

Predictions of Performance by EEG and Skin Conductance

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Abstract

The present study analyzed the predictive power of lateralized cortico-electrical patterns (measured by EEG) and arousal (measured by Galvanic Skin Conductance) on performance during a visuo-spatial, motor-response task. The task was a videogame specifically designed to induce flow based on the criteria for flow state established by Csikszentmihalyi (1999). Specifically, alpha activity (8-12Hz) and delta activity (1-4Hz) in the temporal lobes, and skin conductance were examined as predictors of improved performance on the videogame. A regression analysis of the data found that greater left temporal alpha activity, compared to that of the right temporal lobe, was a positive predictor of performance. No significant results were found regarding delta activity, however skin conductance was found to positively correlate with performance. Surprisingly, theta activity (4-8Hz) and mid beta activity (16-20Hz) were also found to have a main effect on performance.

1. Introduction

Performance on motor tasks varies greatly depending on the mental state of the participant. Sports psychology has ascertained for decades that mental states can lead to improved performance, but several other areas of human performance such as music and problem solving have also shown optimal psychological states for participants (Legrand and LeScanff, 2003; Strack, 2003; Kraus, 2003; Lindsey, 2005; Csikszentmihalyi, Abuhamdeh & Nakamura, 2005). Of particular interest is the state of "flow", a state of complete absorption in an activity focusing solely on the pleasure of the challenge at hand and ignoring fatigue, time, and difficulty. Measures of flow generally depend on subjective ratings such as the Jackson and Marsh Flow State Scale or online ratings during pauses in performance (Jackson and Marsh, 1996; Kraus, 2003). However, little is known about the neurological correlates for state of flow. Electroencephalography (EEG) research on performance indicates that high performance on motor tasks relates to high Alpha (8-12Hz) frequencies; however no study has examined the EEG patterns of performance on a flow state-inducing task. In the present study, participants will engage in a simple motor response task designed to highlight the features of flow in an attempt to locate electroencephalography (EEG) patterns correlated with high performance.

Several studies have associated the subjective state of flow with high performance, ranging from archers to musicians (Kraus, 2003; Lindsay, Maynard & Thomas, 2005; Csikszentmihalyi et al., 2005). Despite the focus on professionals and experts, flow is an experience anyone can feel during a deeply enjoyable, challenging activity (Csikszentmihalyi, 1999). Csikszentmihalyi (1999) wrote, "It [flow] is reported by teenagers

who love studying, by workers who like their jobs, by drivers who enjoy driving". Activities such as reading a good book, completing a crossword, or finishing a writing assignment can induce high levels of absorption associated with flow. Commonly, flow state is measured through questionnaires regarding postmortem analysis of performance. Jackson and Marsh designed the Flow State Scale in 1996, which assesses flow on a scale of 9 factors with 36 total items (Jackson and Marsh, 1996). The factors were derived from the work of Csikszentmihalyi (1990) and include: challenge-skill balance, action awareness merging, clear goals, unambiguous feedback, concentration on the task at hand, sense of control, loss of self-consciousness, transformation of time, and an autotelic experience. Other studies have employed similar questionnaires or measures of flow based on subjective self-assessment (Jackson and Eklund, 2002). Overall, three key criteria are generally accepted as necessary to induce the flow state: clear goals, online feedback and an acceptable level of difficulty. Certain lines of research indicate that the flow experience is a rare one and involves skill and perseverance (Csikszentmihalyi, Abuhamdeh, & Nakamura 2005), still some form of flow state may be present whenever enjoyable absorption occurs.

This study is designed to make use of the often-addictive nature of videogames with the intention of inducing flow. By employing an engaging and enjoyable videogame that requires constant attention, participants should experience some form of flow. However, instead of analyzing flow states through self-reports and subjective measures, this study will make use of the concept of flow to evaluate performance. Utilizing Csikszentmihalyi's (1999) criteria of flow, this videogame was designed to highlight these features. The videogame is a simple driving game in which a vehicle travels down a winding road and must not crash into the walls of the road. Keeping the three criteria in mind: clear goals, online feedback, and appropriate balance of challenge and skill. First, as a participant, achieving a higher score than that of previous trials becomes the long-term goal. By design, the goals are very clear; last as long as possible without crashing. Second, online feedback is accomplished very clearly through the direct responsiveness of the game. One button press corresponds to one movement and all crashes are the result of a mistimed movement. For the last criteria, balance of challenge and skill, a person's ability must be adequately challenged without causing excessive frustration. If the challenge is too easy, the participant becomes bored and if the challenge is too difficult, frustration sets in (Csikszentmihalyi, 1999). By keeping participants informed of their personal high-score, the challenge of the game is relative to the participant's own skill. Participants compete against themselves thereby keeping the balance of challenge and skill reasonable. Ideally, by highlighting these criteria for flow, participants will reach states of flow during trials of high-performance on the videogame.

Due to the fast-paced, fluid nature of the videogame, testing participants' flow while playing was not feasible. However, the level of flow is not of interest in this study, but rather the neurological correlates to high-performance. The criteria for flow have been employed in the design of this game in an effort to maximize flow; however subjects are being tested for peak performance, not flow. Prior research indicates that increased mean alpha power prior to a visuo-spatial task leads to better performance (Kerick, Douglass, Hatfield 2004; Landers et al. 1994; Hatfield et al. 1984). In particular, studies on novice pistol shooters, archers, and riflemen indicate that a hemispheric difference in mean alpha power correlates to improvement on the task. Specifically, increased alpha in the left temporal region and no change, or reduced alpha power in the right temporal region led to an improvement in performance (Kerick, Douglass & Hatfield, 2004; Landers et al., 1994; Hatfield et al., 1984).

The most common hypothesis suggests that this decrease in left temporal activity indicates a reduction in internal verbalizations allowing the visuo-spatial right brain greater dominance, “This increase in EEG activity within the alpha frequency range has been interpreted as representing a reduction of cortical activation in the left-temporal region, reducing the covert verbalisations of the left-brain and allowing the visual-spatial processes of the right hemisphere to become more dominant” (Vernon, 2005). The present study examined the relationship between hemispheric differences of mean alpha power and performance using EEG recording. Increased mean alpha power in the left temporal lobe prior to game play (Prior Condition) was predicted to correlate with better performance as indicated by a longer trial on the videogame. For the right temporal lobe, no significant results were expected for the Prior Condition. When comparing the difference between the two hemispheres, it was predicted that the left temporal lobe would have a higher mean alpha power in relation to that of the right temporal lobe in the 10s prior to game-play (Prior Condition).

Additionally, very few studies have examined the role of EEG patterns during the participant’s actual performance on an activity due to the logistics of measuring an athlete during prolonged performance. Most studies examined athletic events with a single momentary visuo-spatial event like dart throwing or archery, but virtually none were able to record during an activity like basketball or long-distance running. By using the videogame designed for this study, EEG recording occurs over a prolonged visuo-spatial performance. Limited research indicates that decreased delta frequency (1-4Hz) during motor activity leads to higher performance (Crossroads Institute, 2005). Delta power indicates low arousal often associated with sleep, while decreased delta indicates high arousal and alertness, with the latter conditions advantageous in performance. For the present study mean delta power during the actual trial (Trial Condition) was hypothesized to inversely relate to improved performance.

Since the videogame allows for evaluation over the length of a performance as well as prior to the performance, EEG is most useful to the present study due its ability to record continuously. Thus EEG can reveal relationships between cortical activity over a period prior to a trial and to the participant’s performance on that trial. Skin conductance was also analyzed for a correlation to performance. Since skin conductance measures arousal to a reliable degree (Andressi, 2000), a low skin conductance prior to performance and a high skin conductance during performance should relate to improved performance. Thus the present study included a skin conductance measure and predicted the aforementioned pattern.

Overall, prior studies suggest that a state of flow correlates with peak performance. The criteria for inducing flow include plain goals, immediate feedback, and an appropriate challenge to skill ratio. These criteria set the basis for creating a simple motor-response videogame with the intention of inducing flow. The present study utilized EEG to examine the neural activity associated with high performance on a flow-inducing task. Participants playing a videogame were predicted to show an increase in mean alpha power 10 seconds prior to a high performance trial (Prior Condition). Right hemisphere activation was predicted to remain stable prior to activity and have no predictive value for performance due to the stability of visuo-spatial reasoning for a trial (Prior Condition). Subtracting mean alpha power in the right temporal lobe from that of the left was predicted to have a positive relationship with trial length in the Prior Condition. Additionally, an inverse relationship between mean delta power, over both hemispheres, and high performance was predicted (Trial Condition). Low skin conductance was expected for the Prior Condition and high skin

conductance was expected for the Trial Condition, where both results predict high performance on the motor-response task.

2. Methods

2.1. Participants

The participants in this study were 5 male and 5 female volunteer undergraduate and graduate students from a large, private Midwestern University. All participants were right handed to ensure consistency for hemispheric differences.

2.2. Materials

Data collection was accomplished using Thought Technology Biograph Infinity Software (Thought Technology, Montreal Canada) run on a Hewlett Packard laptop PC. Both EEG and skin conductance were recorded on a Thought Technology Procomp Infinity Encoder and amplifiers (Thought Technology, Montreal Canada). Electrodes were 8mm molded tin cup electrodes placed at T3 and T4 based on the International 10-20 system. A shared reference was placed at FPZ and the ground at the nasion. The raw EEG signal was collected at a sampling rate of 256Hz, digitized and passed through a 60Hz notch filter to remove ambient electrical activity. Fast Fourier Transform (FFT) separated the raw data into individual frequency bands and was calculated as percent power. For parsimony, frequency bands were then grouped into 1-4Hz (delta), 4-8Hz (theta), 8-12Hz (alpha), 12-16Hz (low beta), 16-20Hz (midrange beta), and 20-24Hz (high beta). Galvanic Skin Response Sensors placed on the finger tips were used to record skin conductance in Simens (5-50micromohs).

The videogame was designed by Satoru Suzuki at Northwestern University using Vision Shell (version) and displayed on a 19 inch monitor, with the participant seated approximately .5m from the monitor. A Power Macintosh 8600/300 executed the program. The game consisted of a driving scenario in which a vehicle (the character “^”) is driven through a winding road (comprised of the character “|”). Turns in the road were random with a 3:1 bias in favor of staying straight. Each turn corresponded to one unit of the car. As the game progressed, the difficulty increased via a narrowing of the road at a rate of one car width every 75 car lengths past (that is, when the car has traveled 75 times its own length, the road narrows by one car width) until the road became three car widths across at which point the narrowing ceased; this point was considered the maximum difficulty. Movement was conducted through a left and right key press (the “z” key for movements to the left and the “/” key for movements to the right) and each press corresponded to one car-length movement. Scores were derived from length of game play with each point corresponding to a unit of wall passed.

2.3 Procedure

Participants began by providing informed consent while the electrodes were prepared. Electrodes were placed at T3 and T4 with the shared reference placed at the FPZ and the ground placed at the nasion. Skin conductance sensors were placed on the left hand on the ring and middle finger. Once ready, a 60s baseline was recorded in which participants stared at the blank screen. After the 60s baseline, participants were given these instructions: “Please control the car using the keys marked by a green and yellow sticker. Your goal is to avoid the walls for as long as possible”. Following these instructions the game was started

using the Vision Shell software, the game was started and participants played for as long as possible. The beginning of a trial until crash was marked by the researcher using a marker feature imbedded in the Thought Technology Biograph Infinity software. After a crash, 15-30s of rest was recorded in which participants were allowed to relax before the next trial. Only the last 10s of rest before a new trial were used for analysis of the Prior Condition. The entire trial was used for analysis in the Trial Condition. Each participant played as many trials as possible for 25 minutes and a 60s baseline was recorded at the conclusion of the session. Any trials lasting past the 25-minute trial session were discarded.

Mean power for each frequency band was analyzed for both the Prior Condition and the Trial Condition. All frequency bands were subjected to a regression analysis using JMP software (SAS institute, Cary, NC). Initially hemispheric differences were evaluated by comparing analogous frequency bands. Next, bands were combined and regression analyses were conducted again in order to see any whole brain effects. Skin conductance was analyzed based on average skin conductance for both the Prior Condition and the Trial Condition and a regression analysis was used in a similar manner to that of the frequency bands.

3. Results

This study was designed to evaluate the relationship between electrical patterns of activation in the cortex and performance on a motor response task. A relationship between arousal and performance on the same task was also assessed. These relationships were analyzed using a regression analysis. Specifically, mean EEG power over several frequency bands was used to measure electrical patterns in the cortex. The independent variables measured were the individual frequency bands of 1-4Hz (delta), 4-8Hz (theta), 8-12Hz (alpha), 12-16Hz (low beta), 16-20Hz (midrange beta), and 20-24Hz (high beta). For arousal, a Galvanic Skin Response Sensor recorded skin conductance in Simens (5-50micromohs). Both measures were evaluated in two separate conditions. During the Prior Condition data was averaged for both measures over a period of 10s prior to the start of a trial. During the Trial Condition data was averaged for both measures over the length of the trial. The regression analysis was conducted using the formula:

$$\text{Duration of Trail} = a + b_1(\text{Skin Conductance}) + b_2 (1\text{-}4\text{Hz LH}) + b_3 (4\text{-}8\text{Hz LH}) + b_4 (8\text{-}12\text{Hz LH}) + b_5 (12\text{-}16\text{Hz LH}) + b_6 (16\text{-}20\text{Hz LH}) + b_7 (20\text{-}24\text{Hz LH}) + b_8 (1\text{-}4\text{Hz RH}) + b_9 (4\text{-}8\text{Hz RH}) + b_{10} (8\text{-}12\text{Hz RH}) + b_{11} (12\text{-}16\text{Hz RH}) + b_{12} (16\text{-}20\text{Hz RH}) + b_{13} (20\text{-}24\text{Hz RH}) + \epsilon_{13}$$

In the Prior Condition, the predictors accounted for 12.3% of the variance in the duration of the trials, $R^2 = .123$, $F(13, 206) = 2.23$, $p < .05$. Examination of the individual predictor variables revealed a significant positive effect of skin conductance, (0.44), $t = 2.00$, $p < .05$. Such a result indicates that when all other variables were controlled, a 0.44 increase in skin conductance resulted in an increase in videogame play by 1s. The frequency band of 4-8Hz (theta) in the left temporal lobe also showed a significant effect as a predictor variable, (-2.67), $t = -2.32$, $p < .05$. The theta band for the right temporal lobe showed a positive significant effect, (2.44), $t = 2.25$, $p < .05$. A significant effect was found in the left temporal lobe for the frequency band correlating to mid range beta, (-4.11), $t = -2.70$, $p < .05$.

For the Trial Condition, the predictors accounted for 18.0% of the variance in the duration of trials, $R^2 = .180$, $F(13, 206) = 3.47$, $p < .05$. Examination of these individual

predictor variables revealed a significant positive effect of skin conductance as well, (0.775), $t=3.10$, $p<.05$. The only other predictor variable that showed a significant effect was the mid beta frequency range (16-20Hz) in the left temporal lobe, (-4.17), $t=-2.93$, $p<.05$.

Again using a regression analysis, I evaluated the individual variables as differences in mean power between hemispheres (LH- RH). For the Prior Condition, the predictor variables accounted for 7.75% of the variance in the duration of trials, $R^2=.775$, $F(6, 213) = 2.98$, $p<.05$. When comparing the individual predictor variables as differences between mean power in the hemispheres the alpha frequency range (8-12Hz) had a significant effect, (2.13), $t=2.11$, $p<.05$. This result agreed with the predictions of this study. The theta frequency range (4-8Hz) also revealed a significant effect, (-2.82), $t=-2.27$, $p<.05$.

Comparing the difference in mean alpha power between hemispheres for the Trial Condition showed that the predictor variables accounted for 8.89% of the variance in the duration of trials, $R^2=.0889$, $F(6, 213) = 3.46$, $p<.05$. Only the mid beta frequency range (16-20Hz) showed significance when comparing the difference between temporal lobes, (-4.11), $t=-3.69$, $p<.05$.

In summary, left hemisphere mean alpha power failed to show statistical significance ($p=0.380$ with an alpha level of .05) in the Prior Condition. Right hemisphere mean alpha power also showed non-significant results ($p=0.0762$). Such a result agrees with the predictions made in this study. A comparison of left temporal lobe mean alpha power versus right temporal lobe mean alpha power revealed a positive significant result ($p<.05$), which was also expected. For the Trial Condition, mean delta power did not show significance in either hemisphere ($p=0.206$).

Skin conductance showed statistical significance for both conditions, ($p<.05$ in the Prior Condition and the Trial Condition). The results for the Trial Condition showed support for the hypothesis, but the results for the Prior Condition did not.

Unexpectedly, mean theta power showed significance in the Prior Condition over both hemispheres ($p<.05$), but with a negative correlation to performance in the left hemisphere and a positive correlation to performance in the right hemisphere. This resulted in a statistically significant difference in mean theta power over the hemispheres ($p<.05$). Mid beta range frequency also showed significance over the left hemisphere in the Prior Condition ($p<.05$). For the Trial Condition, mid beta again showed significance in the left hemisphere ($p<.05$). The results of both conditions indicate that a decrease in mid range beta predicts performance. A statistically significant difference between left hemisphere mid beta and right hemisphere mid beta was also found in the Trial Condition ($p<.05$).

4. Discussion

The present study evaluated the relationship between electrical patterns and performance on a prolonged motor-response task. Specifically, electrical patterns measured by EEG were analyzed in the temporal lobes of each hemisphere and examined for their role in performance on a flow-inducing task. A videogame was designed to highlight Csikszentmihalyi's criteria of flow (1999). By presenting clear goals, immediate feedback, and a proper balance between challenge and skill, participants were likely to have the most success while in a state similar to flow. Past flow studies have generally focused on the behavioral results and showed that increased flow led to improved performance, but few have

examined the psychophysiological correlates (Kraus, 2003; Lindsay, Maynard & Thomas, 2005; Csikszentmihalyi, Abuhamdeh & Nakamura, 2005).

For the present study both EEG and skin conductance were measured prior to game play (Prior Condition) and during game play (Trial Condition) in an effort to discover the patterns of activation correlated with peak performance. Past research indicated that mean alpha power increased over the left temporal lobe for elite athletes prior to performance (Kerick, Douglass & Hatfield, 2004; Landers et al., 1994; Hatfield et al., 1984). However, these studies focused on highly skilled athletes and not the general population. This study sought to generalize these findings by presenting subjects of the general population a chance to perform a visuo-spatial task that does not require exceptional skill to master. Additionally, the videogame tested performance on a continuous visuo-spatial task as opposed to the single action tasks generally examined (i.e. dart throwing, archery, etc.). It was predicted that as performance improved, mean alpha power in the left temporal lobe would increase and right temporal lobe alpha power would remain the same in conjunction with past research. Also, prior to a trial an increase in mean alpha power in the left temporal lobe when compared to that of the right was predicted to positively correlate with improved performance. Additionally, this study examined the role of arousal in performance on a videogame. Decreased arousal in the Prior Condition, measured through galvanic skin conductance, was predicted to lead to better performance and increased arousal during the Trial Condition, as measured through skin conductance and decreased mean delta power, was also predicted to lead to improved performance.

Past research such as that of Landers et al. (1994) and Hatfield et al. (1984) found that an increase in mean alpha power in the left temporal lobe prior to a visuo-spatial task led to improved performance, however the present study failed to find a significant correlation between improved performance and alpha power in either temporal lobe. The hypothesis that mean alpha power in the right temporal lobe in the Prior Condition would remain stable was supported by the lack of significant results in this condition; however without the subsequent support regarding the left temporal lobe, this result has little weight. Still, a significant result was found during the Prior Condition when examining mean alpha power differences between the left temporal lobe and the right. Greater mean alpha power in the left hemisphere, when compared to that of the right, in the 10s before a trial resulted in improved performance. This indicates some support for the trends established by past studies.

The hypothesis that arousal, as measured by skin conductance and mean delta power, would positively correlate with performance was partially supported by the data. It was hypothesized that average skin conductance over the Prior Condition would negatively correlate with performance and average skin conductance over the Trial condition would positively correlate with performance. Both the Prior Condition and the Trial Condition showed a positive correlation with performance. The results of mean delta power analysis failed to show the expected negative correlation with performance.

Investigating other traditionally defined frequency ranges, a significant negative correlation was found for mean theta activity (4-8Hz), in the Prior Condition, over the left temporal lobe and a positive correlation was found for mean theta activity over the right temporal lobe in the same condition. Thus an increase in performance occurred when theta activity decreased in the left temporal lobe, and simultaneously increased in the right, over the 10s prior to a trial. A negative correlation between performance and mid beta activity (16-20Hz) was also found in the Prior Condition. The Trial Condition yielded a negative

correlation between mean mid range beta activity and performance. A brief discussion of these results will follow.

First, the specific pattern of increased mean alpha in the left hemisphere and maintained mean alpha in the right, as shown by Landers et al. (1994) and Hatfield et al. (1984), lacked full support from this study, however promising indications of similar activity were found. Significant results were not found for mean alpha during the Prior Condition, however a trend in the data indicates that a decrease in mean alpha in the right temporal lobe leads to better performance. The current theory on alpha activation proposes that “verbal thoughts are associated with a decrease in alpha in the left hemisphere and visual thoughts are associated with a decrease in alpha in the right hemisphere” (Vernon 2005). The trend found in this study suggests that a decrease of alpha power in the right hemisphere prior to a trial increases visuo-spatial processing leading to better performance and supports the work of Salazar et al. (1990).

Moreover, the increase in alpha power in the left temporal lobe 10s prior to a trial (Prior Condition) compared to that of the right was found to significantly predict performance. The difference between alpha power in the two hemispheres showed that the alpha activation in the left hemisphere should be higher than that of the right for an improvement in performance. Such a finding strongly agrees with the proposed pattern of activation indicated by Landers et al. (1994) and Hatfield et al. (1984). Even without a significant finding for each hemisphere independently, the interaction between the two supports the theorized correlation between alpha power in the left hemisphere and performance. Thus, such a finding seems to be robust; visuo-spatial tasks elicit a predictable pattern of activation whether the participant is an elite athlete or part of the general population. Previous studies have shown that inexperienced athletes do not exhibit the same EEG activity (Landers et al., 1994); however the present study was conducted entirely with inexperienced subjects. Such a finding implies a contradiction to past studies regarding EEG patterns in novice and elite athletes such as the work of Landers et al. (1994). Perhaps on a prolonged visuo-spatial task, a novice will show the same pattern of activation as that of an elite athlete performing a task of short duration. Landers et al. (1994) claimed that the increased alpha power in the left hemisphere only applies when an individual has habituated the motor response. The results of this study indicate that when the motor response is continuous, all individuals exhibit the same basic activity.

On the other hand, the simplicity of the videogame may allow for a quick learning curve and thus the findings of the present study would be consistent with the research of Landers et al. (1994). Conceivably the participants in this study took very little time to become experienced and therefore differences in left and right alpha activity apply only to experienced participants. A much greater motor response is necessary for the aiming of a dart throw than the simple movement of the vehicle in this game and thus participants in this study may have habituated to the task almost immediately.

Alternately, the lack of strong findings in left temporal lobe activity may reflect a difference in novices when compared to experts. Landers et al. (1994) showed non-significant hemispheric differences for novice archers. The present study only showed significant results when performance was predicted by a difference in left and right activity, but lacked any significant results for left temporal activation when viewed alone. Perhaps strong left temporal activation prior to a visual motor-response task only correlates to improved performance in experts. Novice participants may show a reduced version of this

pattern, present only as a difference between left temporal activity and right temporal activity. Future areas of research might help discern between these possibilities.

Overall, a difference in left and right temporal alpha activity positively correlating to performance supports the idea that alpha activity inhibits cognition in preparation for another task (Salazar et al. 1990). If an improvement in performance can be predicted by a significant difference in right hemisphere alpha activity when subtracted from left, the idea that the left temporal lobe requires “quieting” to perform a visuo-spatial task seems plausible. Salazar et al. (1990) suggest that verbalizations occurring in the left temporal lobe should be inhibited by alpha activity prior to performance. Csikszentmihalyi et al. (2005) describe flow state as that of a low level of internal verbal thought; such a description lends itself to the conclusion that these two processes share similarities. Certainly flow states and differences in hemispheric alpha activation both lead to improved performance and further studies may reveal a more detailed relationship between the two.

Arousal also seems to play an important role in performance; increased arousal, indicated by high skin conductance, also significantly correlated with peak performance. Such a result suggests that high levels of performance over a prolonged motor-response task require maintained arousal. Additionally, it was predicted that skin conductance would correlate inversely with task success in the Prior Condition implying a state of calm prior to action. The opposite result was found indicating that arousal prior to performance (as well as during performance) leads to improvement.

Delta power has been well established as a correlate to sleepiness and a motor response task requiring arousal should hold an inverse relationship with such a state. No significant results were found regarding delta in this study, thus delta power appears to not play a role in predicting performance.

Other frequency bands, however, did show significance and may play a similar role. The significant relationship between mean theta power (4-8Hz) and performance in the Prior Condition is difficult to interpret. Theta activity is generally associated with memory encoding and retrieval (Gladwin, Lindsen & de Jong, 2006). Further complications result from the exhibited pattern of an increase in right temporal lobe theta activity accompanied by a decrease in left temporal lobe theta activity, in the Prior Condition, leading to improved performance. Very little literature exists on lateralization effects for theta activity in the temporal lobe, thus, although this finding is interesting, it was not predicted in this study due to a lack of prior literature.

Mid range beta activity (16-20Hz) occurring in the left hemisphere was also found to negatively correlate with performance in both the Prior Condition and the Trial Condition. In the Trial Condition, a significant result was found when comparing left temporal activity to that of the right. This indicates that, during a trial, maintaining higher mid range beta in the left hemisphere, when compared to that of the right, aids performance. Again, such a finding has not appeared in any of the literature reviewed for this study. Mid range beta activity has been linked to a state of alertness coupled with subjective feelings of self-awareness (Crossroads Institute 2005). Reducing self-awareness is part of the state of flow (Csikszentmihalyi 1999), however little empirical data exists to provide a rationale regarding a correlation between mid range beta activity and flow or performance. Overall, these findings are quite interesting and offer encouragement for future studies on EEG patterns and performance.

The results of this study concur with certain aspects of past research on performance and fail to support others. Since this study tested non-experts on a visuo-spatial activity, the

results make for a more robust finding. Elite athletes show increased alpha power over the left hemisphere prior to performance, and the present study shows that non-elite athletes show a similar pattern. However, level of expertise was not evaluated for this study. Additionally, only a comparison of left temporal alpha activity compared to right temporal alpha activity showed significance. Perhaps novice participants demonstrate a reduced pattern of alpha activity only. A possible future study examining the EEG patterns in participants at different levels of expertise on such a videogame may shed more light on the true nature of this EEG pattern. Moreover, the pattern of arousal shown in this study indicates that a state of alertness is ideal during game play and before. Further analysis of arousal in future studies might reveal a more complete picture of the physiological correlates to peak performance.

Additionally, much of this study relied on Csikszentmihalyi's (1999) criteria for flow without actually testing these criteria. Establishing the degree of flow the videogame induces would create a stronger relationship between the neurological correlates of peak performance and flow. A state of flow seems to be useful for many aspects of life and discovering the EEG correlates for such a state allows for the possibility of biofeedback training. Helping individuals reach a state of flow consistently may aid in better performance on tasks ranging from athletics, to musical performance, to mathematical reasoning and locating the EEG correlates for such a state is highly valuable.

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