Neuro- and physio-logical analysis

First experiment neurophysiological results
Neurophysiological measurements used multiple sources of input: Electroencephalography (EEG), electrocardiography (ECG), and functional near-infrared (fNIR). These tools provide high degrees of temporal sensitivity to change with minimal interference with the first-person experiences during stimulus presentation. The B-Alert X10 wireless EEG will collected data from brain activity across nine channels, with sensors placed bihemispherically in anterior, central, and posterior brain areas (F3, Fz, F4, C3, Cz, C4, P3, POz, P4). The ECG data was also collected within the B-Alert device, with sensors placed on the chest. The fNIR measurements were collected using the INVOS oximeter. Two sensors are embedded in a neoprene headband to collect cerebral oxygenation information from the frontal cortex.

Neuro- and Physio-logical responses were measured using the EEG, ECG, and fNIR. A one way between-subjects ANOVA was run to compare physiological responses of AWCH experiencers and AWCH non-experiencers during the space flight. During the Earth condition, higher levels of left hemisphere theta ($F(1, 18) = 5.048$, $p = .038$), right hemisphere theta ($F(1, 18) = 4.725$, $p = .044$) were found among non-experiencers of awe compared to experiencers of awe. No significant effects were found during the Deep Space (DS) condition. A one way Repeated Measures ANOVA was run to compare Earth and DS conditions, with greater levels of frontal lobe beta ($F(1,16) = 5.201$, $p = .037$), parietal/occipital lobe beta ($F(1,18) = 5.951$, $p = .025$), left hemisphere beta ($F(1,18) = 8.235$, $p = .010$), and right hemisphere beta ($F(1,18) = 5.177$, $p = .036$) being found during the Earth condition. No significant differences were found among the ECG or fNIR.

Second experiment: Neurophysiological results
Here is an overview of the experimental results regarding neurophysiological activity during the observation of the space simulation. First, analyses were conducted to examine the effect of experimental condition on neurophysiological behaviors over simulation time. This addresses the experimental manipulations. Then, the neurophysiology is compared to self-reports from the psychological metrics. These analyses address the questions of the nature and structure of experience, as posed by the neurophenomenological method, by using psychological reports to assist in the interpretation of the neurophysiological findings.

A 2x7 (condition: focal and global by minute: 1-7 min of simulation viewing) mixed ANOVA with repeated measures on the last factor was conducted for each EEG hemisphere by frequency (alpha, beta, and theta) and for each fNIR hemisphere RO^2 to identify any physiological difference between conditions and processing requirements for the duration of the simulation. This will be used to consider the efficacy of the methodological changes. The results also help determine the impact of the visual stimuli on processing requirements and the influence of time on cognitive resource demands. Due to technical challenges, the sample size for EEG was 68 and for fNIR 72.

First, the effect of condition by minute on left hemisphere was examined by frequency. For left hemisphere alpha, SPSS's Greenhouse-Geisser was applied to correct for violations of sphericity. The main effect for minute during simulation time was significant, F (3.634, 239.864), $p < .001$. The main effect for condition on left hemisphere alpha was not significant. The interaction for minute by condition was not significant. Data from the left hemisphere beta also showed a violation of sphericity and was corrected using SPSS's Greenhouse-Geisser. The main effect for minute during simulation time was not significant. However, the main effect of condition on left hemisphere beta was significant, F (1, 66), $p = .016$ and interaction for minute by condition was significant, F (3.560, 234.961), $p < .001$. The third frequency, theta, also demonstrated a need to correct sphericity. Consequently, degrees of freedom were corrected using SPSS's Greenhouse-Geisser estimate.No significance was found for main effect of minute, condition, nor interaction for minute by condition.

For the right hemisphere, the effect of condition by minute was also analyzed. Violation of sphericity was corrected using SPSS's Greenhouse-Geisser estimate. The main effect of minute during simulation time was significant, F (2.393, 157.965), $p < .001$. The main effect of condition on right hemisphere alpha was not significant. The interaction for minute by condition was not significant. For beta, sphericity was corrected using SPSS's Greenhouse-Geisser estimate. The main effect of minute during simulation time was not significant. The main effect of group on right hemisphere beta was not significant. In right hemisphere beta, the interaction for minute by condition was significant, F (3.560, 114.864), $p < .022$. For theta DFB, sphericity had been violated, therefore degrees of freedom were corrected using SPSS's Greenhouse-Geisser estimate ($\epsilon = .340$). The main effect of minute was not significant. The main effect of group on right hemisphere theta was not significant. The interaction for minute by condition was not significant.
For fNIR data, left frontal lobe data was corrected for violation of sphericity using SPSS's Greenhouse-Geisser estimate The main effect of minute during simulation time was significant, F (2.328, 153.627), $p = .006$. The main effect of group on left hemispheric oxygenation was not significant. The interaction for minute by condition was not significant. Likewise, right frontal lobe data was corrected for spericity using SPSS's Greenhouse-Geisser estimate . The main effect of minute during simulation time was not significant. The main effect of group on right hemispheric oxygenation was not significant. The interaction for minute by condition was not significant.
To determine the condition and minute most influential to physiological experience, significant EEG results were further analyzed by post-hoc comparisons using one-way between subjects ANOVAs with Welch's F correction applied when needed to correct for non-homogeneity of variance. The following takes a closer look at alpha, beta, and theta by minutes one through seven.

EEG data was reported as difference from baseline (DFB), unless otherwise noted.

Left Hemisphere

The left hemisphere alpha differences between the FOC and GLO conditions were significant during the second minute F (1, 67) = 4.423, p = .039; FOC (M= -8006.92) $<$ GLO (M= -4997.41). Significant differences were also recorded during the seventh minute: F (1, 66) =4.040, p = .049; FOC (M= -6458.06) $<$ GLO (M= -3731.10). No other minutes were significantly different between conditions for alpha left hemisphere. During the second, third, and seventh minutes, there was a significant effect of condition presentation on left hemisphere beta. Left hemisphere beta during minute two was significantly different between conditions, F (1, 67) = 18.639, p .001; FOC (M= -1342.86) $<$ GLO (M= 388.10). A difference was found in this region during the third minute, F (1, 67) = 14.238, p = .035; FOC (M = -755.83) $<$ GLO (M = -133.070) and seventh minute F (1, 67) = 6.368, p = .014; FOC (M = -914.825) $<$ GLO (M = -184.498). No significant differences were found for minutes one, four, five, and six.
No significant differences were reported between conditions by minute for the left hemisphere theta.

Right Hemisphere

No significant differences were reported between conditions by minute for the right hemisphere alpha. Significant differences between conditions by minute for the right hemisphere beta were found for minutes two and three. In minute two, the difference was significant F (1, 67) = 17.245; $p < .001$; FOC (M = -1128.564) $<$ GLO (M = 623.349) and minute three F (1, 67) = 5.647; p = .020; FOC (M = -609.296) $<$ GLO (M =103.237). No other minutes showed significant differences between conditions for right hemisphere beta. No significant differences were recorded between conditions by minute for the right hemisphere theta.

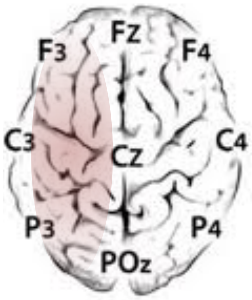
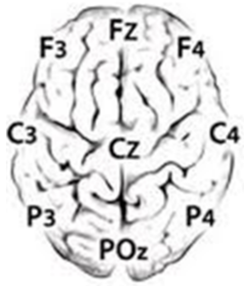
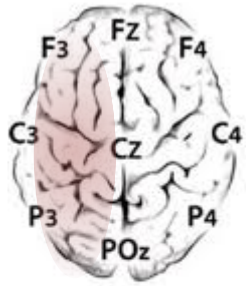
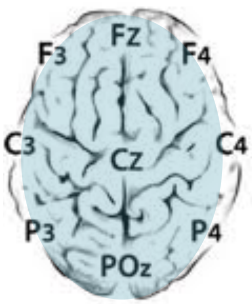
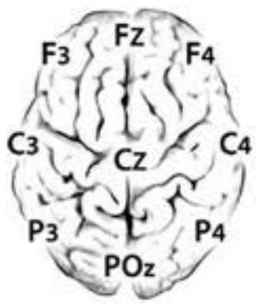
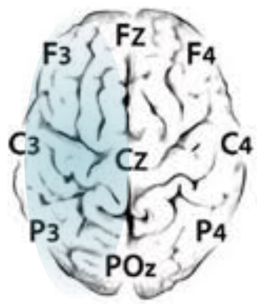
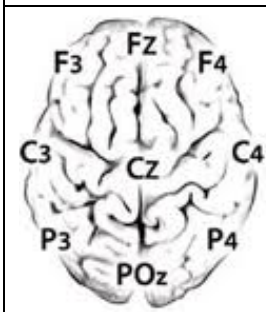
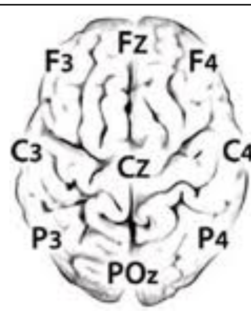
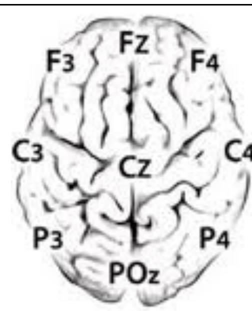
Contextual differences

The EEG results indicated that there was a difference for participants who began their simulation with a near-earth focal vantage and those who started the simulation with a broader view of the globe. To interpret these findings, each brainwave category (alpha, beta, and theta) will be discussed in light of the difference in the simulation context cues (see Table 1).

Alpha activity has been associated with a broad spectrum of conscious cortical activity, so there are numerous ways to explain the significance found along this bandwidth. Here we can try to disentangle some likely explanatory candidates.

Traditionally, alpha has been observed in “cortical idle” (Pfurtscheller & Lopes da Silva, 1999), meaning alpha activity oscillates during alert awake states when one is not engaged in a task. In terms of the contextual change in conditions, the greater change of left hemisphere alpha in the FOC group suggests integration of context and perception.

Table 1. Summary of significant EEG findings for FOC and GLO conditions during the observation of the earth for a simulated space perspective. Artist representations of the involved regions are included to represent the cortical regions that showed significance

Time Segment 1	Time Segment 2	Time Segment 3	Observation
 **Alpha**	 Alpha	 Alpha	Both groups experienced decreases in alpha, but the FOC group had a greater decrease during the second and seventh minutes.
 **Beta**	 Beta	 Beta	While beta decreased globally for the recipients of the FOC condition, beta increased for GLO during the first time segment. There was no difference during the middle portion of the simulation. Both groups experienced drops in beta activity in the seventh minute, with the FOC decreasing significantly more in the left hemisphere.
 **Theta**	 Theta	 Theta	Theta signals were not significantly different by condition group.

The vehicle for the contextual integration may be a combination of lexical and embodied factors. Changes in alpha signal in the left hemisphere (Weems, Zaidel, Berman, & Mandelkern, 2004) have been associated with lexical retrieval. During the phenomenological interviews, participants recalled engaging in impromptu "gamification" of the stimuli while viewing the simulation, which may have been connected to lexical retrieval. The participants described trying to remember the names of landforms and bodies of water as the earth rotated. The alpha levels in the FOC group may also be explained in relationship to unpleasant visual movement (i.e. the rotation and lift simulated as the vantage moved from the earth to space) (de Toffol, Autret, Degiovanni, & Roux, 1990).

Viewing negative stimuli can also cause a depression in alpha (Makarchouk, Maksimovich, Kravchenko, & Kryzhanovskii, 2011), possibly linked to limbic response. There was a drop in both groups, with a greater drop in FOC, potentially indicating an unpleasant affective response to the grounding of the experiential context to the local campus starting point. The early presence of this effect may be attributed to the sense of dizziness that some participants reported when the simulation moved quickly over land. However, the discrepancy also appeared at the end of the experiment, when the visual stimuli were quite similar. Participants were not informed how long the simulation would last. In another interpretation, alpha differences at the beginning and end of the simulation may be related to changes in lateral gaze as the simulation moved from a full screen image to focus in the center of the visual field (de Toffol, Autret, Degiovanni, & Roux, 1990). A final interpretation of these findings would be that the changes in alpha indicate shifts of task attention (Bonnefond & Jensen, 2012). In consideration of the role of context, the view of the campus may have helped the FOC group generate and maintain attention.

Global beta changes have been implicated in suppression of motor activity (Pogosyan, Gaynor, Eusebio, & Brown, 2009). GLO participants had a significantly higher beta at both the beginning and the end of the simulation experience. GLO participants may have experienced a reduction of motor response while viewing the condition, perhaps due to fewer physical affordances within the stimulus compared to the near-earth vantage of the FOC condition. The significant differences during the final minutes of the simulation are important. By the end of the simulation, the participants are viewing similar images with similar affordances (or the lack thereof). If the beta changes are indicators of motor suppression, this also suggests that context has some influence on subsequent motor action.

Theta poses interesting interpretive challenges for studies involving quiet contemplation, like the present study, as it is associated with both meditation and sleep. The findings from the first experiment showed significant findings in theta activity, but we could not conclusively say whether these were the results of relaxed and thoughtful states or transitions to sleep. We're not alone in struggling with the interpretation of theta. In some cases, left hemisphere theta reduction has been recorded during hypnosis (Taddei-Ferretti & Musio, 1999) and suggests an increase in cognitive effort. Theta changes have been associated with meditative states, though studies conflict on the directionality of the changes for certain types of meditation (Cahn & Polich, 2006). In the second study we reduced the length of simulation time, hoping to reduce the likelihood of sleep. Drowsiness may explain the similar theta findings between groups as the simulation progressed, keeping in mind that for both conditions, the last few minutes were of a quiet, tranquil view of a slowly turning planet. The phenomenological interviews indicated that many participants felt relaxed, and even sleepy, by the end of the experiment. The conditions of the experiment were relaxing, with no audio stimulation, low lighting, and, according to most participants, pleasurable visuals. Future work should disentangle the phases between thoughtful relaxation and drowsiness as it pertains to the first-person articulation of experience.

FNIR measurements in the right frontal lobe also showed significant differences between groups during the two conditions. Again, the key is the timing. In the first minute, the significant differences are to be expected. The images are different, with the FOC containing various familiar images that, during the interviews, participants said they recognized. Many participants who received the focal condition also reported looking for places, (e.g. trying to locate a girlfriend's apartment building or the route they take home). This type of engagement, or *gamification* could account for the differences in the frontal lobe behaviors, which are typically associated with executive function. Interviews from the GLO participants indicated a different sort of cognitive task, as they experienced a less familiar starting point. They started in darkness and the first landscape images were not familiar. The vantage was over a red-toned landscape of Africa, and some participants reported thinking they were on Mars. The lack of familiarity at this stage may have made it more difficult to engage cognitively (Tulving, Markowitsch, Craik, Habib, & Houle, 1996). A similar issue of novelty versus familiarity may explain the differences during the fourth minute as well. However, this trend appeared throughout the experiment, even though the significance was only found during minutes one and four, suggesting an enduring effect of the initial contextual grounding on the subsequent frontal lobe behaviors.

Neurological responses to context differences between the FOC and GLO conditions indicate previously unexplored features of experience as it applies to the observation of Earth in a simulation environment. These findings suggest that the grounded context, the notion of coming from "home" and moving into space, increases the neurological behaviors associated with both attention and relaxation. Since the astronaut reports indicated experiences of peace and beauty, it is possible that the types of neural behaviors observed during the experiment are neural behaviors involved in transitioning from the anxiety of launch into a state that allows for more positive spiritual and affective experiences while in space. Astronauts maintain a contextual awareness that they are leaving a specific location on earth and they will return to a location. Results of the experiment suggest that contextual grounding is associated with differences in brain areas involved in attention, memory, and relaxation. However, while these findings begin to paint a picture of the neurological conditions associated with the experience of looking at Earth from space, they alone are not sufficient for describing the astronaut *experiences* of AWCH. To explore the nature of such experiences, these findings must be considered in their relationship to self-reports of the experiencers while viewing the simulation.

Individual differences

The following graphs provide comparisons between AWCH experiencers and AWCH non-experiencers (see LINK TO "Phenomenological Analysis" for the distinction). Each graph represents the participant EEG DFB in average power spectral density (PSD) shown over the one-minute simulation time blocks. The power spectrum refers to the frequency and amplitude of each signal.

The frontal EEG sensors collected readings from the alpha, beta, and theta wavelengths. In frontal alpha (Figure 1), the AWCH experiencers (P14 & P44) showed greater suppression of frontal alpha than the AWCH non-experiencers (P64 & P65) did. The AWCH experiencers were both below the mean for frontal lobe DFB, whereas the AWCH non-experiencers had higher frontal alpha. The alpha readings were less distinct by experience over the central region (Figure 2). Alpha oscillations in the posterior regions (Figure 3) followed a similar pattern to those recorded from the frontal sensors, with the experiencers showing consistently lower alpha in the occipital/parietal areas.

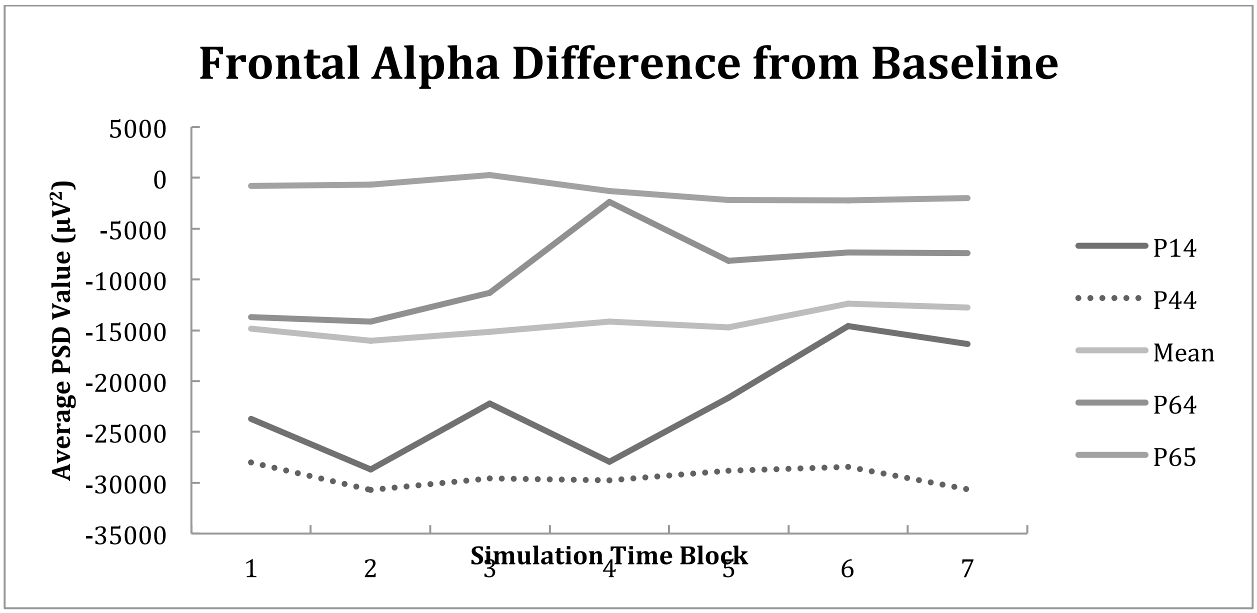


Figure 1. Individual differences examples for EEG frontal alpha (P14 & P44 = AWCH experiencers; P64 & P65 = AWCH non-experiencers).

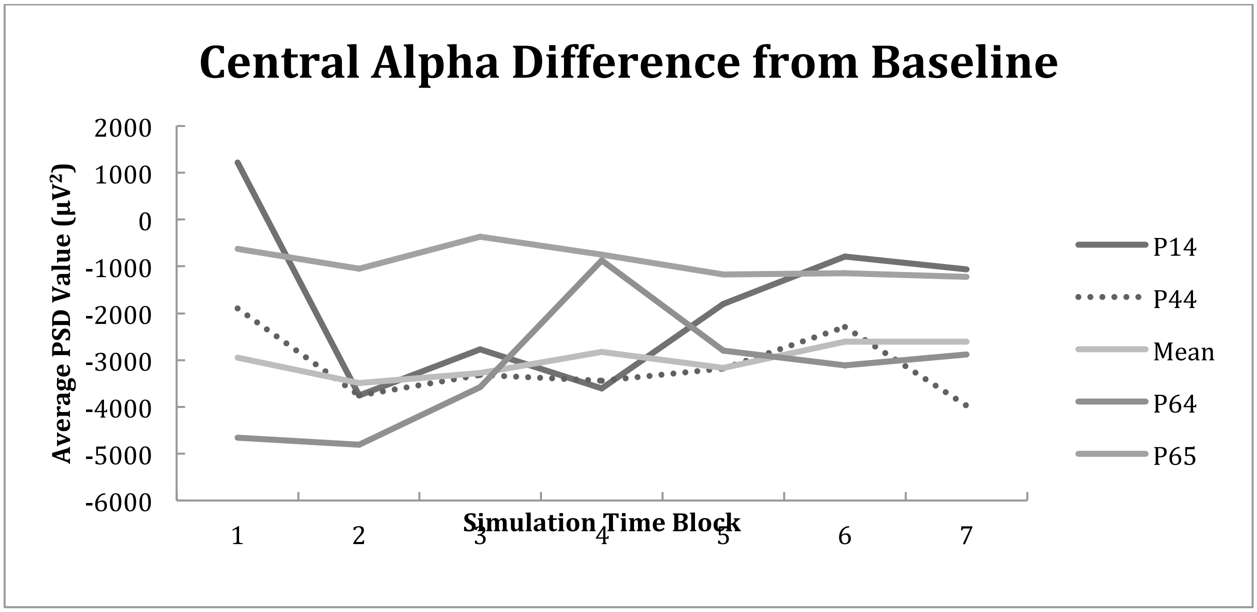


Figure 2. Individual differences for EEG central alpha (P14 & P44 = AWCH experiencers; P64 & P65 = AWCH non-experiencers).

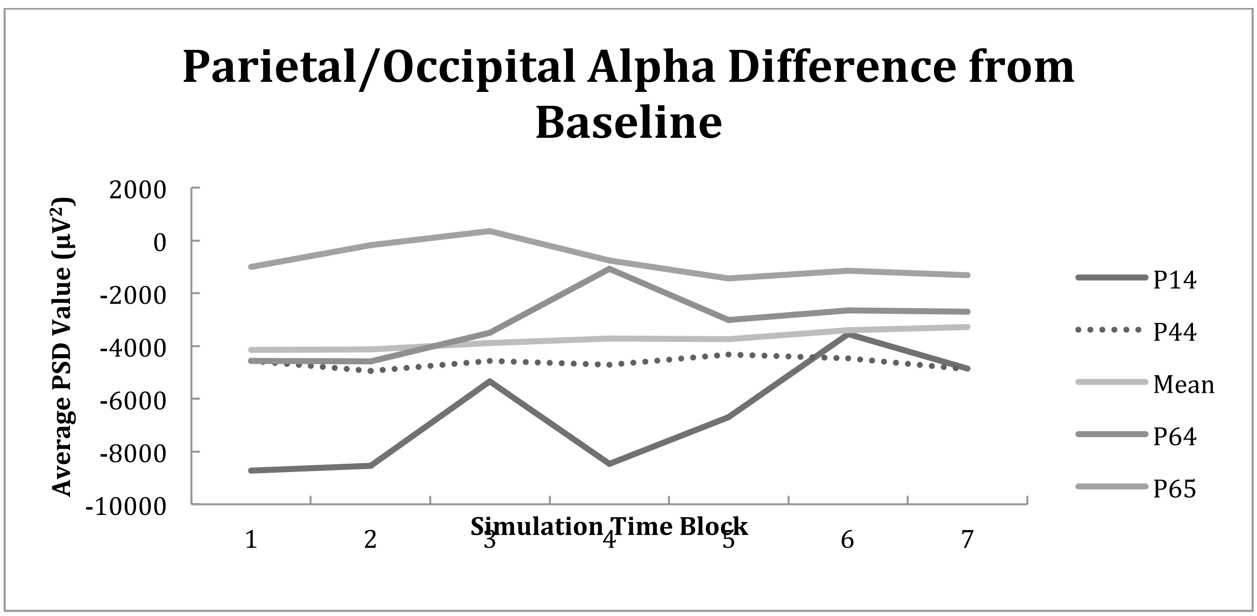


Figure 3. Individual differences for EEG parietal/occipital alpha (P14 & P44 = AWCH experiencers; P64 & P65 = AWCH non-experiencers)..

The alpha findings were similar when analyzed by hemisphere. Alpha in the left and right hemispheres was above the mean (and closer to baseline) for the non-experiencers and below the mean for the experiencers. Of note were P65, whose alpha readings by hemisphere were statistically even with the baseline and P44 whose alpha stayed consistently below the baseline and mean by hemisphere. For the left hemisphere (Figure

4), P65 (*M* = 421.65) stayed statistically even with her baseline, whereas P44 (*M* = -22,026.54) was below both her own baseline and the population mean (*M* = -7,748.91; *SD* = -11,515.40). Similar results were found in the right hemisphere (Figure 5), where P65 (*M* = -115.58) stayed statistically even with her baseline, whereas P44 (*M* = -11,653.96) was below both her own baseline and the population mean (*M* = -5794.17; *SD* = -10,331.16).

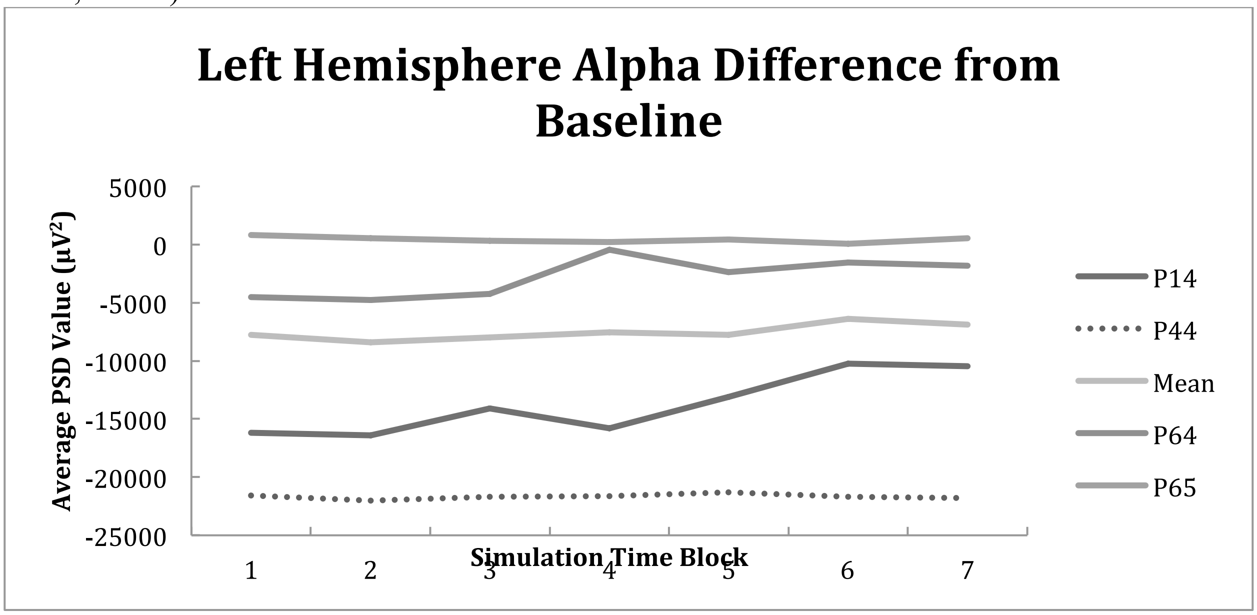


Figure 4. Individual differences for EEG left hemisphere alpha (P14 & P44 = AWCH experiencers; P64 & P65 = AWCH non-experiencers).

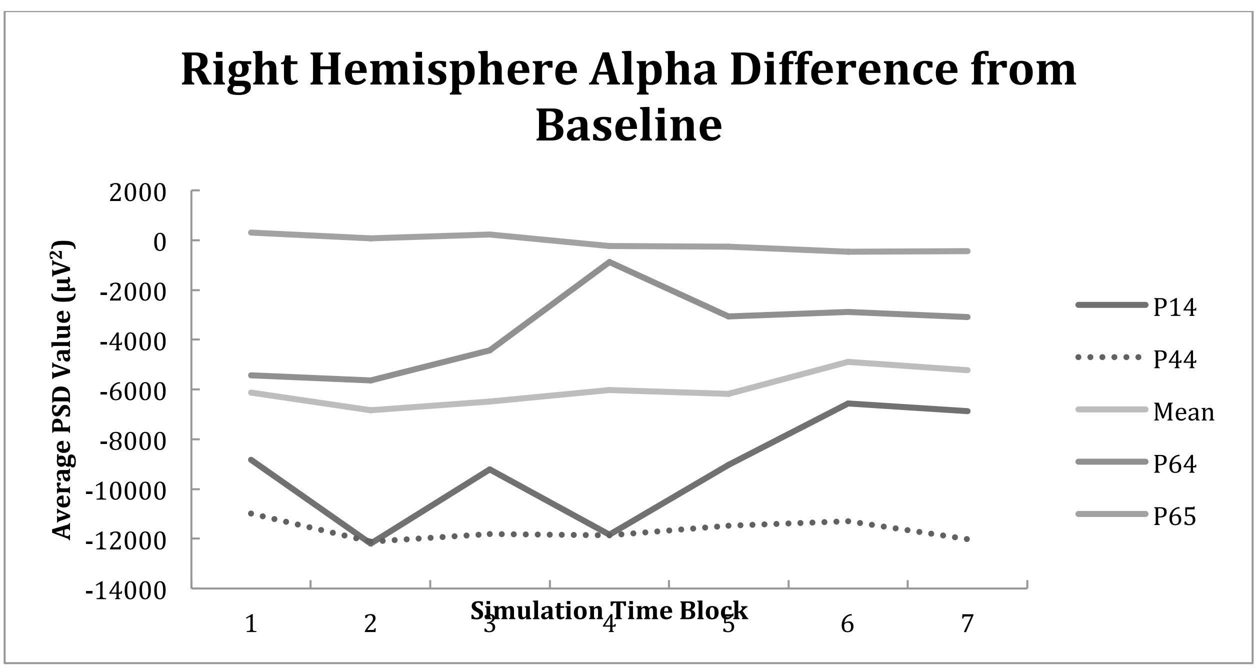


Figure 5. Individual differences for EEG right hemisphere alpha (P14 & P44 = AWCH experiencers; P64 & P65 = AWCH non-experiencers)..

For the beta and theta wavelengths, the differences from baseline were not as ordered, with these AWCH experiencers and AWCH non-experiencers showing no significant difference or consistency across sides of the mean. These results support the functional utility of phenomenological data from the interviews in exploring individual differences for AWCH experiencers and AWCH non-experiencers.

It should be noted that this alpha pattern was not found in all participants who reported AWCH experiences. For example, P27 articulated experiences of AWCH, yet alpha DFB (left hemisphere $M = -6616.48$) was close to the population mean ($M = -7355.37$, $SD = 11460.96$) throughout the simulation. Inversely, P4 displayed alpha-suppression ($M = -26699.76$), yet did not explicitly articulate AWCH experiences. P4 did indicate in the ESSE that he experienced wonder, curiosity, and humility, each at 50 points on the 100 point scale. He also indicated on the ESSE that the simulation felt familiar (90 out of 100) and self-identified as a “reflective person” (60 out of 100) and “logical person” (100 out of 100).