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UNITED STATES ARMY AEROMEDICAL RESEARCH LABORATORY

Evaluation of a Commercial EEG System Beneath the Aviator's Helmet: Data Quality and Comfortability

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14. ABSTRACT
A non-research activity was conducted to assess the comfort and signal quality of a research electroencephalography (EEG) system beneath the aviator's helmet. Three aviators participated in the activity. The EEG system was evaluated using two helmet liner types to determine comfort and quality of the EEG signal. Each aviator wore the EEG beneath each liner type for a total of one hour of simulated flight. Activities to increase movement by the aviators occurred throughout the flights to further test signal quality. Subjective measures were taken to assess comfort. Overall, both liners resulted in significant discomfort after an hour of wear; however, one liner was preferred by two of the three aviators. Regarding signal quality, both liners resulted in usable EEG signals. In the current set up, it is not recommended to use the EEG beneath the helmet in research studies exceeding 30 minutes of wear. However, there may be ways to improve comfort, which should be further explored to determine whether the EEG can comfortably be worn beneath the helmet beyond 30 minutes.

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EEG, helmet, aviation

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Introduction

The U.S. Army Aeromedical Research Laboratory (USAARL) has been actively engaged in an operator state monitoring (OSM) research program. This research program aims to result in a system that can track Army aviators' cognitive state in real-time using physiological monitoring (e.g., electroencephalography [EEG], eye tracking, and heart rate variability [HRV]). With the anticipated change in the operational flight environment, the cognitive demands placed on aviators are expected to increase. Consequently, certain aspects of cognition including but not limited to workload, vigilance, and situational awareness, will likely be affected and deteriorate, leading to performance degradation. An OSM system that can identify adverse cognitive states and predict the likelihood of performance degrading could have the potential to introduce methods to offset these degradations.

EEG has been identified as a promising physiological biomarker to use in an OSM system. Past research has shown that EEG can be used to detect differences in high and low cognitive workload, levels of fatigue, and hypoxic vs. non-hypoxic states (Duffy & Feltman, 2022; Feltman, 2020; Feng et al., 2018). These are all states that can adversely impact aviator performance. Early detection through a measure such as EEG could prevent potential accidents that can lead to serious injury and even death. Moreover, EEG's wireless capabilities, high temporal resolution, and non-invasiveness furthers its appeal as a possibility for an integration in an OSM system (Warfighter Performance Group, 2024).

However, there are several limitations to be addressed prior to adopting EEG into an OSM system. One significant limitation faced by EEG is its ability to fit adequately and comfortably under the aviator helmet. The helmets are currently designed to fit snugly to the aviator's head and as such do not allow room for extraneous material to be fit inside. Any additional materials can introduce significant discomfort. In addition to comfort, the ability to collect usable data is of question. Wilkins et al. (2023) conducted a Delphi method survey of subject matter experts that addressed physiological wearables' compatibility and reliability within the military aviation operational setting. This study found that EEG is unlikely to withstand vibrations and maintain adhesion which would likely result in unreliable data. To-date, the research team has been unable to identify any published studies where EEG was successfully collected in helicopter flight.

Given the promise of EEG for detecting operator states, being able to collect EEG data in realistic settings is critical. Doing so will aid in determining whether EEG is worth pursuing for an OSM system. This can help guide the commercial development of helmet-compatible systems. The objective of this non-research activity was to evaluate a current USAARL-owned EEG system for its suitability for in-flight research. Specifically, the research device was evaluated for its fit beneath the aviator helmet, comfortability for an extended period, and ability to collect usable data in a simulated flight environment. The following objective was addressed: To evaluate an electrode placement methodology to determine whether comfort can be maximized while maintaining signal quality; and to evaluate new system equipment that allows for mounting of the transmitter device onto the back of the helmet.

Methods

This study evaluated two types of protective liners to determine fit, comfort, and usable signals of the EEG system beneath the standard UH-60 helmet. Each participant went through two iterations, one wearing the ThermoPlastic Liner and one wearing the Zeta Liner. Once the EEG and helmet were donned, the participants flew a one hour long simulated flight in the full motion UH-60 Black Hawk simulator, with motion on. Subjective measures were taken during and after simulation to evaluate the comfort of wearing the device. EEG data were continuously recorded to evaluate signal quality.

The U.S. Army Aeromedical Research Laboratory Exempt Determination Official (EDO) reviewed the test plan and objectives prior to execution. The USAARL EDO determined that this activity does not constitute research as defined under the human subjects protection regulations, as it is not "...designed to develop or contribute to generalizable knowledge" (32 CFR 219.102).

Participants

Three (one female) currently rated UH-60 aviators local to the Fort Rucker, AL area participated in this activity. All three aviators were familiar with the helmet donning procedures and the tasks to be completed within the simulator. Two of the aviators wore a size small helmet, while the third wore a medium.

Materials and Equipment

Flight simulator.

USAARL's NUH-60 research flight simulator consists of a simulator compartment containing a cockpit, instructor/operator station, observer station control room and a six-degree-of-freedom motion system. It is equipped with a twelve-channel visual image generator system, ten-foot radius collimated optical display providing a 200x45 degree field of view and two chin displays. The collimated optical display system consists of seven RGB+IR LED projectors, each providing 2560x1600 pixels resolution for a combined resolution of 1.8 Arcminutes/Pixel. The visual system simulates the natural helicopter environment surroundings for day, dusk, and night.

EEG system.

The Advanced Brain Monitoring (ABM) B-Alert X24 (Carlsbad, CA) is a wireless wet electrode system with 20 channels corresponding to scalp locations according to the International 10-20 system (frontal channels: Fp1, Fp2, F7, F3, Fz, F4, F8; central channels: C3, Cz, C4, T3, T4; parietal and occipital channels: P3, POz, Pz, P4, T5, T6, O1, O2; Figure 1). The B-Alert uses soft, sponge-like electrodes that are connected to a flexible plastic strip (Figure 2). This system was chosen for use in the study due to the flexibility of the strip, wireless capabilities, and accessibility. In this study, a modified electrode strip was used (Optios Inc, San Diego, CA) (Figure 3). This strip (Figure 3) includes a longer "tail" that allowed for the placement of the receiver onto the back of the aviator's helmet, rather than left at the nape of the neck.

Outcome measures from the EEG system included raw power spectral density (PSD) values from each channel and artifacts from each channel. The ABM software automatically identifies and tabulates artifacts from each channel. Identified artifacts are categorized into the following types: spike, excursion, saturation, electromyography (EMG), and eye blink. This information provides insight into the data and signal quality.

In addition to examining the output provided by the ABM software, the raw signals were also processed, and the signal-to-noise ratios (SNRs) were evaluated. Due to the continuous recording in an uncontrolled environment, traditional task-based SNRs to evaluate EEG signal quality were unsuitable. As such, we adopted a time-domain SNR calculation used in previous studies (Radüntz, 2018; Yue et al., 2025). In this approach, the signal was defined as the EEG signal after artifact removal, while the noise was defined as the difference between the artifact-removed EEG signal and the band-pass filtered signal. The SNRs were then calculated as the ratios of the sum of the squared signal to the sum of the squared noise over time, then converted to decibels (dB). This was performed for each channel. This analysis was performed offline.

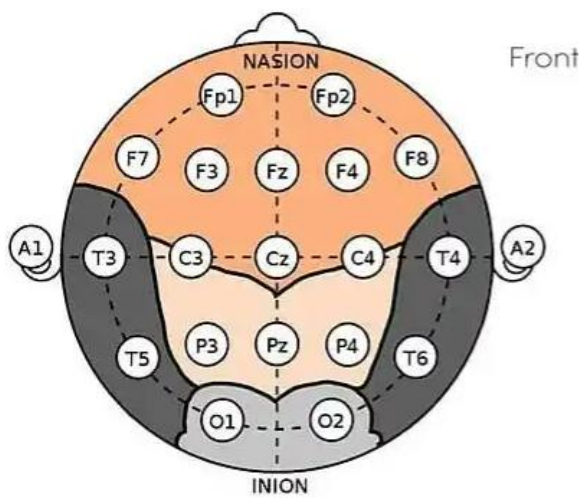

Figure 1. Depiction of the 10-20 electrode sites.

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Figure 2. EEG system used in study.

Figure 3. Extended EEG sensor strip.

ThermoPlastic Liner.

The Gentex ThermoPlastic Liner (TPL) (Carbondale, PA) is the standard Head Gear Unit-56/Personal (HGU-56P) helmet liner that consists of molded polyvinyl acetate sheets that are covered by a removable, washable cloth (Figure 4). The liners can be softened using heat and custom-fitted to improve comfort. The TPL is used to provide protection, comfort, and helmet stability.

Figure 4. ThermoPlastic Liner.

Zeta III® Helmet Liner.

The Zeta III Helmet Liner (Scappoose, OR) is designed and manufactured by Oregon Aero® for HGU-56P helmets (Figure 5). This liner has been designed for comfort, protection, and helmet stability. The liner is made of a foam material and was designed to replace the liner between the aviator's head and the styrene crush liner in the flight helmet.

Figure 5. Zeta III® Helmet Liner.

Comfort-Discomfort Questionnaire.

The Comfort-Discomfort Questionnaire was designed in-house (Appendix A) to evaluate participant comfort levels with the worn liner. It was administered at three key time points: before flight, mid-flight, and end of flight. The questionnaire includes a 10-point Likert scale (0 indicating very uncomfortable and 10 indicating very comfortable), a 10-point pain intensity scale, and a head diagram for the participant to indicate specific areas of discomfort. The research team aligned the marked areas on the head diagram to the brain region where the electrodes were for evaluation (i.e., forehead marked = frontal region).

Procedures

EEG and helmet fitting.

Each participant was asked to bring their own helmet to ensure an appropriate fit. USAARL supplied the TPL, as they were molded to fit with the EEG system in place, and the Zeta Liners, as not all aviators own them.

First, participants were fitted with the EEG system following the standard application procedures. Then an initial impedance check was done to determine if the EEG placement was adequate prior to fitting the TPL or Zeta Liner. Once the impedance values were sufficient, the transmitter was removed so that the liner could be fitted in place.

For the TPL iteration, the TPL was fitted with the assistance of a certified Aviation Life Support Equipment technician according to Technical Manual (TM) 1-8415-216-12&P sections 4-12 through 4-18 (Department of the Army, 1996). This included heating the TPL, placing it inside the helmet and molding it to fit with the electrodes in place. The TPL was heated within a T800 oven at a temperature of 200° Fahrenheit for 10 minutes. The participant was then instructed to apply pressure to the helmet at any hot spots by placing the helmet against a hard surface and slowly rotating at the site of the hot spot. This was done by the participant standing near a wall and rolling slowly where the hotspots were located. This action helped conform the liner around the electrodes. By fitting the TPL with the EEG in place, discomfort resulting from the EEG foam electrodes was expected to be minimized. Note, the Zeta Liner does not require special fitting beyond determining the correct size.

Finally, the transmitter was mounted to the back of the helmet. Velcro was used to secure the transmitter in a similar location that is used for night vision goggle battery packs (Figure 6). Adjustments were made as needed to maximize comfort such as modifying the mastoid placements as they may interfere with the earcups. Once the participant verbally indicated the placement was comfortable, an impedance check was completed with the EEG software. This allowed the research staff to determine whether the sensors were able to record data. Additional adjustments were done as needed to ensure proper connections. Next, the participant was moved into the full-motion UH-60 Black Hawk simulator.

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Figure 6. Depiction of EEG receiver mounted on back of helmet.

Simulated flight.

To assess the comfort and data quality of the EEG system beneath the helmet, the participant completed a simulated flight scenario lasting approximately one hour. This flight was completed twice (once for each liner). The activities described in Table 1 occurred at the beginning of the flight period and again at the end of the flight period, lasting for 3 to 5 minutes each, with routine, straight and level flight in between for approximately 30 minutes (see Table 2). These activities were selected to evaluate whether execution impacted EEG signal and data quality.

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Table 1. Description of Flight Activities to Assess EEG Data Quality

Activity	Purpose	Execution
Increased communication (reading task)	To evaluate the effect of facial movements related to talking on the signals.	Each participant was asked to read a Flight Fax publication out loud for 5 minutes (min). A timer indicated when to discontinue reading.
Increased physical movements (motion task)	To evaluate the effect of increased physical movement by the participant on the signals.	Participant completed the following activities: • Identifying and resetting an alternating current primary circuit breaker • Conducting a traffic pattern while in LOCKOUT on opposite side engine • Scanning from all available windows – opposite door, left/right/center windscreen, greenhouse, side door, chin bubble.
Increased simulator movement (turbulence task)	To evaluate the effects of vibrations and movements from the simulator on the signals.	Participants conducted a 5 min terrain flight loop while on motion with increased turbulence.

EEG data was recorded throughout the duration of the simulated flight(s) to evaluate signal quality. Table 2 below describes the flight scenarios used. A database consisting of San Francisco, California and the surrounding area (PLW Modelworks, LLC) was used for the flights.

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Table 2. Flight Scenario Timeline

Task Number	Timeline	Task	Location
1	00:00 to 05:00 m	Reading Task	On Ground
2	05:00 to 10:00 m	Physical Movement Tasks	Stadium
3	10:00 to 15:00 m	Terrain Flight	Threat Route
4	15:00 to 45:00 m	Routine Straight/Level Flight	In Local Area
Flight frozen at 30:00 m to complete mid-flight comfort assessment.			
5	45:00 to 50:00 m	Terrain Flight	Threat Route
6	50:00 to 55:00 m	Physical Movement Tasks	Stadium
7	55:00 to 60:00 m	Reading Task	On Ground

All participants completed the study in a single day. After the first flight was completed, the participant was given a 15-minute break prior to the second liner being prepared, and the second flight took place. Once finished, the participant was excused from the study.

Results

To address the study's objective, "To evaluate an electrode placement methodology to determine whether comfort can be maximized while maintaining signal quality; and to evaluate new system equipment that allows for mounting of the transmitter device onto the back of the helmet," a number of steps were completed. First, summary statistics were calculated, by liner type, from the Comfort-Discomfort Questionnaire to assess comfort. In addition, written comments from the participants were reported, along with notes taken by the research team during the data collection process. To assess the usability of the EEG data, summary statistics for artifacts computed from the EEG software are reported. In addition, the SNR analysis was conducted and is reported below. Evaluation of the new equipment was also addressed through examining EEG artifacts and the SNR analysis.

Comfortability Evaluation

Comfort ratings were provided at three timepoints (initial/pre-flight; mid-flight/30 minutes of wear; and end-of-flight/60 minutes of wear) and presented by participant and by liner (Table 3). The Zeta Liner had higher ratings of comfortability for two of the participants compared to the TPL. Overall, the Zeta Liner was rated more comfortable by 1 point on the scale. Figure 7 depicts individual ratings by liner as well.

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Table 3. Comfort Scale Ratings

	Participant	Initial Comfort	Mid-Flight Comfort	End-of-Flight Comfort	Mean (SD)
	A	7.50	6.00	3.75	5.75 (1.89)
TPL	B	5.00	3.00	1.00	3.00 (2.00)
	C	5.00	6.00	6.50	5.83 (0.76)
				Total TPL	4.86 (2.00)
	A	7.20	4.75	3.00	4.98 (2.11)
Zeta	B	7.00	4.00	2.00	4.33 (2.52)
	C	9.00	7.50	8.00	8.17 (0.76)
				Total Zeta	5.82 (2.45)

Note. Ratings range from 0 (very uncomfortable) to 10 (very comfortable).

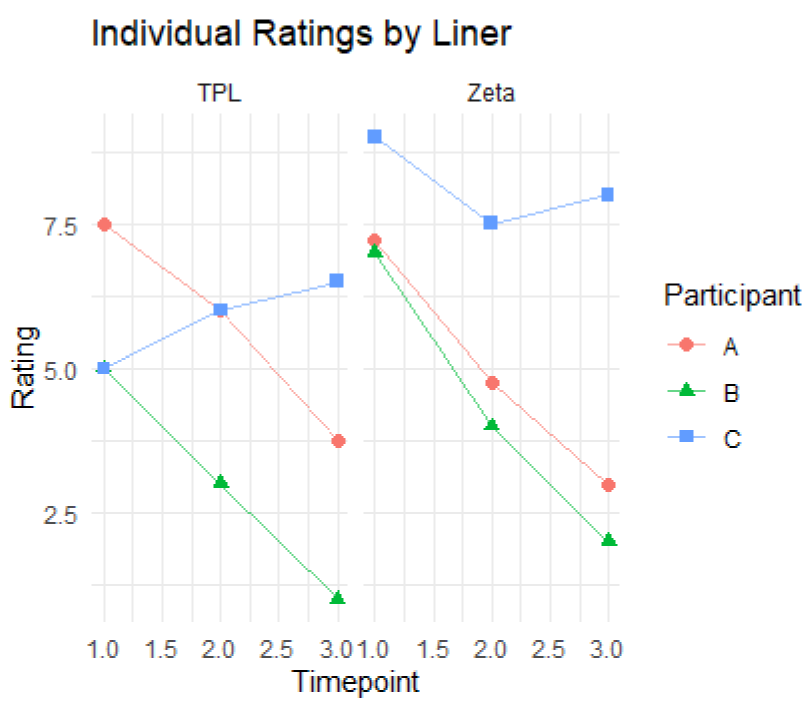

Figure 7. Comfort ratings by liner.

Discomfort ratings were also provided at the same time points as the comfort ratings, including the locations where discomfort was experienced (Table 4). The Zeta Liner had higher ratings of comfortability for two of the participants compared to the TPL. Overall, the Zeta Liner was rated more comfortable by 1 point on the scale. Participant comments and research team notes are supplied in Table 5.

Table 4. Discomfort Scale Ratings

	Participant	Initial Area	Rating	Mid-Flight Area	Rating	End-Flight Area	Rating	Mean (SD)
TPL	A	Frontal	1.50	Frontal	2.75	Frontal	6.50	3.58 (2.60)
	B	Frontal, both mastoids	3.00	Frontal, both mastoids	7.00	Frontal, both mastoids	9.00	6.33 (3.06)
	C	Right frontal above the right eye, right mastoid, occipital	5.00	Frontal (center of forehead)	6.00	Center forehead (frontal) w/ left eye, left mastoid, occipital	6.50	5.83 (0.76)
							Total	5.25 (2.40)
Zeta	A	Frontal	1.75	Frontal	4.25	Frontal, both mastoids	6.00	4.00 (2.14)
	B	Both mastoids	3.00	Frontal, left mastoid	5.00	Frontal, both mastoids	7.00	5.00 (2.00)
	C	None indicated	0.00	Frontal	2.00	Frontal, left ear	3.00	1.67 (1.53)
							Total	3.56 (2.22)

Note. Scale ranged from 0 (no pain) to 10 (worst pain imaginable), where 1-3 = mild pain, 4-6 = moderate pain, and 7-9 = severe pain.

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Table 5. Participant Comments Specific to Each Liner and Research Team Observations

Participant Comments	
TPL	**Zeta**
At the 45 min mark was the most intense discomfort; at the conclusion 1 + 00 hour (hr) same discomfort as 30 min	At 45 min same discomfort; at the 60 min mark comfort was 8 and discomfort was 3 mild; T-5 electrode slid off adhesive
yuck. So distracting I couldn't read the pain scales, also made me fairly nauseous…nauseated*	Zeta hurt most; TPL also hurt, but slightly less than Zeta. Depending on workload, probably could have done another 10-15 min with either TPL or Zeta without getting grumpy.
	Zeta and heat formed TPL not sufficient to make up for bulky items under helmet. Severely distracting at a minimum.
Research Team Notes	
Participant noticed the neoprene band as an initial source of discomfort. Also had the plastic strip of EEG band touch the ear and cause discomfort. Adjusted as able.	Immediately noted better comfort when switching to Zeta Liner.
42:21 Discomfort is getting progressively worse with time. Suggested comfort scale at 15-minute intervals to capture more changes.	Participant adjusted helmet multiple times from approximately 39 to 49 minutes.
44:00 Three hotspots at frontal region, rating a 6 or 7. Above left eye and mastoid have hot spots.	Participant felt hotspots on mastoids more during the Zeta iteration.
TPL break-in required. Rolling front of helmet to assist with hot spots.	
Front of forehead was red upon removal of helmet. Participant stated it was getting annoying and uncomfortable at the end of the route and said about 20 minutes more they would have "gotten angry"	
Participant felt nauseated after the TPL iteration	

Note. *Participants were instructed they could discontinue at any time.

Finally, at the completion of both flights, participants were asked which liner they preferred. Two of the participants reported preference for the Zeta Liner, while the third participant stated "neither."

EEG Quality Metrics from System Software

Table 6 below presents the summary statistics for each artifact type and each liner. The duration percent (%) was the percentage of time each artifact was present within the data recordings. These were aggregated across the entirety of each flight. Overall, the TPL had fewer artifacts identified as compared to the Zeta Liner.

Table 6. Summary Statistics of EEG Artifacts by Channel and Liner

		TPL		Zeta	
Artifact Type	**Channel**	**Mean *n* (*SD*)**	**Duration % *M* (*SD*)**	**Mean *n* (*SD*)**	**Duration % *M* (*SD*)**
EMG	Fp1	544.00 (103.00)	14.20 (3.15)	884.00 (386.00)	22.80 (9.41)
	Fp2	463.00 (182.00)	12.10 (5.02)	780.00 (320.00)	20.20 (7.77)
	T3	454.00 (332.00)	11.70 (8.27)	589.00 (290.00)	15.30 (7.46)
	T4	427.00 (76.10)	11.10 (1.83)	554.00 (91.90)	14.30 (1.92)
Excursion	Fp1	3620 (904)	1.23 (0.36)	5586 (3152)	1.87 (0.94)
	Fp2	2968 (799)	1.03 (0.37)	5806 (4057)	1.88 (1.12)
	T3	2530 (954)	0.87 (0.35)	3564 (1823)	1.24 (0.67)
	T4	1997 (982)	0.69 (0.38)	2375 (1338)	0.81 (0.52)
Saturation	Fp1	137.00 (94.60)	1.47 (1.37)	168 (148)	1.79 (1.92)
	Fp2	132.00 (100.00)	1.57 (1.35)	136 (110)	1.44 (1.71)
	T3	23.30 (37.80)	0.21 (0.32)	24.70 (13.10)	0.37 (0.06)
	T4	37.70 (53.10)	0.33 (0.45)	15 (8.72)	0.27 (0.16)
Spike	Fp1	3906.00 (1108.00)	2.07 (0.69)	6094.00 (3204.00)	3.20 (1.54)
	Fp2	3269.00 (1092.00)	1.75 (0.69)	6165.00 (3902.00)	3.15 (1.75)
	T3	2951.00 (1173.00)	1.59 (0.65)	4246.00 (2129.00)	2.32 (1.19)
	T4	2263.00 (1145.00)	1.22 (0.68)	2798.00 (1526.00)	1.51 (0.89)

Signal-to-Noise Ratio Analysis

The SNR data were graphed to display the differences in values across the tasks. The data for each participant were parsed based on the task type in order to evaluate how the different tasks impacted signal quality. This was completed for each liner type, with an average across all EEG channels as well as for each individual channel.

Figure 8 presents the SNR data for all participants. The top row shows the SNR values for TPL, while the bottom row displays those for the Zeta Liner. The left column shows the averaged SNR values across all EEG channels, and the right column shows the SNR values for each individual channel.

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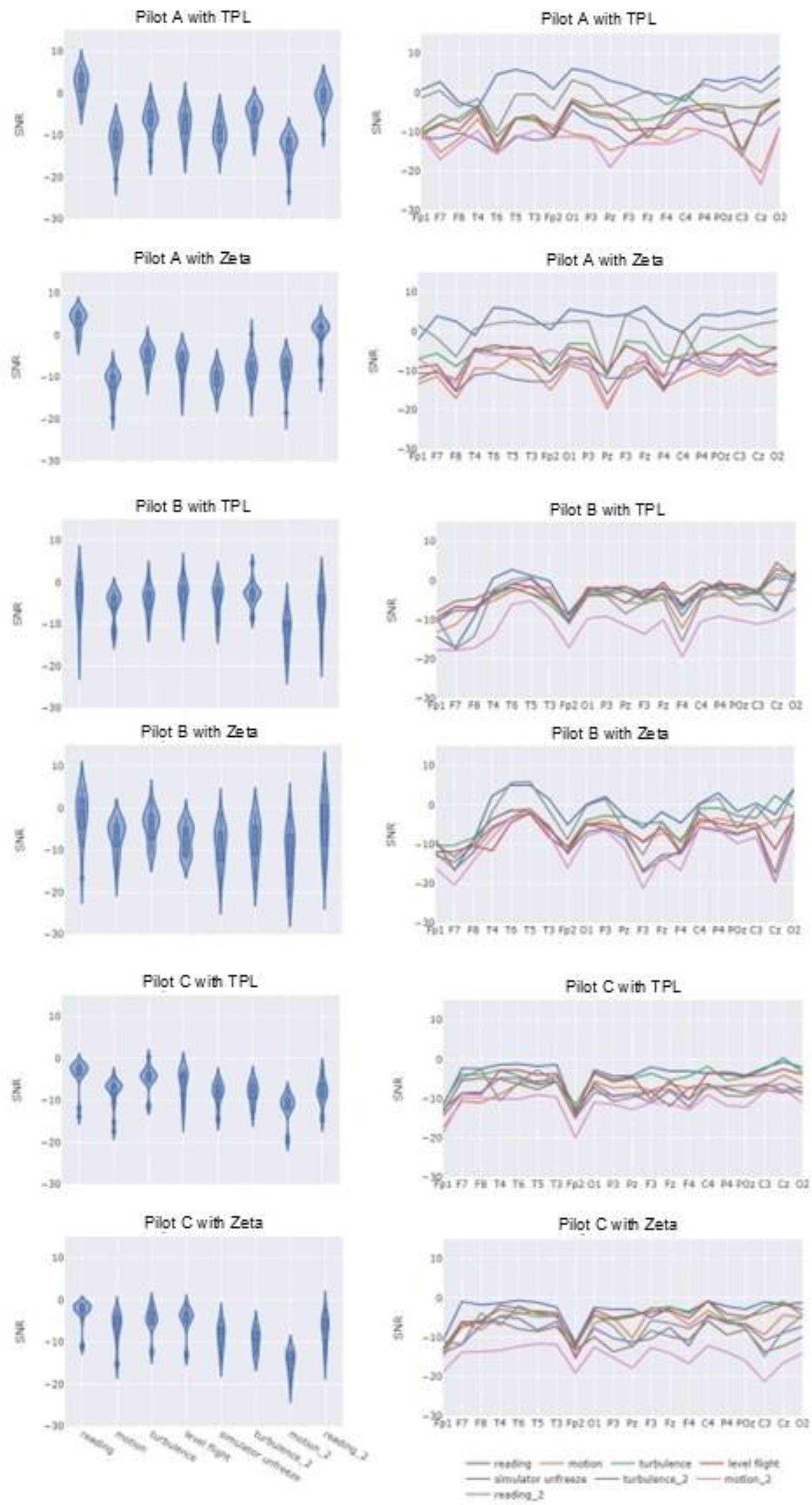

Figure 8. Participant's signal-to-noise ratios.

Discussion

The ability to capture usable EEG data beneath the helmet is a critical component to furthering the development of an OSM system. Capturing usable data beneath a helmet would enable more research to move outside of the laboratory and into the actual aircraft. This is critical for understanding neurophysiological responses during flight tasks that cannot be replicated within the simulated environment. However, comfort cannot be sacrificed, thus this study evaluated two types of liners to determine whether the EEG system would be tolerable. Additionally, modified equipment (longer electrode strip) allowing the transmitter to be placed on the back of the helmet instead of resting on the nape of the neck was tested for signal quality and comfort.

Two different types of liners, both approved for use beneath the HGU-56/P helmet, were evaluated. Through evaluation of the subjective ratings and comments from the participants, there was a clear preference for the Zeta Liner. However, the differences in rating values were minimal. For the overall comfort rating, the Zeta Liner only scored approximately 1 point higher than the TPL, on average. Regarding the discomfort ratings, the Zeta Liner neared 2 points lower than the TPL. Two of three participants indicated preference for the Zeta Liner over the TPL (the third indicated neither). Examination of the graphed responses suggests there may be individual differences in pain tolerance. For example, Participant C demonstrated the least changes in comfort ratings, whereas Participants A and B both demonstrated steep declines in ratings over time. In addition, Participant C's comfort ratings for the TPL actually *increased* over time. As such, future development of integrated OSM systems will need to take care in how potential individual differences in pain tolerance will impact system comfort and use.

Despite the higher comfort ratings participants gave the Zeta Liner over the TPL, comments rendered by the participants and research team suggest that forty-five to sixty minutes is likely the maximum time either liner with EEG donned could be worn, albeit not without significant discomfort. The locations of greatest discomfort were reported at the mastoids and frontal regions. Due to the shape of the helmet and form factors of these electrodes, this finding is unsurprising. However, with the individual differences in pain tolerance, it is possible that that contributed to the ratings. Other factors such as head size and shape may have also contributed to the differences identified.

In terms of data quality, as measured by the EEG system's software, the TPL tended to have better performance compared to the Zeta Liner. This was characterized by fewer instances of artifacts and shorter durations of those artifacts within the data stream. The SNR evaluation, however, found little difference in SNR values between the two liners. In addition, both liners indicated the highest SNR values during the reading task, and the lowest during the motion task. This finding is likely due to participants remaining still with only their mouth and eyes moving during the reading task, whereas during the motion task, participants were more dynamic, moving arms, legs, torso and head. Finally, the new equipment was determined usable from this evaluation, as data was transmitted appropriately, as evidenced by the SNR analysis.

Recommendations

The EEG system evaluated here could have potential to be used in research studies beneath the helmet, but several modifications are recommended. To improve comfort near the mastoid region, different earcups should be pursued. The same company that produces the Zeta Liner has earcups that would likely result in less pressure on the mastoid electrodes and increase comfort. The potential for the earcups to improve comfort was suggested by the study participants. This would need to be assessed to determine whether or not they improve comfort. Regarding the discomfort from the frontal region, if used in a research study, the research team may consider not placing the sponge electrodes on sites Fp1 and Fp2. These two sites are located directly on the forehead and appear to have been the areas of greatest discomfort (outside of the mastoids). Not including these sites in data collection would not negatively affect the quality of the EEG outcomes. It is common practice to discard data from these sites due to the high degree of ocular activity they capture that creates artifacts in the data.

Beyond the use of this specific system beneath the helmet, the study provided insight for methodological considerations of *any* EEG system (or similar device) beneath a helmet. First, it was clear that prior to integrating any sort of EEG or similar device beneath a helmet for research purposes, evaluations of comfort and signal usability should be completed first. Second, future research methods should take into consideration the two liners evaluated here as well. While the Zeta Liner was preferred for comfort, the TPL liner produced better data quality from examination of the EEG software's data. However, the SNR evaluation did not support a preference for either liner. Thus, the research team took both into consideration when making determinations for which liner to implement in the study with EEG beneath the helmet.

The third consideration for using such a device beneath the helmet in a research study includes the amount of time required for the participants to don the device beneath the helmet and whether there would be opportunities for readjustments or removal. It was clear that one participant experienced significant discomfort, to the point where had the device been required to be worn longer, the participant may not have continued with the study. Had that point been reached and the study was in an actual aircraft, the research team would not have been able to remove the device. Therefore, duration of wear and whether removal is possible, let alone convenient, would need significant consideration by the research team. It is recommended that prior to using this EEG system or other devices beneath a helmet in-flight, that all study participants should first wear the system in the same configuration during a simulation of the same duration. In doing so, the research team would have the opportunity to assess how each individual responds to the comfort of the device prior to placing them into the aircraft where removal is not possible.

Finally, the tasks to be performed while collecting in-flight data will need to be considered as well. The motion tasks produced the lowest SNR values, suggesting there may be an increased propensity for misinterpreting the findings. Along this vein, although the motion was turned on within the simulation, the actual vibrations of flying a real aircraft would likely produce different effects on the signal. Thus, before executing a research protocol using EEG in flight within a helicopter, test flights should first be performed to determine the impact of the helicopter vibrations on signal quality.

Conclusion

The study successfully demonstrated the EEG system could be worn beneath a helmet, under both liner types, and collect usable data. This is a significant step in moving toward the realization of an OSM system. However, the EEG system and liner configurations evaluated here suffered from significant comfort concerns for the participants. Several recommendations were presented to overcome these concerns within research settings. The current evaluated systems are not at a point to be a usable tool for a practical OSM system, but with modifications to the methods used here, may be able to be used as a research tool in furthering the development of the OSM system.

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Appendix A. Comfort Scale Questionnaire

Date:____________________

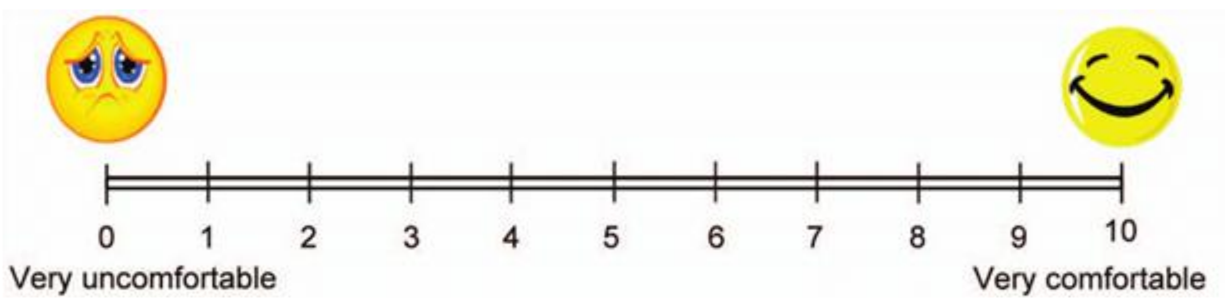
Participant:_______________

Liner Type: TPL Zeta

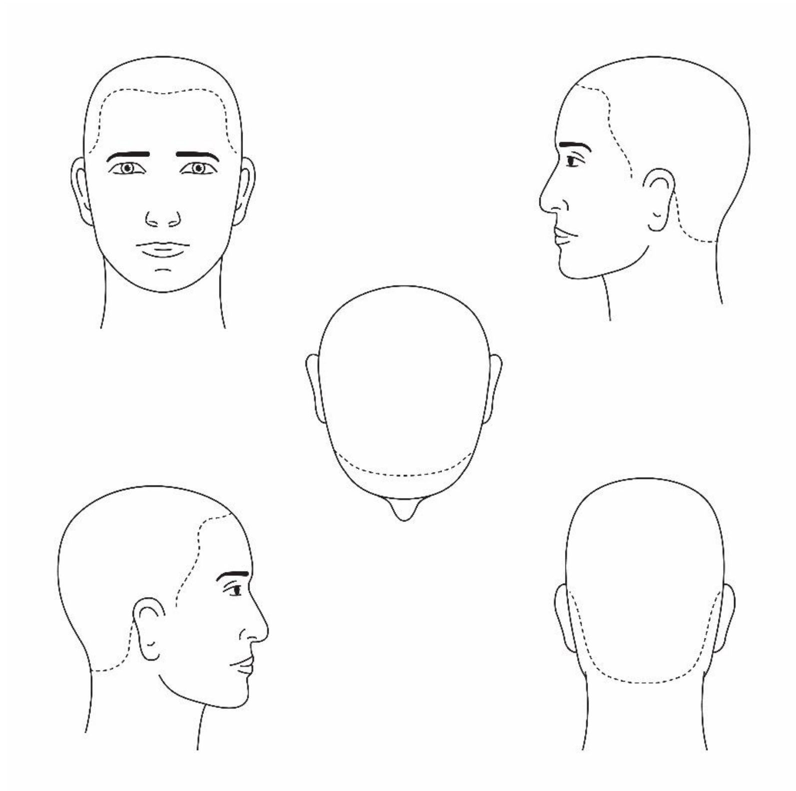
Comfort Scale

Initial Assessment after Its Placement and the Helmet Fitted

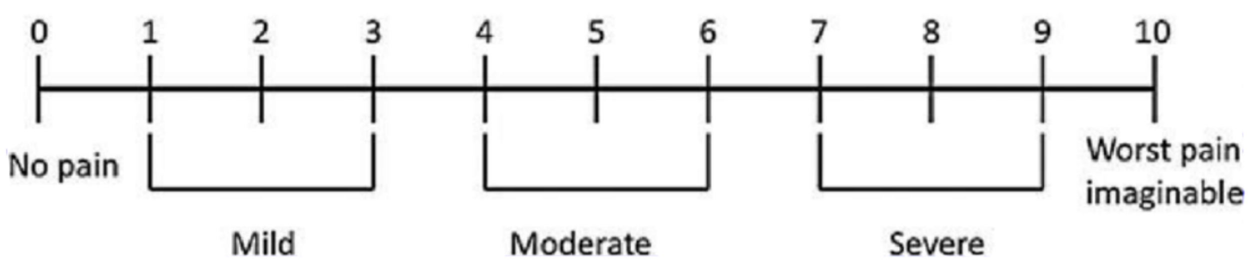
1. How would you rate the overall comfort of this device? [indicate on the scale below]



2. Are there any areas of discomfort? If so, please indicate in the picture below.

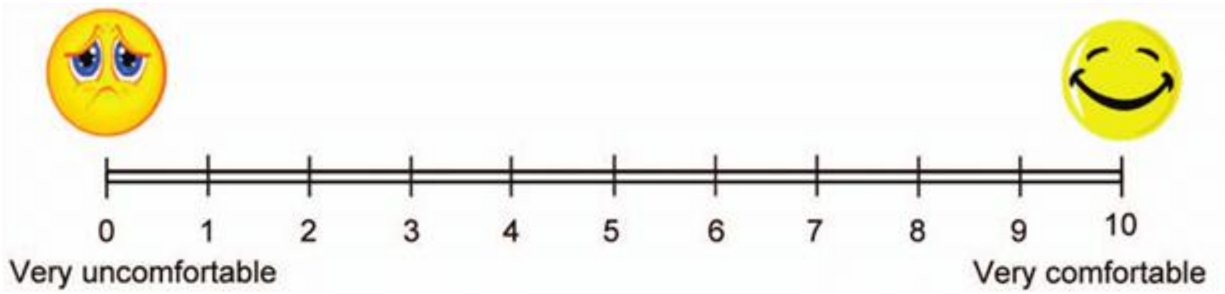


3. How would you rate the intensity of these points of discomfort?

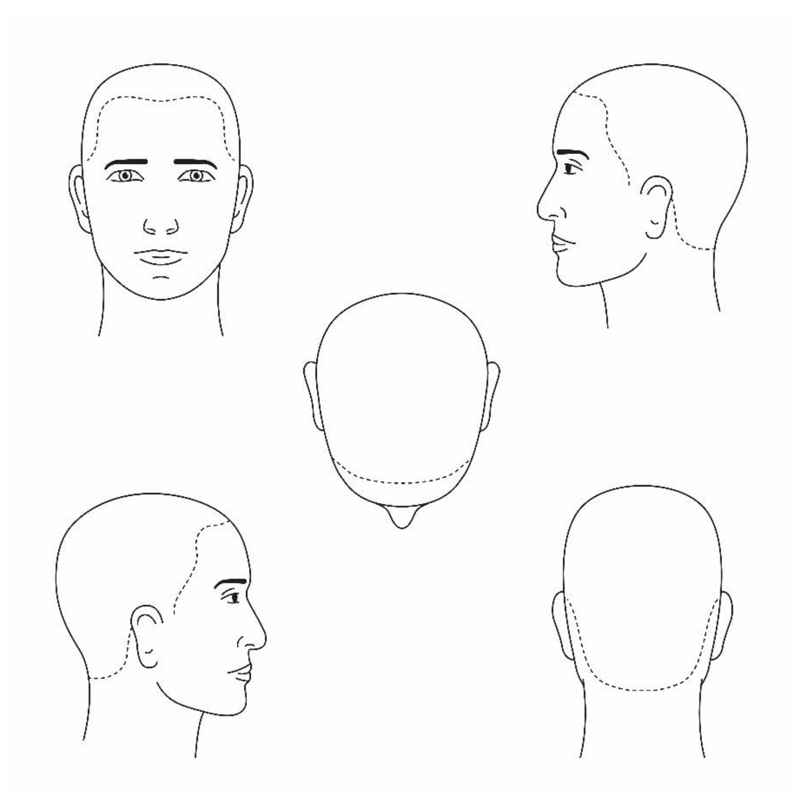


Mid-Flight Assessment (pause flight at 30 minutes and complete assessment)

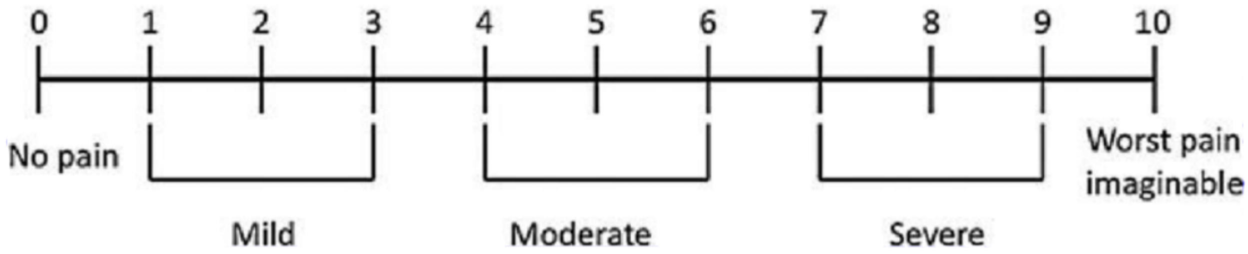
1. How would you rate the overall comfort of this device? [indicate on the scale below]



2. Are there any areas of discomfort? If so, please indicate in the picture below.

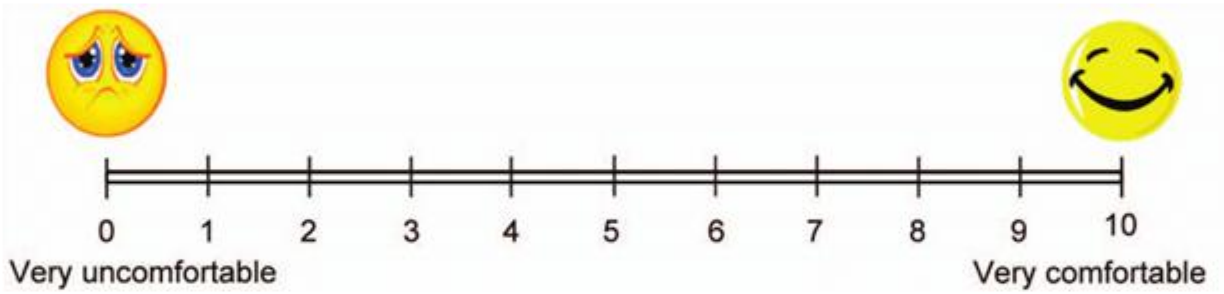


3. How would you rate the intensity of these points of discomfort?

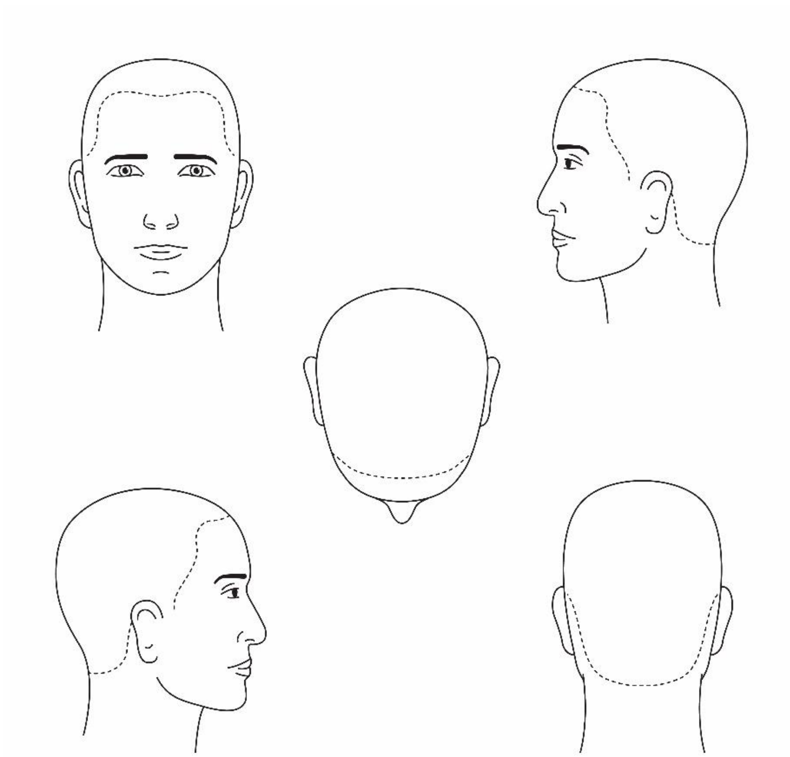


End-of-Flight Assessment

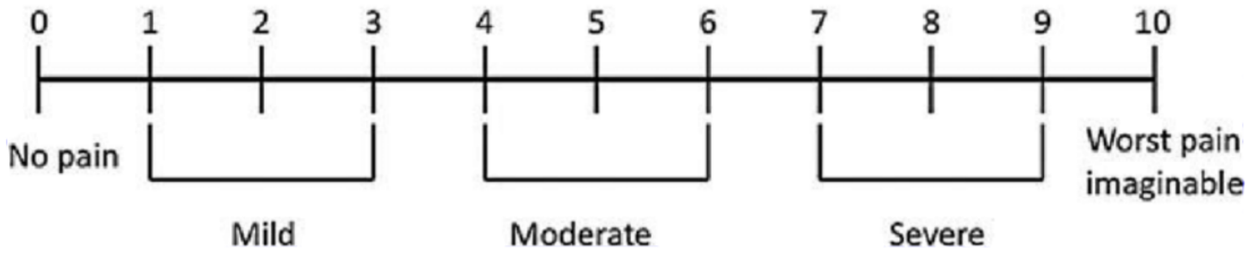
1. How would you rate the overall comfort of this device? [indicate on the scale below]



2. Are there any areas of discomfort? If so, please indicate in the picture below.



3. How would you rate the intensity of these points of discomfort?



4. If this was your final flight, please indicate which liner you preferred (mark NA if not final flight):

TPL Zeta N/A Neither

5. If you have any additional comments you would like to share, please do so:

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