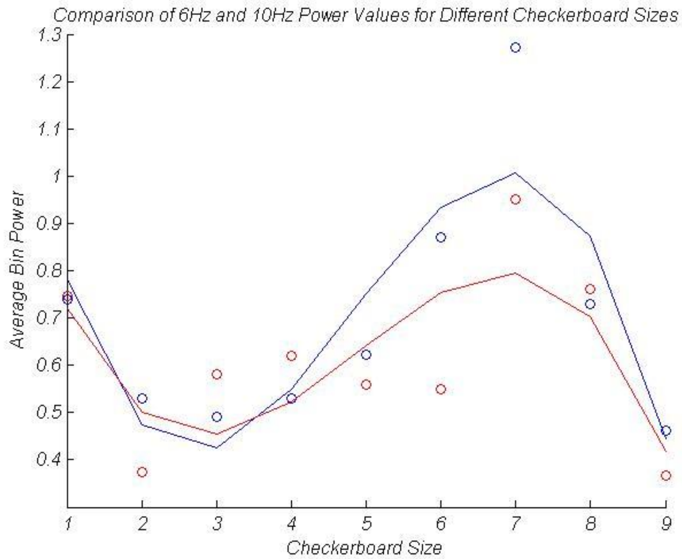

Figure 3. This scatter plot shows a comparison of 6 Hz and 10 Hz PSD values for the 9 different checkerboard sizes. A power regression line was drawn to show the trend of changes in power as checkerboard size increased. There is a peak at checkerboard size 7, and then a significant decrease at checkerboard size 9.

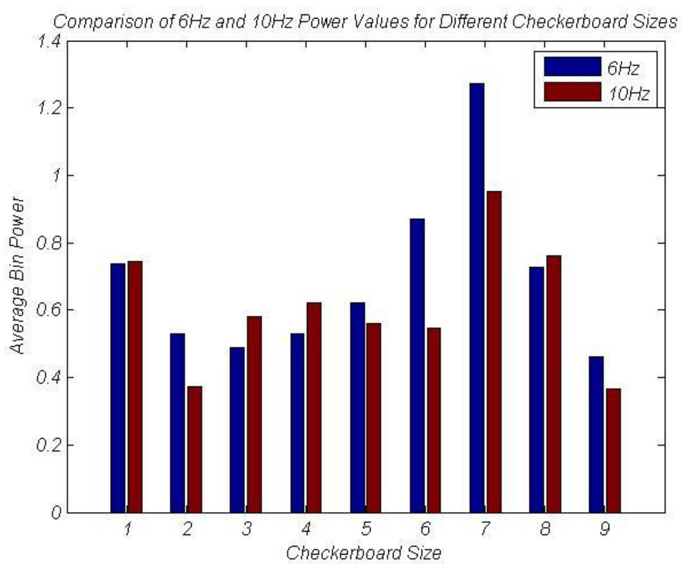

Figure 4. This bar graph shows a comparison of 6 Hz and 10 Hz PSD values for the 9 different checkerboard sizes. This arrangement makes it easier to see how the 6 Hz and 10 Hz PSD values differed between each other for each of the 9 checkerboard sizes. Although the frequencies generally created the same bin power for each checkerboard size, there are some significant differences at checkerboard sizes 2 and 7. However, this may be due to alpha noise that appears in the 8-12 Hz frequency range, which will amplify the 10 Hz signal.

A paired t-test was done between the alternating checkerboard sizes and solid stimuli with their respective frequencies to see if there was any significant power difference. The non-averaged powers were used to compute the p-value because it would be incorrect to use the averaged powers since they are averaged, resulting in a wrong number of trials.

The t-test chart created (see appendix) shows the results of the 5 subjects t-tests. Subjects GCM001, GCS001, GDJ001, NRW001, and YS001 represent the 5 subjects used in the study. The null hypothesis, H0, is that there is no significant difference in the altering checkerboard size PSD and the solid color stimuli PSD. A 1 indicates that the H0 is rejected ($p<0.05$) and a 0 indicates that the H0 is not rejected ($p>0.05$). The alpha level used was 0.05 significance. If there was a significant difference in the PSD, then a second paired t-test was done to see if the checkerboard stimuli PSD was significantly larger than the solid SSVEP stimuli. The p-value for each of the first t-tests is given. This was done for both the 6 Hz and the 10 Hz signals and repeated for all subjects. NaN indicates that a t-test was not able to be conducted because a t-test cannot compare an observation with itself.

At the very bottom of the t-test chart is a tally of how many subjects indicated that there was a statistical significance. It is organized in the same way as the t-test data for the subjects. The results show that for most subjects, the 2x2 and 4x4 checkerboard size PSD was statistically larger than the solid SSVEP stimuli. The number of subjects indicating a statistical difference gradually decreased as the checkerboard sizes increased, reaching a low at checkerboard size 7 (64x64). Interestingly, approximately half the subjects indicated that checkerboard sizes 8 (128x128) and 9 (256x256) PSDs were statistically larger than the solid SSVEP stimuli. This may be due to the fact that when the Samsung TV screen was flashing a pixel sized checkerboard, we observed a very faint line flashing with the SSVEP. The Samsung TV may not have been capable of flashing a pixel sized checkerboard, resulting in a faint line appearing. However, this may explain why the 256x256 checkerboard had a greater PSD. Because the faint line was also flickering, this may have created an unintended SSVEP signal. This line was not observed in any of the other SSVEP checkerboard patterns..

4.0 Discussion

This study shows that overall, the 2x2 and 4x4 checkerboard sizes exhibit the greatest PSD values which can be used in the future for increased detection accuracy of SSVEP checkerboard stimuli. We recognize that there are some issues, such as alpha noise influencing the 10 Hz SSVEP signal and the faint line appearing in the pixel sized checkerboard, however, the results are still reliable. Though the data was slightly influenced by alpha noise and the faint line on the pixel sized checkerboard, the data was mostly uninfluenced. The 6 Hz data, most of the 10 Hz data, and all the checkerboard sizes with the exception of the pixel sized checkerboard all showed legitimate and proper results. The general trend in the data was that as checkerboard sizes decrease, the PSD value will also decrease. However, as we approach pixel size, there was an increase in power and statistical analysis showed that it was statistically larger than the solid flashing stimulus's power value. But, due to the faint line interfering with the pixel sized stimulus, more research needs to be done on whether pixel sized checkerboards really do have an increased power. Nevertheless, this data shows that 2x2 and 4x4 sized checkerboards are optimal and that SSVEP size may be a major factor when considering which SSVEP stimulus to use.

4.1 Future Research

In the future, I would like to do an extended version of this study, which would resolve the issues mentioned in this paper as well as conduct an online study to measure accuracy rate, ITR, and bit rate. By doing another study similar to this one, I could explore if frequency would have a significant effect on the power of changing checkerboard sizes. In addition, I could also monitor how stimulus size impacts the detection of the SSVEP signal. his would allow researchers to select which stimuli to use in order to maximize accuracy and reliability.

5.0 Acknowledgements

I would like to thank Mr. Patrick Hughes, my teacher, from Ridgefield High School in Ridgefield, CT, for guiding me through my research and helping me set long term goals for myself to complete my research. I would also like to thank Professor Krusienski from Old Dominion University in Norfolk, Virginia and his PhD students for teaching me proper BCI protocol and how to code in C Sharp and MATLAB. These people were immensely helpful and I would not have been able to complete my research without them.

6.0 References

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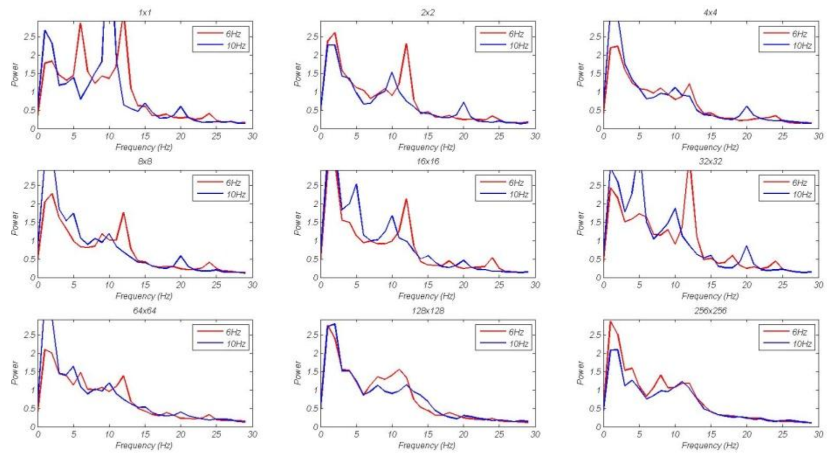
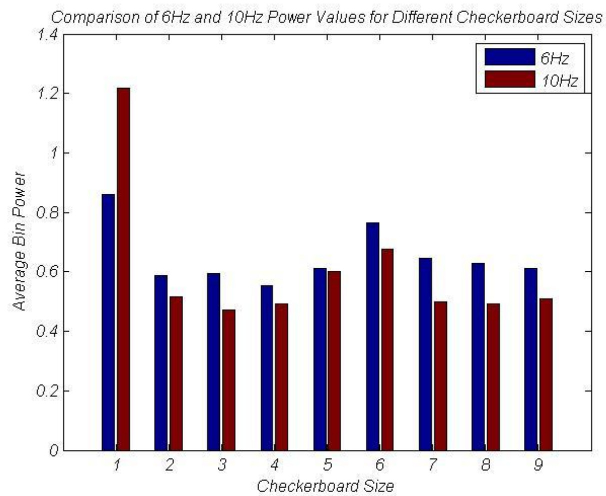
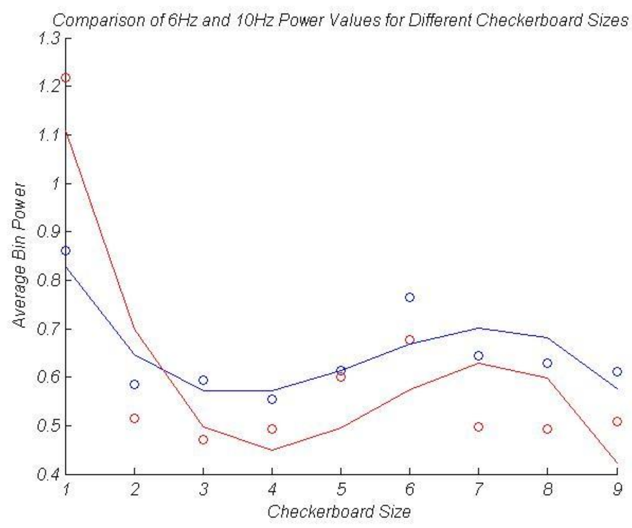
Appendix A - Graphs of the power values for the following 5 subjects: GCM001, GCS001, GDJ001, NRW001, and YS001

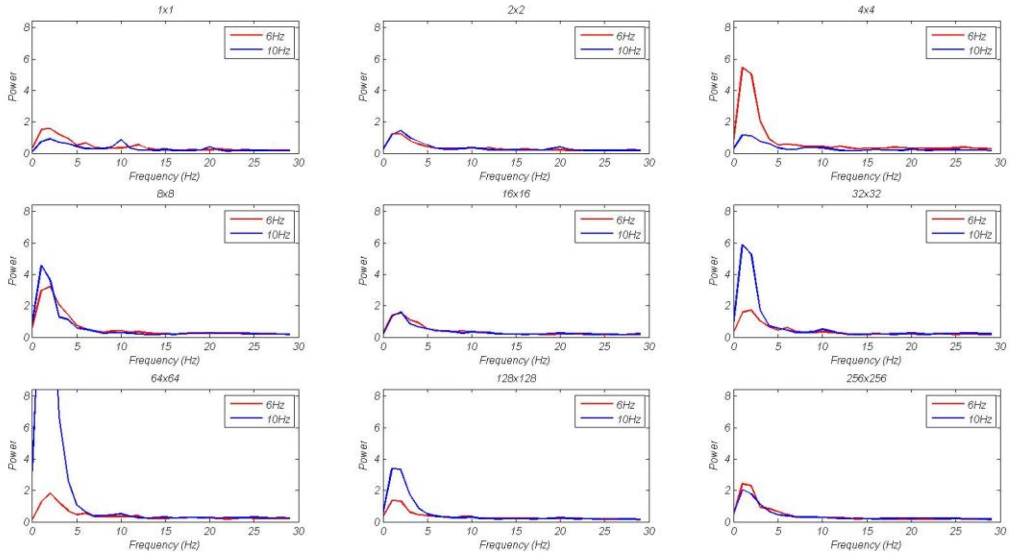
GCM001

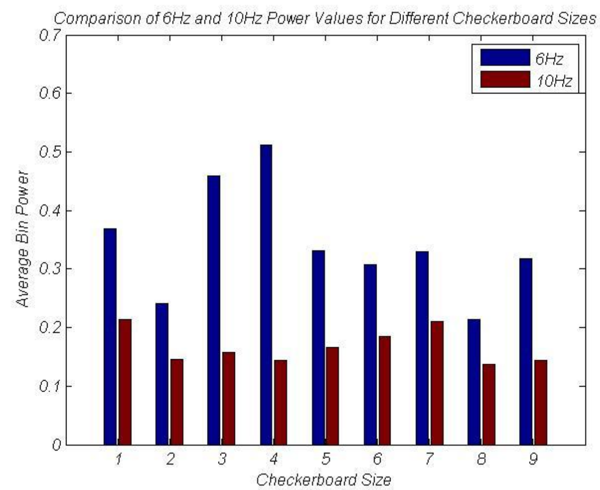


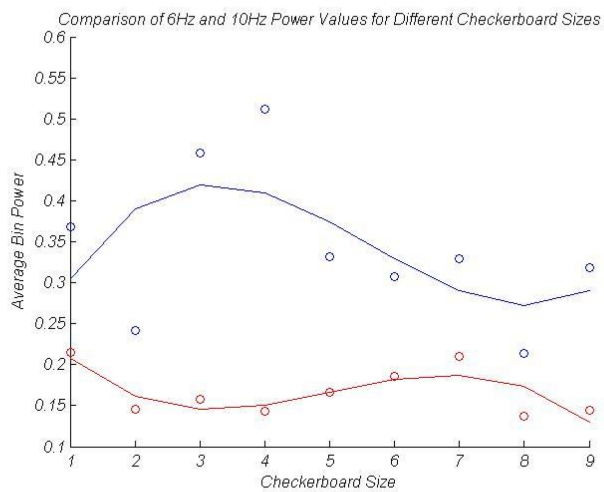




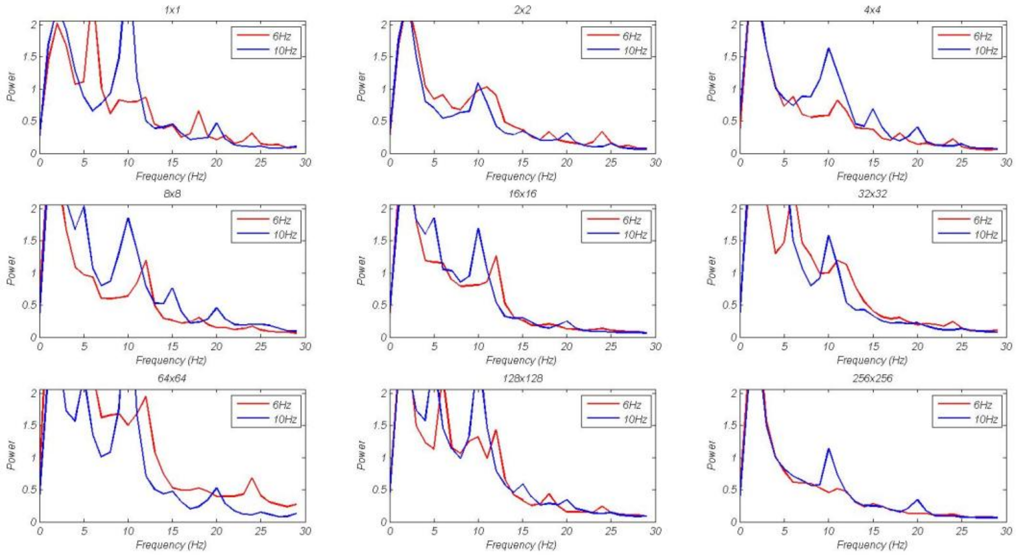
GCS001


1x1
2x2
4x4
8x8
16x16
32x32
64x64
128x128
256x256
6Hz
10Hz
Power
Frequency (Hz)


Comparison of 6Hz and 10Hz Power Values for Different Checkerboard Sizes
6Hz
10Hz
Average Bin Power
Checkerboard Size


Comparison of 6Hz and 10Hz Power Values for Different Checkerboard Sizes
Average Bin Power
Checkerboard Size

GDJ001


1x1
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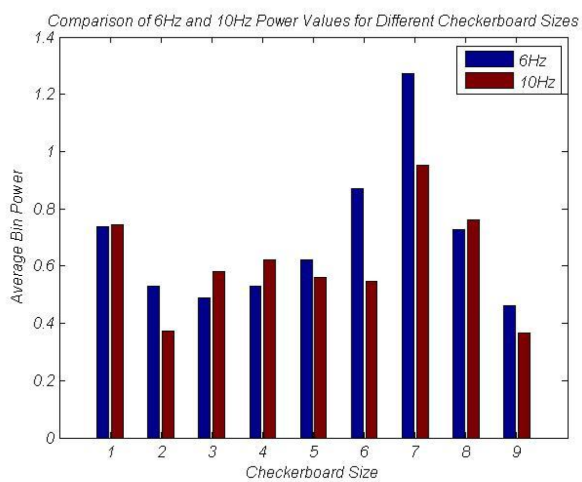
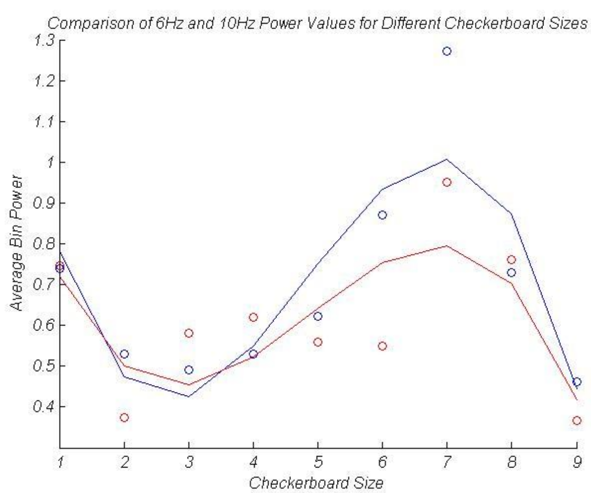
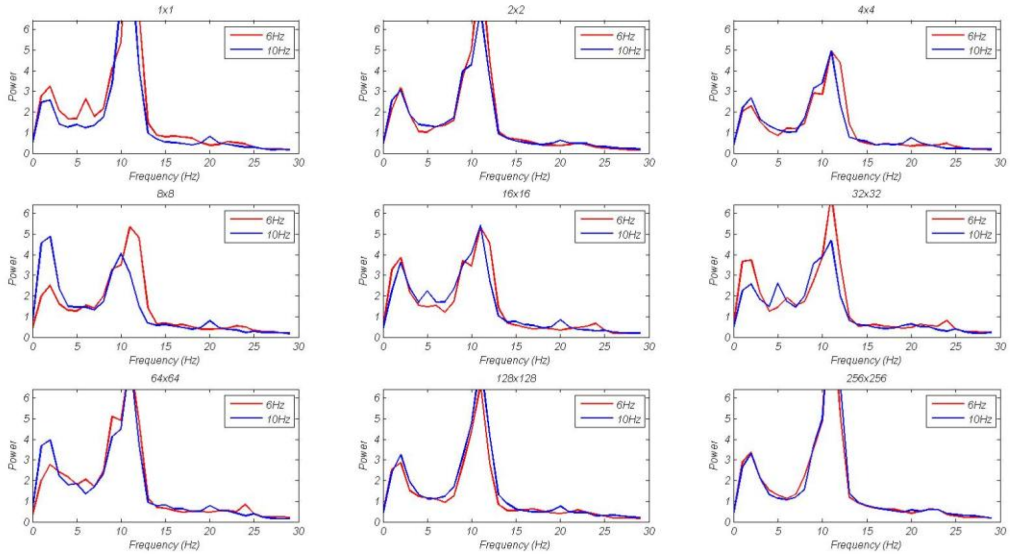
32x32
64x64
128x128
256x256
6Hz
10Hz
Power
Frequency (Hz)


Comparison of 6Hz and 10Hz Power Values for Different Checkerboard Sizes
6Hz
10Hz
Average Bin Power
Checkerboard Size


Comparison of 6Hz and 10Hz Power Values for Different Checkerboard Sizes
Average Bin Power
Checkerboard Size


1x1
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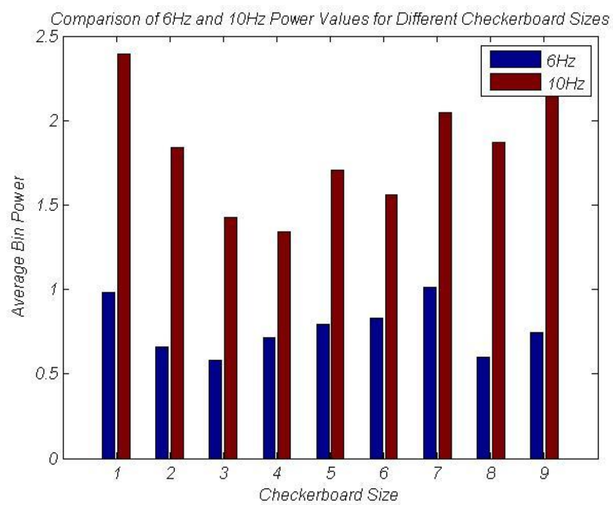
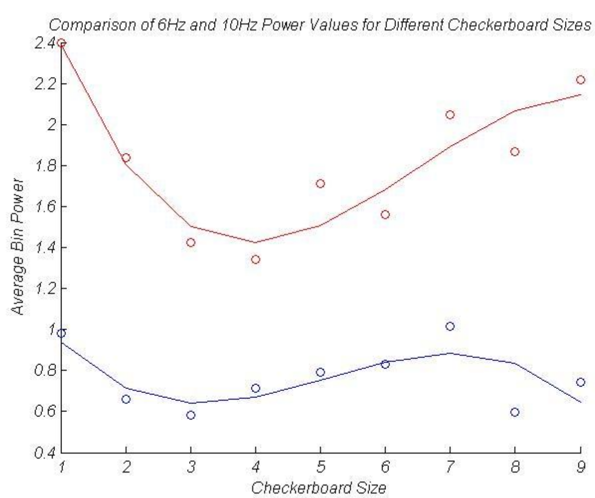
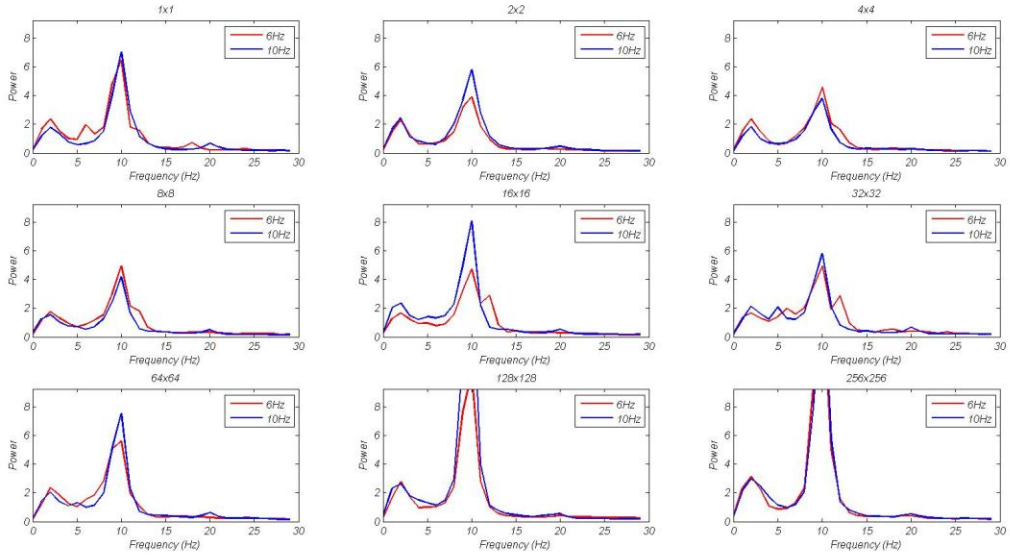
4x4
8x8
16x16
32x32
64x64
128x128
256x256
6Hz
10Hz
Power
Frequency (Hz)


Comparison of 6Hz and 10Hz Power Values for Different Checkerboard Sizes
6Hz
10Hz
Average Bin Power
Checkerboard Size


Comparison of 6Hz and 10Hz Power Values for Different Checkerboard Sizes
Average Bin Power
Checkerboard Size

YS001



1x1
2x2
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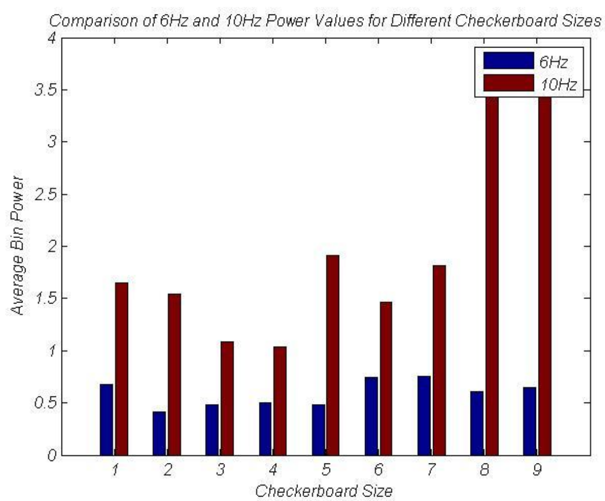
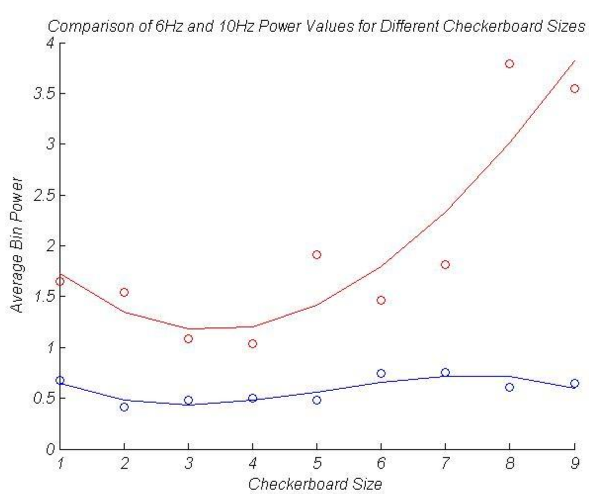
16x16
32x32
64x64
128x128
256x256
6Hz
10Hz
Power
Frequency (Hz)



Comparison of 6Hz and 10Hz Power Values for Different Checkerboard Sizes
6Hz
10Hz
Average Bin Power
Checkerboard Size



Comparison of 6Hz and 10Hz Power Values for Different Checkerboard Sizes
Average Bin Power
Checkerboard Size

Appendix B - The t-test results with the p-value of the first t-test for each of the 5 subjects

T-Test Results	1=reject H0	0=fail to reject H0							
0.05 Significance									
GCM001	1	2	3	4	5	6	7	8	9
	1x1	2x2	4x4	8x8	16x16	32x32	64x64	128x128	256x256
6 Hz	NaN	1	1	1	1	0	1	1	1
Tail Right 0.05	NaN	1	1	1	1		1	1	1
P-Value	NaN	2.29E-07	6.06E-07	1.37E-08	1.06E-05	1.54E-01	4.93E-05	9.27E-05	3.33E-05
10 Hz	NaN	1	1	1	1	1	1	1	1
Tail Right 0.05	NaN	1	1	1	1	1	1	1	1
P-Value	NaN	1.87E-15	6.34E-17	2.21E-16	1.08E-11	1.68E-09	1.28E-16	1.88E-17	2.87E-14
GCS001	1	2	3	4	5	6	7	8	9
	1x1	2x2	4x4	8x8	16x16	32x32	64x64	128x128	256x256
6 Hz	NaN	1	0	0	0	0	0	1	0
Tail Right 0.05	NaN	1						1	
P-Value	NaN	7.30E-03	3.03E-01	9.65E-02	3.89E-01	2.05E-01	4.86E-01	4.58E-04	4.43E-01
10 Hz	NaN	1	1	1	1	0	0	1	1
Tail Right 0.05	NaN	1	1	1	1			1	1
P-Value	NaN	4.56E-05	3.72E-04	5.06E-05	0.0023	0.1347	0.8452	5.69E-07	1.03E-05
GDJ001	1	2	3	4	5	6	7	8	9
	1x1	2x2	4x4	8x8	16x16	32x32	64x64	128x128	256x256
6 Hz	NaN	1	1	1	0	0	1	0	1
Tail Right 0.05	NaN	1	1	1			0		1
P-Value	NaN	4.43E-05	5.74E-06	1.33E-04	6.98E-02	7.07E-02	9.30E-03	8.62E-01	5.50E-07
10 Hz	NaN	1	1	0	1	1	1	0	1
Tail Right 0.05	NaN	1	1		1	1	0		1
P-Value	NaN	3.17E-09	4.01E-02	1.93E-01	4.40E-03	1.40E-03	4.83E-02	8.50E-01	5.66E-09
NRW001	1	2	3	4	5	6	7	8	9
	1x1	2x2	4x4	8x8	16x16	32x32	64x64	128x128	256x256
6 Hz	NaN	1	1	1	1	0	0	1	1
Tail Right 0.05	NaN	1	1	1	1			1	1
P-Value	NaN	6.35E-05	5.27E-07	1.40E-03	1.19E-02	5.93E-02	8.22E-01	5.40E-07	3.10E-03
10 Hz	NaN	1	1	1	1	1	0	1	0
Tail Right 0.05	NaN	1	1	1	1	1		1	
P-Value	NaN	2.38E-02	4.47E-05	2.31E-05	3.20E-03	2.27E-04	1.52E-01	3.22E-02	5.44E-01
YS001	1	2	3	4	5	6	7	8	9
	1x1	2x2	4x4	8x8	16x16	32x32	64x64	128x128	256x256
6 Hz	NaN	1	1	1	1	0	0	0	0
Tail Right 0.05	NaN	1	1	1	1				
P-Value	NaN	6.92E-08	1.10E-03	6.43E-04	1.35E-04	3.19E-01	2.24E-01	2.81E-01	6.56E-01
10 Hz	NaN	0	1	1	0	0	0	1	1
Tail Right 0.05	NaN		1	1				0	0
P-Value	NaN	5.96E-01	5.58E-04	2.03E-04	1.97E-01	2.80E-01	3.37E-01	1.88E-10	8.47E-07
Tally Significance	1	2	3	4	5	6	7	8	9
	1x1	2x2	4x4	8x8	16x16	32x32	64x64	128x128	256x256
6 Hz	NaN	5	4	4	3	0	2	3	3
Tail Right 0.05	NaN	5	4	4	3	0	2	3	3
10 Hz	NaN	4	5	4	4	3	1	4	4
Tail Right 0.05	NaN	4	5	4	4	3	1	3	3