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UNITED STATES ARMY AEROMEDICAL RESEARCH LABORATORY

Evaluation of Signal Quality and Comfort for Wearable EEG Device in the UH-60 Flight Simulator

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14. ABSTRACT

This research test plan activity assessed the comfort, physical durability, and signal quality of the CGX Patch, a two-channel electroencephalogram (EEG) wearable, to determine its viability for simulated flight and performance research at the U.S. Army Aeromedical Research Laboratory (USAARL). Three active-duty soldiers wore the device across three distinct testing phases including resting baselines, a 60-minute physical training (PT) session designed to challenge device adhesion through motion and perspiration, and two simulated UH-60 flights. While subjective ratings indicated the device was well-tolerated in climate-controlled, low-exertion settings, the hydrogel adhesive frequently compromised or failed under moderate-to-heavy perspiration during the PT phase. Beyond physical adhesion, power spectral density analysis of the raw EEG data revealed significant limitations regarding signal quality. The device's aggressive built-in signal filtering suppressed physiologically meaningful neural activity, failing to capture the expected alpha-band increases during the eyes-closed condition. Because of its susceptibility to adhesive failure and its inability to detect rapid, transient neural changes, the CGX Patch is unsuitable for research requiring high temporal validity which limits its potential use case for USAARL research. With that being said, the compact form factor of the device may still have an applicable use case for long-duration, stationary physiological monitoring, such as sleep studies.

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Summary

This non-research activity assessed the comfort, physical durability, and signal quality of the CGX Patch, a two-channel electroencephalogram (EEG) wearable, to determine its viability for simulated flight and performance research at the U.S. Army Aeromedical Research Laboratory (USAARL). Three active-duty Soldiers wore the device across three distinct testing phases including resting baselines, a 60-minute physical training (PT) session, and two simulated UH-60 flights. While subjective ratings indicated the device was well-tolerated in low-exertion settings, the hydrogel adhesive frequently compromised or failed under moderate-to-heavy perspiration during the PT phase. Beyond physical adhesion, power spectral density (PSD) analysis of the raw EEG data revealed significant limitations regarding signal quality. The device's aggressive built-in signal filtering suppressed physiologically meaningful neural activity, failing to capture the expected alpha-band increases during the eyes-closed condition in the baseline phase. Because of its susceptibility to adhesive failure and its inability to detect rapid, transient neural changes, the CGX Patch is unsuitable for research requiring high temporal validity which limits its potential use case for USAARL research. With that being said, the compact form factor of the device may still have an applicable use case for long-duration, stationary physiological monitoring, such as sleep studies.

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Introduction

Electroencephalography (EEG) devices can be uncomfortable, cumbersome to use, and bulky, often encompassing an individual's entire head. In addition, current EEG technologies require sufficient time and trained personnel to ensure proper device fit and adequate signal transmission. Traditional EEG monitoring systems, while effective in controlled laboratory settings, are often impractical for use in-flight or in a simulator due to their size, complexity, and setup requirements (D'Alessandro et al., 2024). The sensors and wearables industry has been making strides in developing compact, lightweight, and user-friendly devices. Such devices may hold promise for easy use in a range of environments. However, they must first be evaluated for suitability in different use-cases to determine where they will have the greatest utility.

One such lightweight, easy-to-use and portable EEG system has been developed by CGX, LLC (San Diego, CA). CGX developed a 2-channel EEG system, called the Patch (CGX, 2025; Onton et al., 2024). This system was designed to be used for at-home data collection, with single-use electrodes and a 20 hour recording time. Setup requirements are minimal compared to traditional EEG recording devices. The Patch is placed directly on an individual's forehead, reducing overall setup time and making application easy and comfortable due to the small size. This small form-factor and ease of application suggests the device could have utility in flight simulation studies and studies that take place outside of the laboratory. Studies outside of the laboratory can include a variety of environments, such as flight simulators at different locations (including industry and/or training), in the field, or within actual aircraft or other military vehicles.

Before this type of device can be used in these settings for research purposes, it is critical to first evaluate whether the device can withstand unique exposures associated with these settings. Some unique environmental conditions and effects a person experiences in a full-motion flight simulator include vibration and possible jerking motions, sweat, and required movements of the head/body to perform flight-related tasks. Field environments can expose an individual to different bodily movements and increased likelihood of perspiring. Of specific concern with the CGX Patch is loss of adhesion to the forehead due to sweat and other flight-simulator factors such as motion, potentially resulting in loss of signal and functionality of the device.

Given the CGX Patch shows promise for use across a variety of settings, an evaluation was conducted to first establish its signal quality, durability, and comfort. This evaluation was done within a full-motion UH-60 flight simulator and during moderate physical training (PT) activity at the discretion of the subject. This evaluation aims to determine the efficacy of a newly acquired EEG wearable device, the CGX Patch, for potential use in future simulated flight research applications. The results of this evaluation will provide valuable insights into the device's suitability for future research projects, particularly in aviation and fatigue-related studies, and will inform decisions on its potential integration into upcoming research protocols.

Study Objective

This non-research activity aimed to comprehensively evaluate the performance, comfort, and reliability of the CGX Patch EEG wearable under various conditions commonly encountered in U.S. Army Aeromedical Research Laboratory (USAARL) research and other military-focused

research applications. The results were intended to inform decisions regarding the device's suitability for future research projects. Three critical aspects for determining its utility in different study settings were evaluated: comfort, durability, and signal quality.

Comfort included evaluating participants' perception of device comfort defined via self-reports (see Appendix C for the device comfort questionnaire) and documentation of any skin irritation. Durability was measured by the maintenance of adhesion and continued functionality/signal transmission throughout the duration of the evaluation (approximately 3 hours). Finally, signal quality was assessed by evaluating the signal-to-noise ratio throughout various tasks included in the evaluation.

Methods

The U.S. Army Aeromedical Research Laboratory Exempt Determination Official (EDO) reviewed the description of the non-research activity 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 were briefed on the study activities and risks prior to beginning participation. Participants were informed that their participation was voluntary and they could discontinue at any time without penalty.

Participants

Recruited participants were Soldiers ($N = 3$, all male) assigned to USAARL. When asked to participate, care was taken to ensure that no one in their chain of command nor senior level civilians were present during recruitment. All Soldiers self-reported to be in good health, and to be medically cleared to participate in PT. Soldiers self-reported no history of motion or simulator sickness and no recent history/episode of inner ear/balance issues. Additionally, there were no known skin conditions affecting the scalp or wounds on the head that could potentially interfere with device functionality.

Materials and Equipment

EEG system.

The CGX Patch is a wearable, wireless, battery-operated, research-grade EEG system capable of continuous recording for up to 14 hours. The system consists of three main components: a central button housing the electronics and battery, a soft carrier for comfort, and a disposable semi-solid hydrogel electrode featuring three electrode sites: two channels and one reference site. This adhesive portion, measuring approximately 4.5 inches wide by 2 inches tall, is placed directly on the center of the forehead just above the brow line. The device digitizes EEG channels with 24 bits of resolution at a 500 hertz (Hz) sampling rate, and data can be either transmitted continuously via Bluetooth or saved locally to an internal MicroSD card. The compact and wireless nature of the CGX Patch allows participants to move freely, making it highly suitable for multiple research environments by reducing the risk of impeding task performance. For USAARL's specific operational concerns, the patch minimally interferes with an individual's ability to complete flight-specific tasks in the UH-60 simulator; however, because the device's current design is not compatible with standard-issue rotary-wing helmets, it was

evaluated without a helmet during this test.

Figure 1. Image of CGX EEG Patch location demonstrated on forehead.

Flight simulator.

USAARL's UH-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 200 x 45 degree field of view and two chin displays. The collimated optical display system consists of seven red, green, blue, and infrared light emitting diode (RGB+IR LED) projectors, each providing 2560 x 1600 pixels resolution for a combined resolution of 1.8 Arcminutes/pixels. The visual system simulates the natural helicopter environment surroundings for day, dusk, and night. No data was collected from the simulator during the activity.

Comfort scale.

Utilizing a visual analog scale, device comfort was assessed with three questions for the three testing sessions (total of 9 questions). Two of the three questions used a visual analog scale ranging from 0 to 10. The first question assessed comfort from *very uncomfortable* (0) to *very comfortable* (10). The second question provided visual depictions of a head from multiple angles to allow participants to highlight or mark any areas of discomfort, and where on the head the discomfort occurred. The third question asked participants to rate the intensity of the prior points of discomfort on a visual analog scale from *no pain* (0) to *worst pain imaginable* (10). Each of the three questions were broken into three sections: after the PT session, after the non-motion simulator session, and after the full-motion simulator session. A final open-ended question was included at the end of the scale, as an optional place for participants to add additional comments as necessary. See Appendix B for a copy of the comfort scale.

Technician observation sheet.

The technician observation sheet was completed by the research technician conducting the data collection. This was developed in-house (see Appendix C) to record observations of the participant wearing the device. The technician completed 7 items. These included documenting:

1. Number of times device became detached. (Describe how/when in comments)

2. Number of times device needed to be adjusted. (Describe reason in comments)
3. Number of times device malfunctioned. (Describe in comments)
4. Was the participant distracted by the device? Yes/No (Add comments as needed)
5. Did the device impact the participant's safety? Yes/No (Add comments as needed)
6. Participant complained the device was uncomfortable. Yes/No (Add comments as needed)
7. Participant complained the device was painful. Yes/No (Add comments as needed)

Procedure

The evaluation procedure was designed to systematically assess the comfort, durability, and signal quality of the CGX Patch EEG device over an approximately 3-hour period. Those who agreed to participate were briefed on the voluntariness of their participation. They were informed of all associated risks and informed they may discontinue at any time without penalty. After participants agreed to participate, the activity consisted of four main phases: initial device application and baseline data collection, a 60-minute PT session to challenge device adhesion through sweat and motion, two simulated flight sessions in the UH-60 simulator (off-motion and full-motion), and post-evaluation assessments. Throughout these activities, researchers monitored both subjective user comfort and objective device performance.

EEG application and baseline.

Participants completed the study individually and were fitted with a CGX EEG device in a designated preparation room at USAARL. Prior to the fitting, participants were instructed to immediately report any discomfort, such as itchiness or pain, caused by the device. To maximize device adhesion and remove excess oil or dirt, study personnel cleared the forehead of any hair and cleaned the skin using a 70% isopropyl alcohol pad. Once the skin was fully dry, the adhesive patch containing the EEG electrodes was placed centrally on the forehead. The patch was positioned below the hairline and approximately 1 centimeter above the brow line to ensure hair did not impede adhesion, and any resulting wrinkles in the patch were smoothed out. The EEG transmitter was then secured to the adhesive patch via three separate buttons. Finally, the device was powered on and paired with a data collection laptop via Bluetooth.

Following the application of the device, baseline EEG data were collected. Participants completed two separate resting baseline recordings, each lasting two minutes. During the first baseline condition (eyes open), participants were instructed to sit quietly with minimal movement while staring uninterrupted at a blank, white wall. For the second baseline condition (eyes closed), participants were instructed to continue sitting quietly while keeping their eyes closed for an additional two minutes. Upon the completion of the baseline data collection, participants transitioned to the PT phase of the study.

Physical training session.

Participants then completed a 60-minute PT session in a designated exercise area at USAARL. The primary objective of this phase was to evaluate the physical durability and adhesion of the CGX EEG Patch under conditions of motion and moderate-to-heavy perspiration; therefore, active EEG data were not collected during this time. Participants were

instructed to engage in self-selected activities at an effort level comparable to organized PT to ensure sufficient sweat production. These activities included a mixture of cardiovascular exercises (e.g., rowing, cycling, running, treadmill walking), weight training, and stretching.

Participants wore the CGX device continuously throughout the 60-minute session. Study personnel monitored the participants for the duration of the PT phase, and a study physician remained on call. To track device performance, researchers documented any necessary adjustments to the patch or instances of adhesive failure on the technician observation sheet (Appendix C). Upon concluding the PT session, participants immediately completed the Comfort Scale.

Simulator session.

Following the PT phase, participants transitioned to a UH-60 flight simulator at USAARL for the final testing phase. Under the supervision of a rated USAARL research pilot, participants completed two simulated flight sessions lasting approximately 15 to 20 minutes each. The first session was conducted without simulator motion, whereas the second session utilized full simulator motion.

Prior to each flight, the research pilot provided a brief familiarization with the UH-60 simulator, reviewed safety procedures, and guided the participant through the simulator start-up. To intentionally engage facial muscles and evaluate device signal quality from the raw EEG data, participants verbally completed the start-up procedure. The pilot then guided participants through a series of predefined gaze locations (see Table 1) to assess device adherence and signal integrity during head movements typically associated with flight operations. Both the verbal start-up and the head movement protocols were completed at the beginning of both the non-motion and full-motion sessions.

Table 1. Key Gaze Locations Performed in UH-60 Stimulator

Collective
Flight instrument panel
Center console (lower and upper portions)
Engine power control levers
Upper console
Lower console
Back of seat
Left window
Right window

During the flight portion of the sessions, participants were given the option to actively pilot the simulator or allow the research pilot to maintain full control. Because the primary objective of this phase was to assess EEG device compatibility within a simulated aviation environment rather than to assess aviator proficiency, there were no specific flight routes, performance objectives, or required tasks. Consequently, each flight was unique, and no simulator performance metrics (e.g., altitude deviations or task success) were extracted.

A member of the research team was present in the simulator throughout both sessions to monitor the device and record qualitative data on the observation sheet. After each of the two flight sessions, participants completed the Comfort Scale and were asked to provide freeform comments regarding their experience. Upon completion of all simulator activities, researchers removed the EEG device, assessed the participant's forehead, and documented any instances of skin irritation. Participants were then dismissed. Total study participation time was approximately 2.5 hours.

Results

Prior to reporting results, participants were randomly assigned a letter to minimize the likelihood of identifying a participant by their participation order.

Comfort Ratings

Responses to the Comfort Scale are reported in Table 2 below. Participant comments from the Comfort Scale are reported below the Table. Overall, participants reported the device was comfortable, with only one participant rating a "5," which is the middle of the scale.

Table 2. Comfort Scale Responses

Activity	Participant	Overall Device Comfort Post-Activity	Areas of Discomfort	Intensity of Discomfort
PT	A	8	None reported	N/A
	B	9	Forehead	0
	C	7	None reported	N/A
	Mean (SD)	8 (1)	N/A	N/A
Non-Motion Flight	A	8	None reported	N/A
	B	9	Forehead	0
	C	5	None reported	N/A
	Mean (SD)	7.33 (2.08)	N/A	N/A
Full-Motion Flight	A	10	None reported	N/A
	B	9	Forehead	0
	C	8	None reported	N/A
	Mean (SD)	9 (1)	N/A	N/A

Comments.

Participant A: "Can feel the weight all the time."

Participant B: "The tingling sensation was increased during vigorous activity. When sweating my skin had a reaction that caused it to become red and raised."

Participant C: "Slight redness at the application site. Attempting to fly required a lot of concentration so participant was not distracted by the device."

Research Team Observations

The responses the research team recorded on the observation sheet are reported by activity and observation sheet item in Table 3 below.

Table 3. Observation Sheet Summary

Item	Activity	A	B	C	Additional Comments
1. Number of times device became detached.	PT	0	1	1	**B:** Outside wings lifted off each side. Center electrode location stayed attached approximately 45 minutes. **C:** 12 minutes into cardio, device became detached.
	Non-Motion	0	0	0	**C:** Edges were a little loose.
	Full-Motion	0	0	0	**C:** Edges continued to loosen but device stayed on head.
2. Number of times device needed to be adjusted.	PT	0	1	0	**B:** Re-applied new adhesive prior to starting simulator session. Participant became extremely sweaty during running.
	Non-Motion	0	0	0	None
	Full-Motion	0	0	0	None
3. Number of times device malfunctioned.	PT	0	0	0	None
	Non-Motion	0	0	0	None
	Full-Motion	0	0	0	None
4. Was the participant distracted by the device?	PT	N	N	Y	**B:** Noticed device was there, but not distracted by it. **C:** Feels tight on eyebrows, reports itchy feeling.
	Non-Motion	N	N	N	None
	Full-Motion	N	N	N	None
5. Did the device impact the participant's safety?	PT	N	N	N	None
	Non-Motion	N	N	N	None
	Full-Motion	N	N	N	None
6. Participant complained the device was uncomfortable.	PT	N	Y	NA	**A:** Reported he could feel the weight of the device. **B:** Adhesive felt slightly itchy. Went away with time.
	Non-Motion	N	Y	NA	**B:** 10 minutes felt itchy, then went away.
	Full-Motion	N	N	NA	None
7. Participant complained the device was painful.	PT	N	N	N	None
	Non-Motion	N	N	N	None
	Full-Motion	N	N	N	**A:** Painful when removed (Pain at level 1).

Signal Quality Evaluation

The CGX Patch, a two-channel EEG system, records data at a sampling rate of 500 Hz. Data were collected across six experimental conditions, including eyes closed, eyes open, no motion, head motion, and full motion. The data were analyzed using MNE-Python to compare power spectral density (PSD) across conditions and evaluate signal quality.

The system appears to include a built-in band-pass filter from 0.1 to 125 Hz. Although this filtering range is not specified in the manual, it was indicated in the data header file. Nevertheless, the data were additionally filtered from 0.1 to 50 Hz before computing PSD. Figure 2 and Figure 3 show the PSD comparison across conditions for each participant for channel 1 and channel 2, respectively, with frequency on the *x*-axis and PSD values on the *y*-axis.

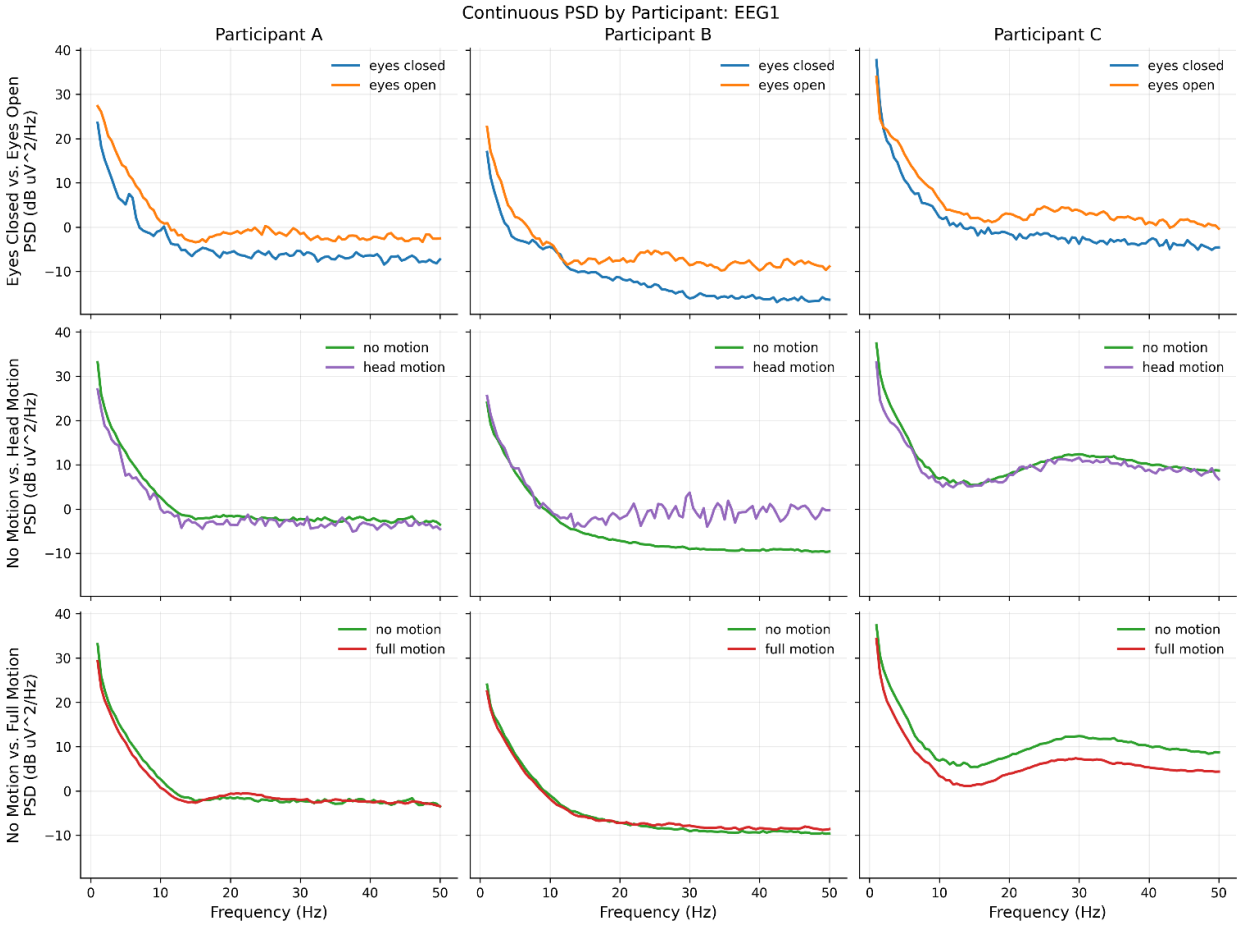

Figure 2. PSD plot for first EEG channel. *X*-axis represents the frequency, and *y*-axis represents the PSD values.

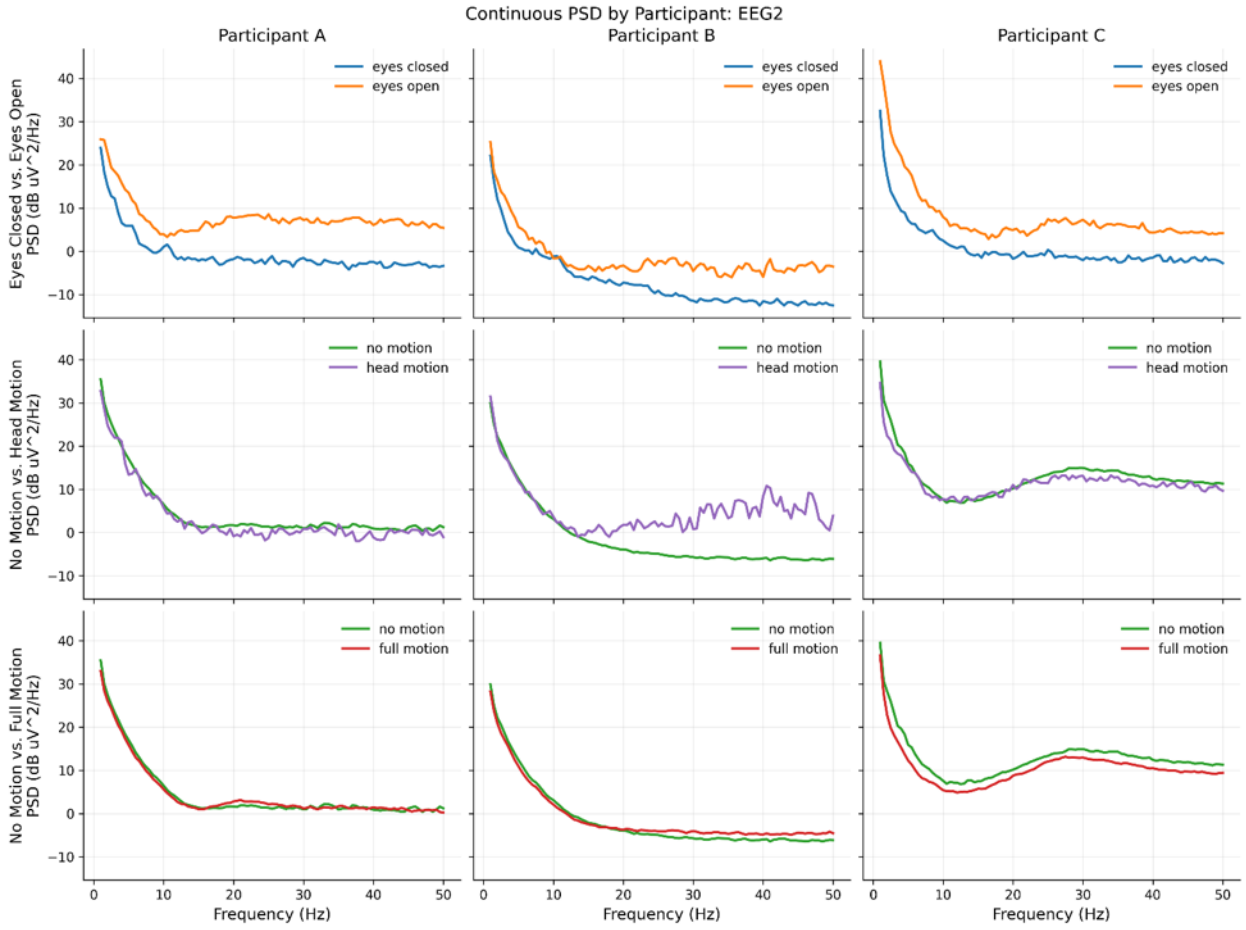

Figure 3. PSD plot for second EEG channel. *X*-axis represents the frequency, and *y*-axis represents the PSD values.

The analysis did not show the expected increase in alpha activity (8–14 Hz) during the eyes closed condition compared with the eyes open condition. In addition, motion conditions did not produce a clear broadband increase in PSD relative to the no-motion condition, suggesting that motion artifacts were not strongly reflected in the recorded signal. On the surface, this could suggest that the device has an excellent signal-to-noise ratio. However, when considered together with the absence of the expected eyes closed alpha increase, the results suggest that the built-in filtering or signal-processing pipeline may reduce not only noise but also physiologically meaningful brain activity.

In other words, the device may have limited sensitivity for detecting rapid and transient EEG changes that are typically associated with task performance in operational settings. These findings suggest that the device may not be well suited for short-duration EEG recordings or task-based EEG analyses. However, the present analysis does not rule out its potential utility for longer-duration EEG recordings, such as sleep studies, where the signals of interest may be more sustained and less dependent on transient task-related brain activity.

Discussion

The CGX Patch demonstrated mixed results regarding subjective comfort and device adhesion. While quantitative comfort ratings were generally favorable, qualitative feedback and researcher observations indicated notable physical limitations. During the PT phase, moderate-to-heavy perspiration and physical movement compromised the adhesive in two of the three volunteers. Furthermore, volunteers reported minor but noticeable discomfort including itchiness, mild skin redness upon removal, and a constant awareness of the device's weight on the forehead. With that said, the device maintained sufficient adhesion and comfort during the flight simulator sessions meaning the CGX Patch could be suitable for research in a low-exertion, climate-controlled environment from a device stability perspective.

Beyond physical adhesion, however, the functionality and signal quality of the CGX Patch present significant roadblocks that limit its applicability for applied aviation research. Analysis of the raw data failed to identify the expected increase in alpha-band power during the eyes closed baseline, a standard physiological marker in EEG recordings. Furthermore, the expected motion artifacts during the PT and full-motion simulator conditions were not observed, indicating that the device employs an overly aggressive built-in filtering pipeline. While this aggressive filtering yields a superficially clean signal with a high signal-to-noise ratio, it appears to simultaneously suppress physiologically meaningful brain activity. As a result, the device demonstrates a distinct lack of sensitivity to the rapid, transient neural changes necessary for evaluating cognitive workload, fatigue, or performance during operational tasks. With that being said, the device may still have an applicable use case for long-duration EEG records, such as sleep studies, where the physiological signals of interest are more sustained and less transient in nature.

Conclusion

The CGX Patch presents distinct advantages regarding portability, rapid setup times, and user comfort in stationary settings. However, it ultimately fails to meet the rigorous physiological and environmental demands of active aviation research. As observed, the device's vulnerability to adhesive failure under sweaty or high-motion conditions severely limits its utility for operational contexts. Beyond these physical limitations, the aggressive internal signal processing obscures vital, task-related neural responses, rendering the device ineffective for assessing cognitive states in dynamic operational contexts. While the CGX Patch is not recommended for short-duration, high-movement, or task-based performance studies within military aviation contexts, its form factor may still have an applicable use case for long-duration, stationary physiological monitoring, such as sleep research.

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Onton, J. A., Simon, K. C., Morehouse, A. B., Shuster, A. E., Zhang, J., Peña, A. A., & Mednick, S. C. (2024). Validation of spectral sleep scoring with polysomnography using forehead EEG device. *Frontiers in Sleep*, *3*, 1349537.

Appendix A. Acronyms and Abbreviations

EDO	Exempt Determination Official
EEG	Electroencephalogram
Hz	Hertz
LED	Light Emitting Diode
PSD	Power Spectral Density
PT	Physical Training
RGB+IR	Red, Green, Blue, and Infrared
UH-60	Utility Helicopter-60 (Black Hawk)

Appendix B. Comfort Scale

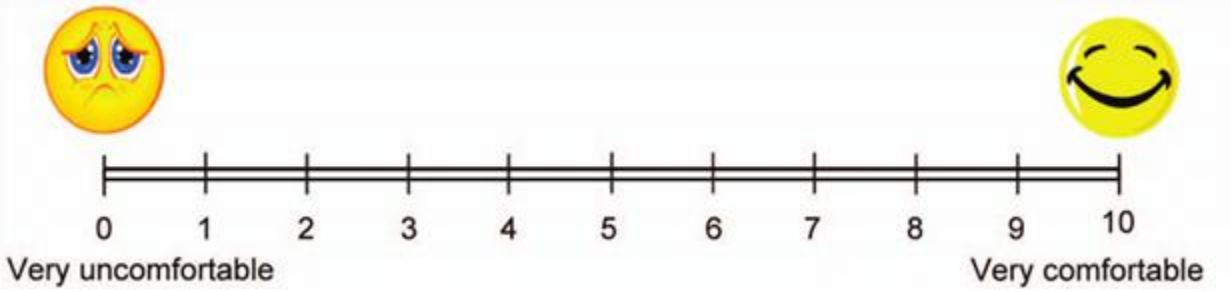
Date: _____

Participant: _____

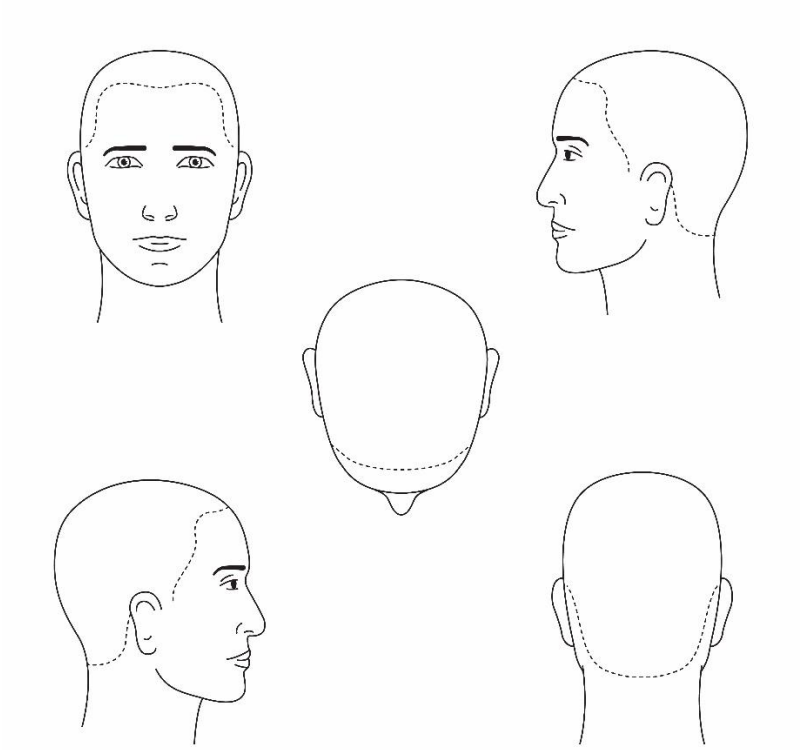
Comfort Scale

After PT session:

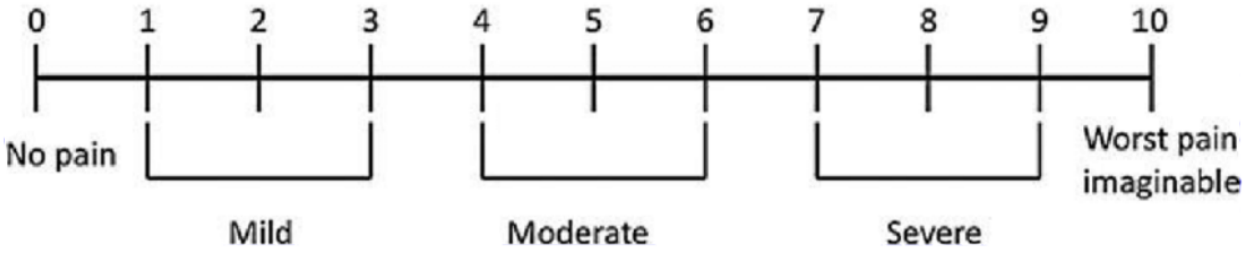
1. How would you rate the overall comfort of this device? [indicate on the scale below]



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

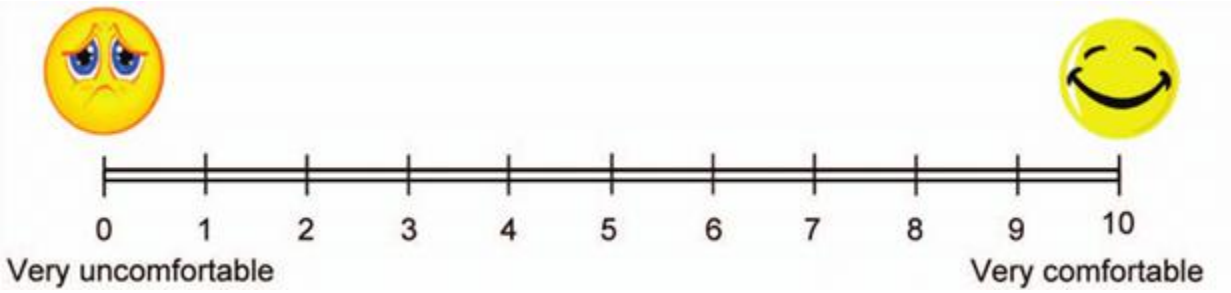


3. How would you rate the intensity of these points of discomfort?

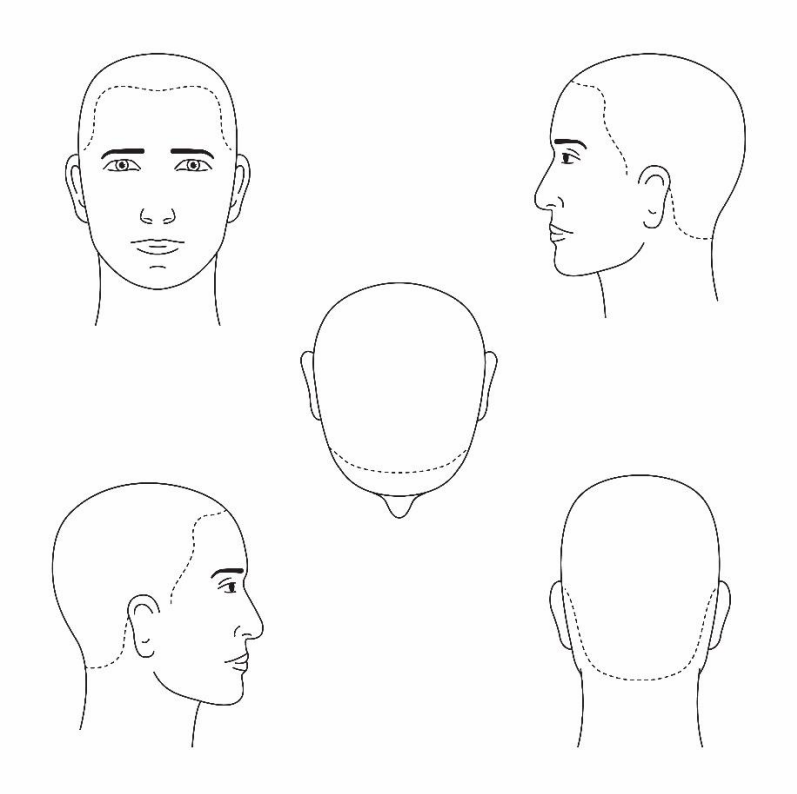


<u>After Non-Motion Simulator Session:</u>

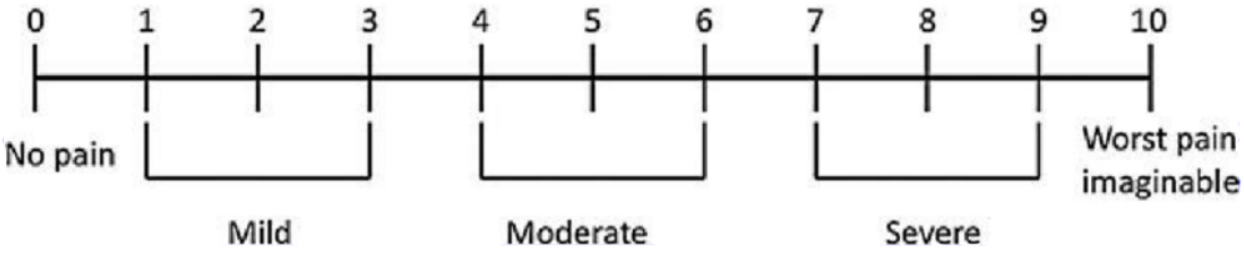
1. How would you rate the overall comfort of this device? [indicate on the scale below]



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

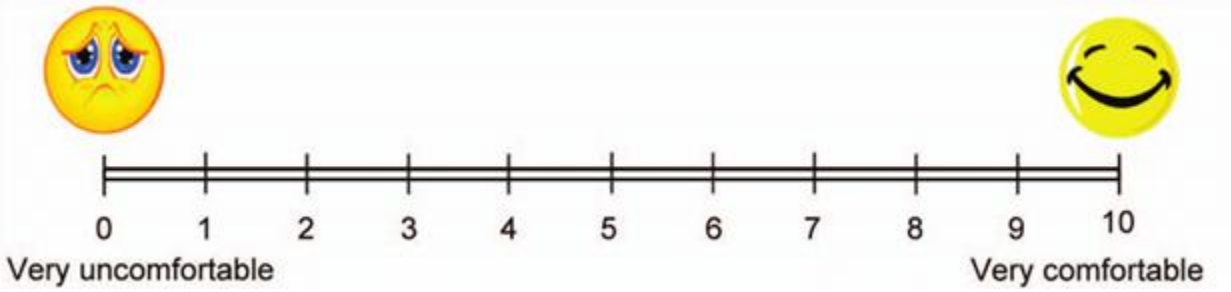


3. How would you rate the intensity of these points of discomfort?

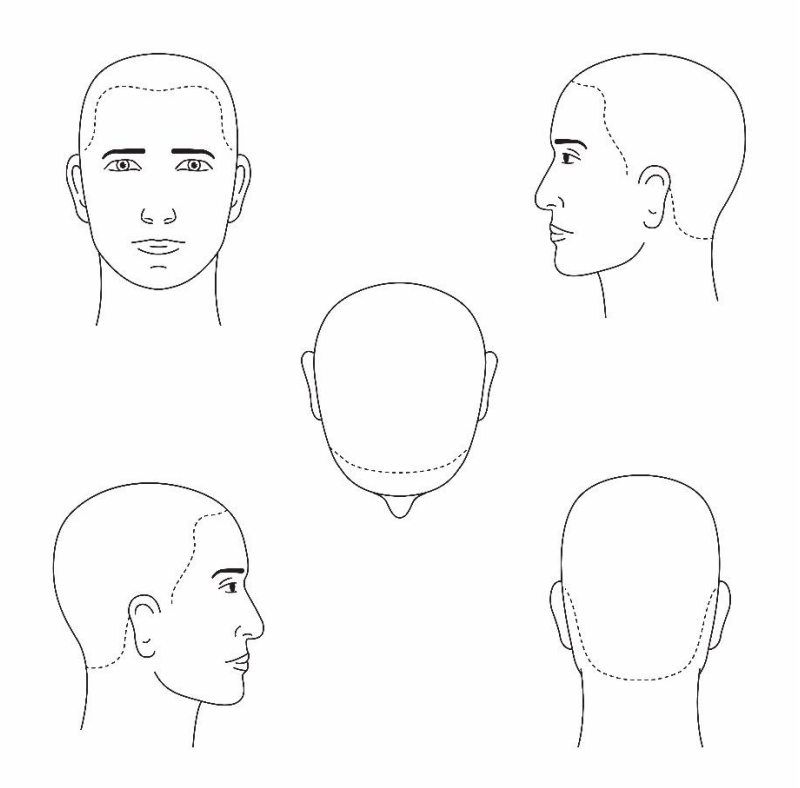


After Full-Motion Simulator Session:

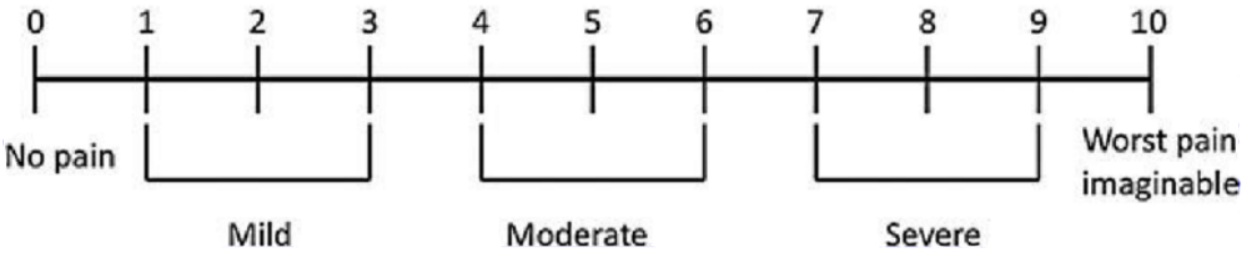
1. How would you rate the overall comfort of this device? [indicate on the scale below]



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

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Appendix C. Technician Observation Sheet

Participant #		
Activity and Location:		
Observer Name:		
Study Physician:		
1. Number of times device became detached. (Describe how/when in comments)	#	Comments
2. Number of times device needed to be adjusted. (Describe reason in comments)	#	Comments
3. Number of times device malfunctioned. (Describe in comments)	#	Comments
4. Was the participant distracted by the device?	YES NO	Comments
5. Did the device impact the participant's safety?	YES NO	Comments
6. Participant complained the device was uncomfortable	YES NO	Comments
7. Participant complained the device was painful.	YES NO	Comments

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