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The Effect of GSM Electromagnetic Field Exposure on the Waking Electroencephalogram: Methodological Influences

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Although there is consistent evidence that exposure to radiofrequency electromagnetic fields (RF-EMF) increases the spontaneous resting alpha spectral power of the electroencephalogram (EEG), the reliability of this evidence is uncertain as some studies have also failed to observe this effect. The present study aimed to determine whether the effect of RF-EMF exposure on EEG alpha power depends on whether EEG is derived from eyes open or closed conditions and assessed earlier (<5-min) versus later (>25-min) in the exposure interval. Thirty-six adults participated in three experimental sessions, each involving one exposure: "Sham," "Low," and "High" RF-EMF corresponding to peak spatial specific absorption rates averaged over 10 g of 0, 1, and 2 W/kg, respectively. Resting EEG was recorded at baseline (no exposure), during, and after exposure. Alpha power increase was found to be greater for the eyes open than eyes closed EEG during both the High ($P = 0.04$) and Low ($P = 0.04$) RF-EMF exposures. There was also a trend toward it being larger at the end, versus the start of the "High" 30-min exposure ($P < 0.01$; eyes open condition). This suggests that the use of eyes closed conditions, and insufficient RF-EMF exposure durations, are likely explanations for the failure of some studies to detect an RF-EMF exposure-related increase in alpha power, as such methodological choices decrease signal-to-noise ratios and increase type II error. Bioelectromagnetics. 2021;42:317–328. © 2021 Bioelectromagnetics Society.

Keywords: **alpha spectral power; ceiling effect; electroencephalography; radiofrequency electromagnetic fields; signal to noise ratio**

INTRODUCTION

Mobile phone ownership has grown considerably over the past two decades, with approximately 90% of people across both developed and developing nations reporting owning a mobile phone [Deloitte, 2017]. When held against the head during calls, the radiofrequency electromagnetic fields (RF-EMF) emitted by mobile phones are absorbed by the brain. Consequently, the question of whether such exposures affect brain function is of considerable scientific interest. The electroencephalogram (EEG), a sensitive marker of neural electrical activity, has been commonly used as an endpoint to assess potential effects of RF-EMF exposure on brain function [Juutilainen et al., 2011; Kwon and Hamalainen, 2011]. The most consistent finding to emerge from this research relates to the alpha (≈8–12 Hz) band of the resting EEG. Specifically, RF-EMF exposure has repeatedly been shown to increase EEG alpha spectral power [Croft et al., 2002, 2008, 2010; Curcio et al., 2005]. However, a number of failures to observe any RF-related effects on EEG alpha power [Roschke and Mann, 1997; Heitanen et al., 2000; Kleinlogel

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et al., 2008], or observations of alpha power decreases during RF-EMF exposure [D'Costa et al., 2003; Ghosn et al., 2015; Perentos et al., 2013], may call into question the reliability of the RF-related alpha power increase. It is possible that methodological differences between studies may account for these apparent discrepancies.

One potentially relevant methodological difference relates to whether EEG is recorded from participants resting with their eyes *open* versus *closed*. A review of the literature shows that whereas positive reports of RF-EMF effects on the resting EEG come both from studies using both eyes open [Croft et al., 2002, 2008, 2010; Perentos et al., 2013] and eyes closed [D'Costa et al., 2003; Curcio et al., 2005] conditions, the negative findings have all come from studies recording EEG from participants resting with their eyes closed [Roschke and Mann, 1997; Heitanen et al., 2000; Kleinlogel et al., 2008]. However, whether this methodological difference importantly affects results is unclear, as there has not been any empirical test of whether eye condition (open versus closed) affects the magnitude of the RF-EMF exposure-related EEG alpha change. There is, however, a theoretical reason to expect that eye condition may affect the magnitude of the signal-to-noise ratio (where the RF-related EEG alpha power change is treated as the signal, and the alpha power change unrelated to RF-EMF exposure is treated as noise), which would affect the likelihood of detecting effects of RF-EMF exposure on the EEG. Closing the eyes substantially increases EEG alpha power [Barry et al., 2007]. Indeed, the magnitude of alpha power increase due to the closing of the eyes [circa 60%; Barry et al., 2007] is considerably larger than the increase due to RF-EMF exposure [circa 5–10%; Croft et al., 2010]. Consequently, the eyes closed condition may provide a reduced opportunity to detect the effect of RF-EMF-related alpha power increase (reduced signal) as alpha may already be at, or be close to, its maxima (i.e., closing the eyes induces a ceiling effect). On the other hand, the eyes open condition may provide a greater opportunity to detect an alpha increase, as EEG alpha power is lower when the eyes are open, thus avoiding this potential ceiling effect (increased signal).

Another source of methodological variability between studies is the duration of RF-EMF exposure administered before evaluating the EEG for potential effects of RF-EMF. Exposure durations reported in the literature vary considerably, ranging from as little as 3.5 min [Roschke and Mann, 1997], where no effect of exposure was observed, to 45 min [Curcio et al., 2005], where RF-EMF exposure was reported to increase EEG alpha power. The variability in exposure duration between studies may be relevant to whether effects of RF-EMF exposure are observed, as RF-EMF-related alpha power increase has been reported to increase as a function of time [first 10 min versus second 10 min of a 20-min exposure period; Croft et al., 2002]. However, this observation remains to be replicated. An understanding of the time course of RF-EMF effects on EEG alpha would aid in the interpretation of the existing literature and the design of future studies, by determining the minimal duration of exposure required to affect the EEG. Furthermore, such knowledge would be useful in guiding study design for experiments aimed at determining the functional consequences of RF-EMF exposure [Valentini et al., 2011; Barth et al., 2012], as these are generally predicated on the assumption that changes in cognition, for example, are a consequence of EEG alterations due to RF-EMF exposure.

Given the differences in results reported in the literature, resolving the question of whether these methodological issues impact the observed effect of RF-EMF on the EEG is of relevance to the field and is the aim of the present research. Specifically, the first aim of the present study was to determine the importance of the choice of the eyes open versus eyes closed condition in the detection of RF-EMF-related EEG alpha effects. Owing to the superior signal-to-noise ratio in the eyes open versus eyes closed condition (and in line with our previous work showing increased alpha due to RF-EMF exposure in the eyes open condition [Croft et al., 2002, 2008, 2010; Loughran et al., 2019]), we hypothesized that EEG alpha power increase would be larger in the eyes open compared to the eyes closed resting condition. Secondly, we aimed to determine whether the effect of RF-EMF on the EEG alpha increase depends on exposure duration. In line with Croft et al. [2002], we hypothesized that for the eyes open resting EEG the effect of RF-EMF exposure would be greater at the end, compared to the beginning of a 30-min exposure period.

MATERIALS AND METHODS

Participants

Thirty-six (18 males, 18 females) healthy, right-handed adults (18–52 years; $M = 24.4$, $SD = 6.3$ years) participated in the study. Participants were excluded if they had any history of neurological disorder, head trauma, or were taking medication that acts on the central nervous system. Participants were instructed to abstain from caffeinated foods and drinks

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within 1 h, and mobile phone use within 2 h prior to their arrival at the laboratory. This was verified via self-report. Written, informed consent was obtained from all participants and the study protocol was approved by the University of Wollongong Human Research Ethics Committee (approval number HE13/146).

GSM Exposure Systems

A simulated 920 MHz Global System for Mobile Communications (GSM) exposure was administered to the left hemisphere using an sXh920 planar exposure system (IT'IS, Zurich, Switzerland) [Murbach et al., 2012]. The exposure system was calibrated to provide peak spatial specific absorption rates averaged over 10 g (SAR_{10g}) of 0, 1, and 2 W/kg for the "Sham," "Low," and "High" RF-EMF exposure conditions, respectively. The high exposure level corresponds to the maximum allowable within the International Commission on Non-Ionizing Radiation Protection ICNIRP [2020] radiofrequency guidelines. These were the levels of the applied exposures in each condition and given that the exposures were applied in a Faraday cage with 80 dB attenuation, any additional RF-EMF from stray fields would be minimal. The signal included the basic GSM frequency components (8.33, 26.6, 1733 Hz, including corresponding harmonics: crest factor 8.3 Hz).

Double-blinding was achieved by having the exposure system programmed by a researcher not involved in the data collection and then controlled by experimenters unaware of the exposure conditions programmed. Any sounds made by the exposure system were masked by brown noise played through speakers throughout the experiment (in all conditions). Participants were asked to identify the exposure condition that they received at the end of each testing session. No participant correctly identified all three conditions [Verrender et al., 2016], and the mean number of "RF ON" responses did not differ across the three conditions ($F\ (2, 70) = 1.61$, $P = 0.21$).

Study Design

A double-blind, counterbalanced, crossover design was used. The study involved four visits to the laboratory, each at least seven days apart, and beginning at the same time of day for all visits in order to minimize circadian effects. The first visit was a calibration session, where participants practiced two cognitive tasks that were administered during the study. The remaining three study visits involved the experimental manipulation of RF-EMF exposure (Sham, Low, or High), with the order of exposure randomized and fully counterbalanced between participants and within gender. The cognitive performance data (event-related potential and behavioral) are reported elsewhere [Verrender et al., 2016; Dalecki et al., 2018].

Physiological Apparatus and Measurements

Participants were fitted with a 19-channel EEG cap (Quik-Cap, Compumedics Neuroscan, Abbotsford, Australia), and EEG data were recorded from 19 scalp channels (FP1, FP2, Fz, F3, F4, F7, F8, Cz, C3, C4, T7, T8, Pz, P3, P4, P7, P8, O1, O2) and M2 according to the international 10/20 system. EEG data were referenced online to the left mastoid (M1) and grounded midway between FPz and Fz. Electrooculogram (EOG) data were recorded from above and below the left eye and from the outer canthi of the eyes. EEG and EOG data were recorded with an online 0.05–500 Hz analog band-pass filter and digitized at a rate of 2,000 Hz. All electrode impedances were below 5 kΩ at the start of the recording.

Participants were also fitted with a water-perfusion suit (a cotton, long-sleeved jacket and pants containing a series of plastic tubes that covered the arms, legs, waist, and torso; Cool Tubesuit, Med-Eng, Ottawa, Canada). The suit was connected to a water pump that distributed water (34 °C) through the tubes for the duration of each experimental session in order to stabilize skin and deep-body temperature. Skin temperature, blood pressure, and cutaneous blood flow were also measured, but these are not relevant to the present analyses and are not discussed further.

Procedure

Participants were seated inside a Faraday cage in between two visually identical boxes, with the left containing an RF-EMF antenna and the right being empty. The box containing the RF-EMF antenna was positioned such that the antenna was 42 mm above the left auditory canal and 115 mm away from the head. The empty box was identically positioned on the right side of the head. A computer screen was positioned approximately 90 cm in front of participants. Researchers verbally explained the task order (physiological recordings, EEG recordings, and cognitive performance tasks) to participants before the onset of each experimental block, gave specific instructions on how to complete tasks, and confirmed that participants understood the instructions.

Participants first completed a 16-min baseline block, during which they performed an EOG calibration task [Croft and Barry, 2000], and resting EEG was then recorded (1 min and 40 s of eyes open

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followed by 1 min and 40 s of eyes closed EEG). The eyes open condition began with the onscreen instruction "Just relax, Eyes Open" and researchers visually checked that the participant had their eyes open. The eyes closed condition began with the onscreen instruction "Just relax, Eyes Closed" and researchers visually checked that the participant had their eyes closed. There was no RF-EMF exposure during the baseline block. Two 30-min experimental blocks followed the baseline, the "Exposure Block," where the RF-EMF exposure was Sham, Low, or High RF (according to that determined by the randomization and counterbalancing procedure), followed by the "No Exposure Block," where there was no RF-EMF exposure. The Exposure and No Exposure blocks each began with a resting EEG recording (1 min and 40 s of eyes open followed by 1 min and 40 s of eyes closed EEG, beginning 20 s after the start of each block, using the same onscreen instructions detailed above), followed by two cognitive tasks [for further details, see Verrender et al., 2016; Dalecki et al., 2018], and ended with another resting EEG recording (identical to that at the start of the block), beginning 26 min after the start of each block. A schematic description of the study procedure is provided in Figure 1.

Data Analysis

As described in Loughran et al. [2019], resting EEG data were down-sampled to 500 Hz (125 Hz low-pass filter, 12 dB/oct), re-referenced to digitally linked mastoids, EOG corrected, and epoched into 2-s segments. Epochs were spline-fit to 512 points and baseline-corrected. Epochs containing EEG activity exceeding $\pm$ 100 μV at any scalp electrode site were rejected (mean epochs rejected = 7.5%, SD = 12.3%). The remaining artifact-free epochs were averaged in the frequency domain (Fast Fourier transform; Hanning window; 20%) with alpha power (8–12 Hz) calculated for nine electrode sites (Frontal: Fz, F3, F4; Central: Cz, C3, C4; Parietal: Pz, P3, and P4), as shown in Figure 2.

Statistical Analyses

The dependent variable was the change in EEG alpha power from baseline to the resting EEG recording conducted during the Exposure Block. As EEG alpha power varies with alertness, to remove the effects of alpha change over time during the experiment, the EEG alpha power values were converted to *z*-scores. This was done by (1) calculating the mean and standard deviation of alpha spectral power for each participant at each electrode for each time period that resting EEG was derived (baseline, beginning and end of the Exposure Block, and beginning and end of the No Exposure Block) for each session separately; then (2) taking participants' raw alpha spectral power values at each EEG electrode site and session and subtracting the mean and dividing by the standard deviation described above in (1).

To test the hypothesis that any exposure-related EEG alpha power increase was dependent on eye condition (open or closed eyes), we conducted a 3 (Exposure: Sham, Low, High) × 3 (Sagittality: frontal, central, parietal) × 2 (Laterality: left, right) × 2 (Eye Condition: open, closed) repeated measures analysis of variance (ANOVA). Planned contrasts (one-tailed) tested whether the global increase in EEG alpha power (i.e., ignoring the Laterality and Sagittality factors) during Exposure compared with Sham depended on Eye Condition, by considering the interaction term (which tested whether any effects of Exposure (Sham versus Low, and Sham versus High RF-EMF separately), were larger for the eyes open than closed condition. Global alpha was used because it is more reliably affected by RF-EMF exposure than localized scalp regions [Perentos et al., 2013; Loughran et al., 2019]; the factors were included within the analysis merely as a means of reducing error variance. For exploratory purposes, analyses were also performed to determine whether any effect of Eye

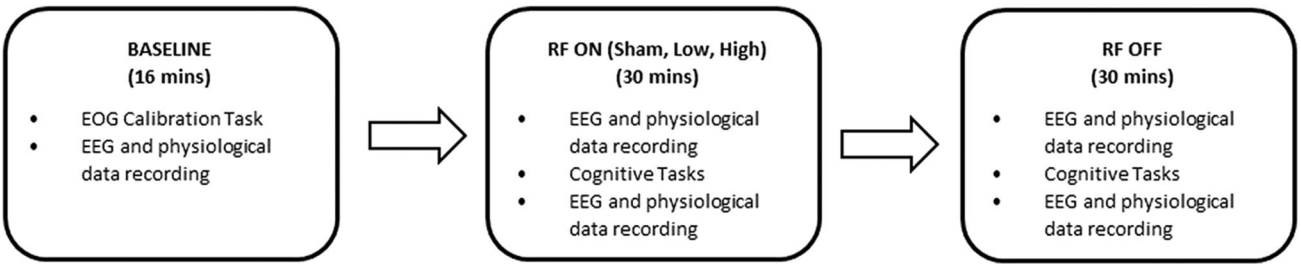


Fig. 1. Schematic illustrating an experimental session. EEG = electroencephalogram; EOG = electrooculogram; RF = radiofrequency.

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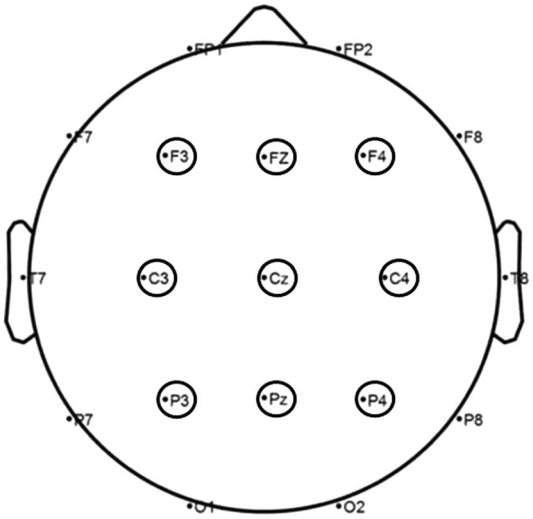


Fig. 2. Head map showing nine EEG electrode sites of interest (circled). EEG = electroencephalogram.

Condition on the effect of Exposure interacted with topography. These used the same ANOVA structure described above, differing only in that the analyses were non-directional, and that linear contrasts (Sagittality: frontal versus posterior; Laterality: left versus right; Sagittality by Laterality) were added to the Eye Condition by Exposure interaction.

To test the hypothesis that under the standard, eyes open, condition the effect of RF-EMF exposure on EEG alpha increase depends on whether EEG was assessed in the first four min (Start) or last four min (End) of a 30-min exposure period, we conducted a 2 (Time: Start, End) × 3 (Exposure: Sham, Low, High) × 3 (Sagittality: frontal, central, parietal) × 2 (Laterality: left, right) repeated measures ANOVA. Planned contrasts (one-tailed) tested whether the increase in EEG alpha power during Exposure compared to Sham depended on Time, by considering the interaction term, which tested whether any effects of Exposure (Sham versus Low, and Sham versus High RF-EMF, separately) were larger for resting EEG recorded at the end than at the start of the Exposure Block.

RESULTS

The effect of RF-EMF on alpha power, without consideration of the factors addressed in this paper, has been reported elsewhere, where, consistent with previous reports, it was shown that it increased alpha power [Loughran et al., 2019]. Raw EEG data, for each condition across frequency, for each of the sites analyzed (as shown in Fig. 2), is provided in Figures 3–6. This is not analyzed further in this paper.

Eyes Open Versus Eyes Closed

Planned contrasts showed that there was a greater increase in EEG alpha power in the eyes open than eyes closed condition in both the Low ($F\ (1, 35) = 3.25,\ P = 0.04,\ \eta_p{}^2 = 0.09$) and High RF-EMF ($F\ (1, 35) = 3.14,\ P = 0.04,\ \eta_p{}^2 = 0.08$) exposure conditions compared to Sham (see Fig. 7). The exploratory analyses indicate that this exposure-related alpha increase in the eyes open than closed condition was larger over right than left hemisphere sites for both the High ($F\ (1, 35) = 6.78,\ P = 0.02,\ \eta_p{}^2 = 0.16$) and Low ($F\ (1, 35) = 6.27,\ P = 0.01,\ \eta_{p_2}{}^2 = 0.15$) exposure conditions, and was larger over posterior than frontal sites for the High exposure condition only ($F\ (1, 35) = 6.88, P = 0.01, \eta_p{}^2 = 0.16$).

Effect of Exposure Duration

Planned contrasts showed that EEG alpha power increase in the standard, eyes open condition, during Exposure compared to Sham, was larger at the End (during the last 4 min) compared to the Start (first 4 min) of a 30-min exposure in the High RF-EMF condition ($F\ (1, 35) = 6.34, P < 0.01, \eta_p{}^2 = 0.15$). This did not reach statistical significance in the Low RF-EMF condition ($F\ (1, 35) = 2.34, P = 0.07, \eta_p{}^2 = 0.06$) (see Fig. 8).

DISCUSSION

The present study demonstrated that the EEG alpha power increase during RF-EMF exposure compared to Sham [Croft et al., 2002, 2008, 2010; Loughran et al., 2019] is larger in the eyes open than in the eyes closed resting EEG condition. Indeed, in this data set no EEG alpha power increase was evident during RF-EMF exposure in the eyes closed resting EEG. This shows that the choice of resting EEG condition importantly affects whether or not an RF-EMF-induced EEG alpha effect is observed, and suggests that the eyes closed resting EEG derivation will increase type II error (failure to detect a real effect). Consistent with this, studies that failed to observe EEG alpha effects during RF-EMF exposure all derived resting EEG from the eyes closed condition [Roschke and Mann, 1997; Heitanen et al., 2000; Kleinlogel et al., 2008]. We note, however, that there are also two positive reports of effects of RF-EMF exposure on the eyes closed resting EEG in the literature [Curcio et al., 2005; Ghosn et al., 2015]. This suggests that the use of the eyes closed resting EEG does not necessarily preclude the detection of the effect of RF-EMF exposure on EEG alpha, but it may substantially reduce the chance of observing an effect.

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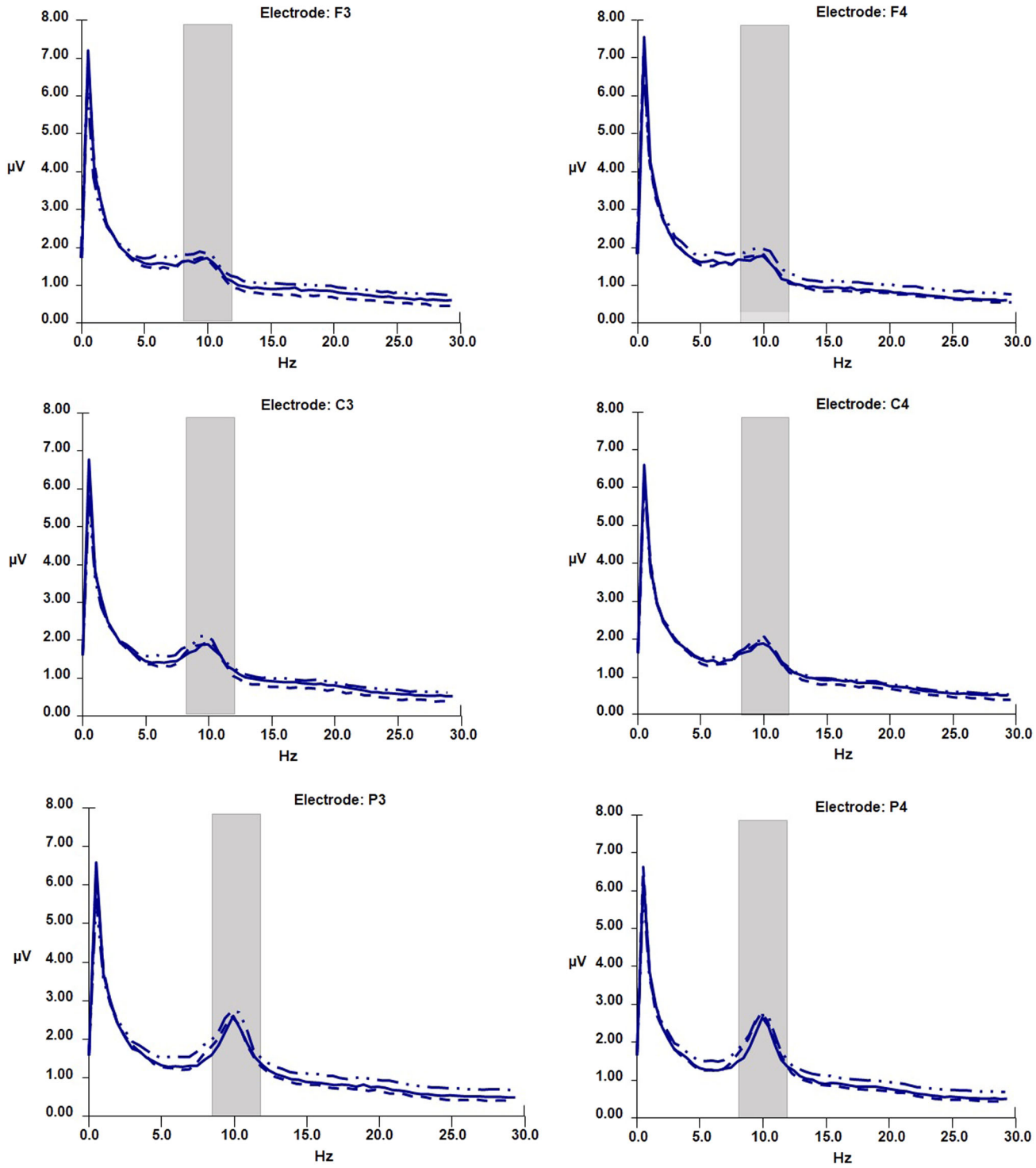


Fig. 3. Eyes Open EEG data during Baseline for the Sham (solid line), 1 W/kg (dashed line), and 2 W/kg conditions (dashed line with dots) for each of the six EEG electrode sites. Shaded box indicates the area of the alpha frequency range that was submitted to the statistical analysis. EEG = electroencephalogram.

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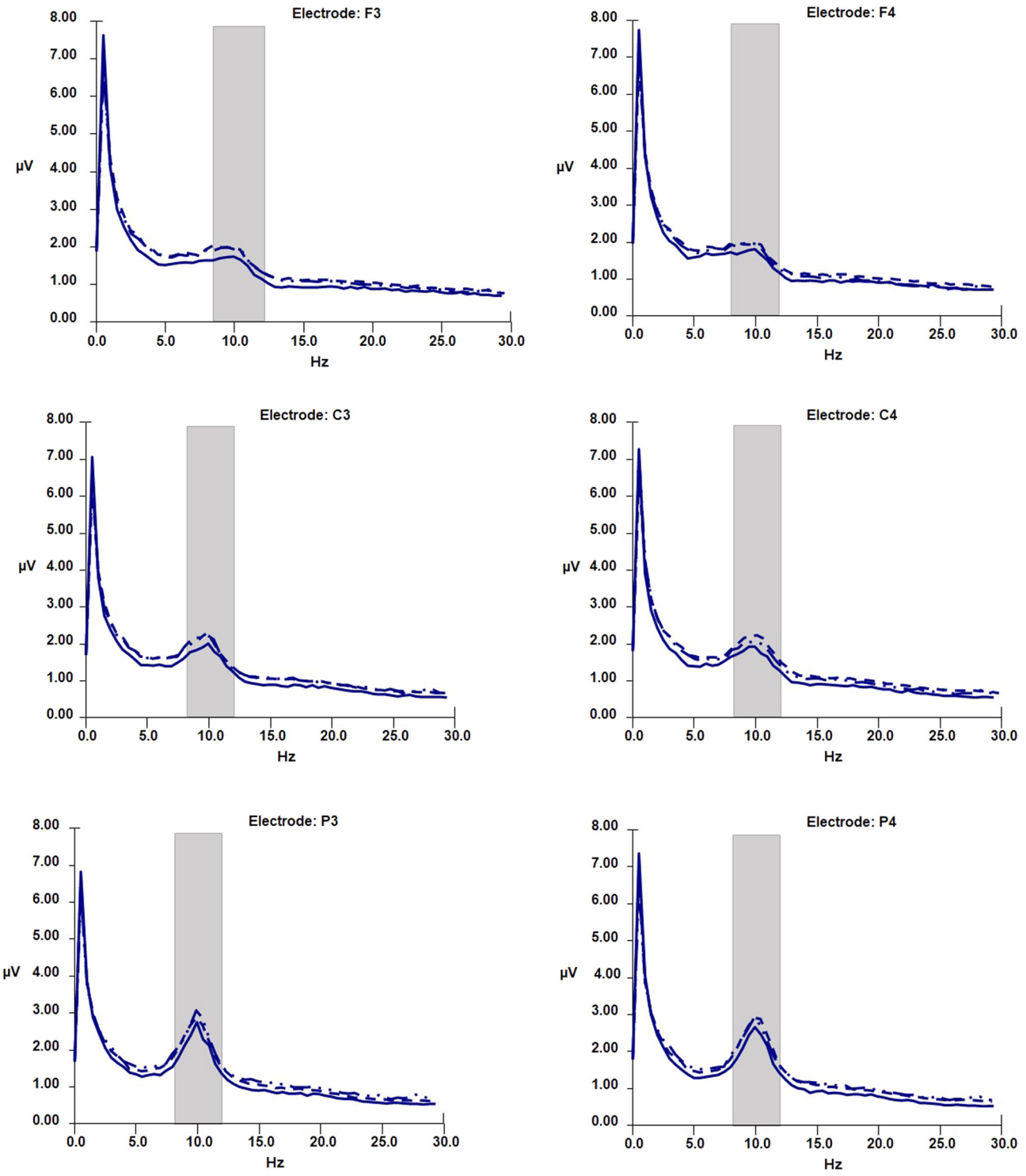


Fig. 4. Eyes Open EEG data during Exposure for the Sham (solid line), 1 W/kg (dashed line), and 2 W/kg conditions (dashed line with dots) for each of the six EEG electrode sites. Shaded box indicates the area of the alpha frequency range that was submitted to the statistical analysis. EEG = electroencephalogram.

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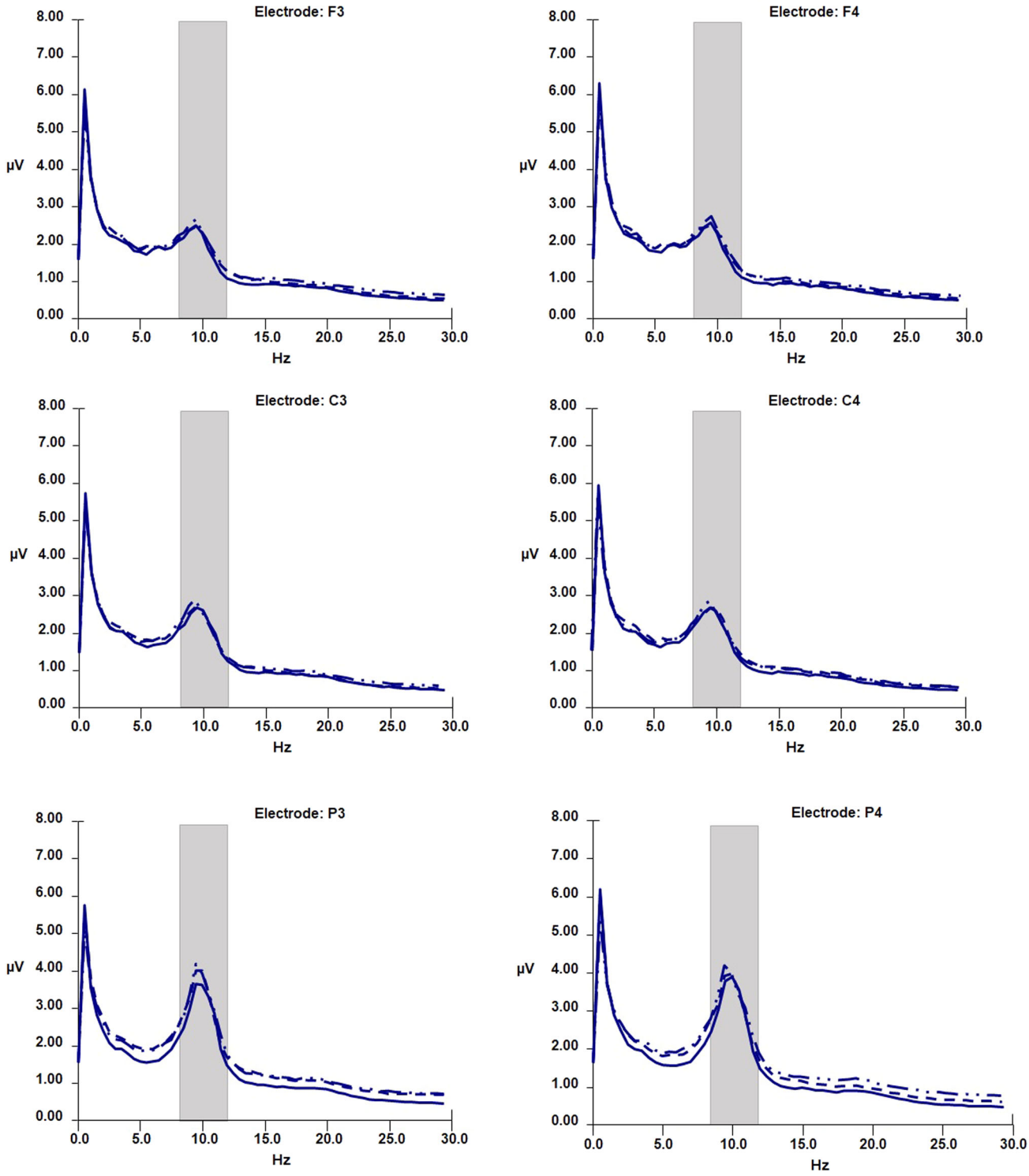


Fig. 5. Eyes Closed EEG data during Baseline for the Sham (solid line), 1 W/kg (dashed line), and 2 W/kg conditions (dashed line with dots) for each of the six EEG electrode sites. Shaded box indicates the area of the alpha frequency range that was submitted to the statistical analysis. EEG = electroencephalogram.

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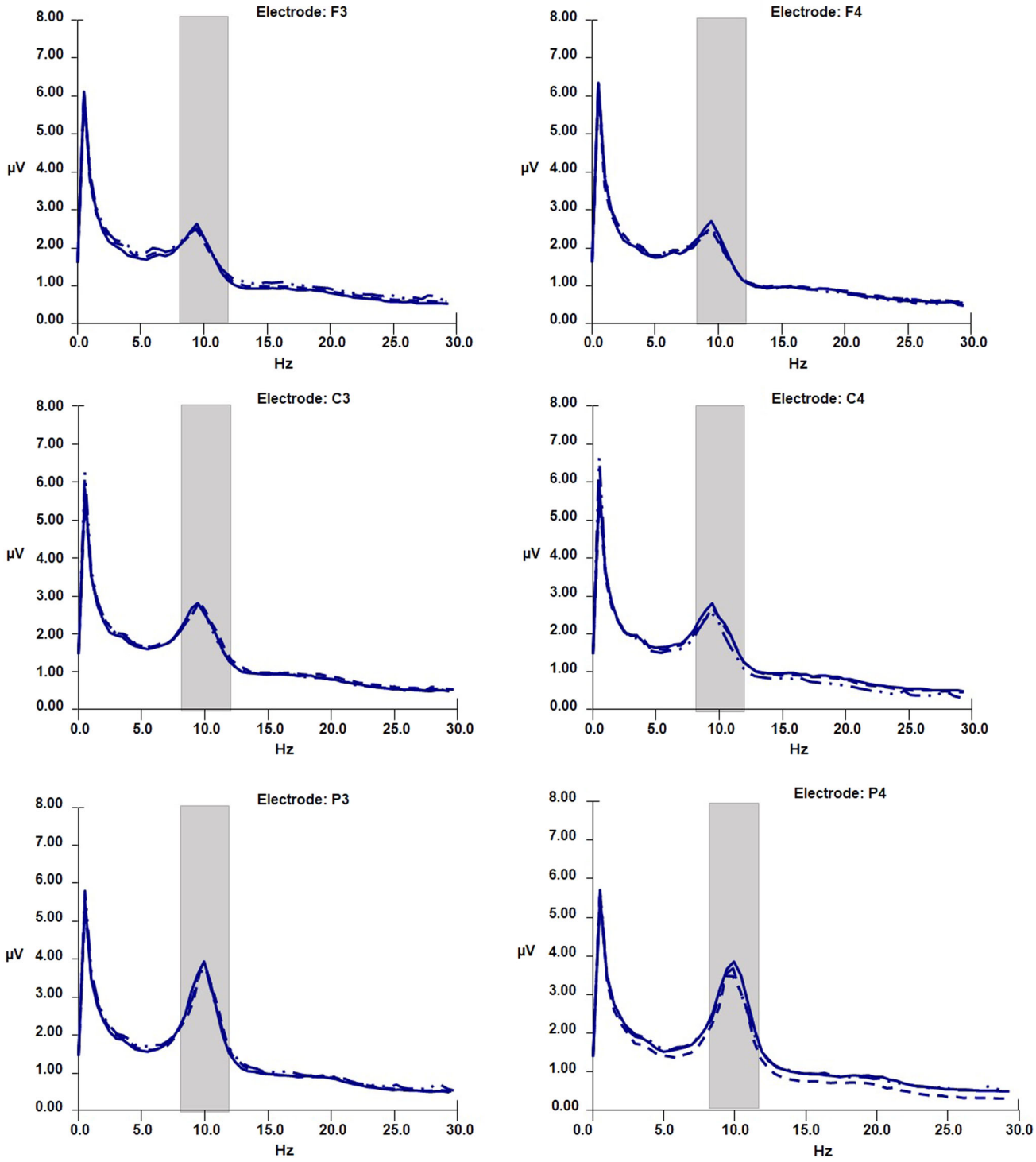


Fig. 6. Eyes Closed EEG data during Exposure for the Sham (solid line), 1 W/kg (dashed line), and 2 W/kg conditions (dashed line with dots) for each of the six EEG electrode sites. Shaded box indicates the area of the alpha frequency range that was submitted to the statistical analysis. EEG = electroencephalogram.

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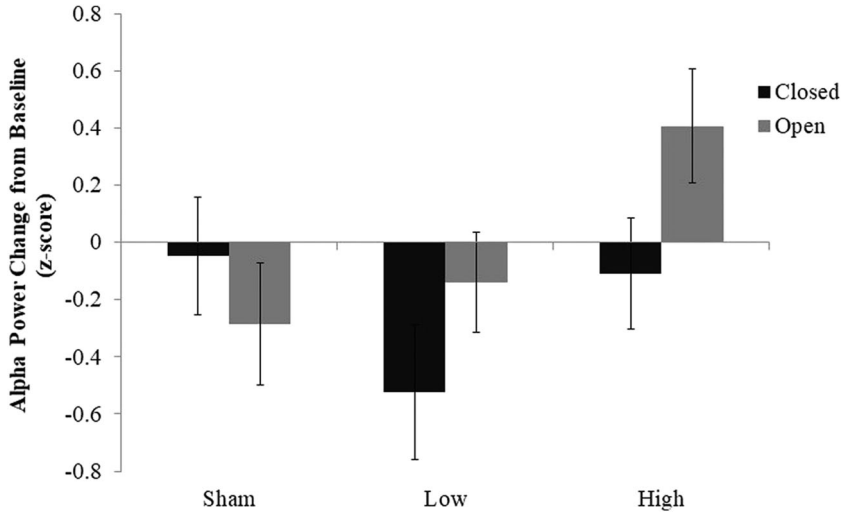


Fig. 7. The change in EEG alpha power (normalized) from Baseline to each of the Sham, Low, and High RF-EMF exposure conditions for EEG derived from participants resting with their eyes open (gray) and closed (black) separately. EEG = electroencephalogram; RF-EMF = radiofrequency electromagnetic fields.

This is consistent with the poorer signal-to-noise ratio under eyes closed conditions, as closing the eyes produces a larger EEG alpha power increase (independent of RF-EMF exposure) than that resulting from RF-EMF exposure itself. To date, most research exploring RF-EMF/EEG interactions has utilized GSM exposures. More recently, effects on EEG alpha power have also been reported during Universal Mobile Telecommunications System (UMTS) and Long Term Evolution (LTE) exposures [Trunk et al., 2013; Vecsei et al., 2018]. However, it remains to be determined whether observed RF-EMF effects on EEG alpha would also be larger under eyes open than eyes closed conditions during these exposures.

The present study also found that in the eyes open resting EEG condition, the RF-EMF-related increase in EEG alpha power was greater for EEG derived during the last 4 min, as opposed to the first 4 min, of a 30-min exposure. This finding is in line with prior work, which similarly observed that EEG alpha power during RF-EMF exposure increased as a function of exposure duration [Croft et al., 2002]. This

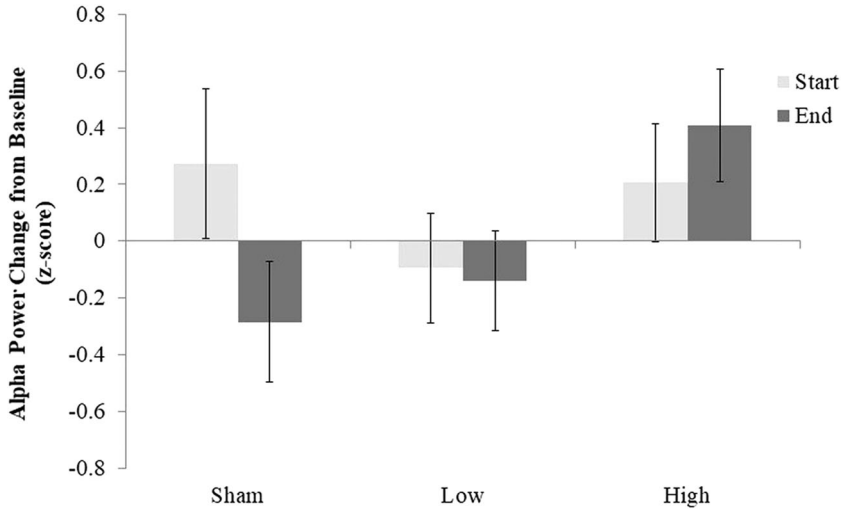


Fig. 8. The change, from Baseline (normalized) in eyes open resting EEG alpha power to each of the Sham, Low, and High RF-EMF exposure conditions is shown for EEG derived from the Start (first 4 min; light gray) and End (last 4 min; dark gray) of the exposure period. EEG = electroencephalogram; RF-EMF = radiofrequency electromagnetic fields.

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observation suggests the possibility that failures to observe RF-EMF effects on EEG alpha in some previous studies [e.g., Roschke and Mann, 1997] may have resulted from insufficient exposure durations. Although the present data suggest that very short (≈4-min) GSM-like RF-EMF exposures are insufficient to affect EEG alpha, a recommendation on the minimal exposure duration necessary to elicit EEG alpha change is beyond the scope of the present study, as EEG effects were only assessed at the beginning and end of the exposure interval. Further research is needed to determine the temporal course of the RF-related EEG alpha change.

An important issue regarding the RF-EMF/EEG relation concerns the mechanism that mediates it. It has been proposed that rather than representing a biophysical relation, the RF-EMF-induced EEG alpha change merely represents artifact due to pickup of the RF-EMF by the EEG recording system [e.g., as speculated by Valentini et al., 2007] or the EEG leads affecting the signal reaching the brain. However, there is no empirical data demonstrating that these hypotheses explain the RF-EMF/EEG results. On the other hand, evidence from sleep research, where the same effects are observed regardless of whether RF-EMF is delivered before or during EEG recording and associated electrode attachment [eg. Huber et al., 2003; Loughran et al., 2005], argues against the possibility that the observed effects are due to direct pickup of the RF-EMF signal. Moreover, as the EEG effect differs as a function of both exposure duration and whether the eyes are open or closed, the relation cannot be explained by electrical interference (as similar interference would be expected across those combinations).

In terms of biophysical mechanisms, given that RF-EMF exposure is known to increase tissue temperature, thermal mechanisms are important to consider. A difficulty with this line of exploration, though, is that the localized temperature rise from mobile phone-like exposures within the ICNIRP local exposure restrictions [ICNIRP, 2020], such as is the case in the present experiment, is very small (circa 0.1°), and it is difficult to imagine how such a small thermal insult could result in a detectable physiological response. However, as part of the same experiment that the present data set was derived from, we have recently demonstrated that the present RF-EMF exposure causes vascular change (increased blood flow to the finger, as indicated by increased finger temperature) that is consistent with a thermoregulatory process engaged to cool the body [Loughran et al., 2019]. This is consistent with suggestions that a thermal mechanism may be responsible for the effect of RF-EMF exposure on the sleep EEG [Danker-Hopfe et al., 2016]. Similarly, a thermal change was recently demonstrated in mice in response to daily exposure to 0.16 W/kg whole body average SAR, which was not present during the first exposure (and thus due to an indirect physiological change rather than dielectric absorption) [Mai et al., 2020]. It follows that low-level RF-EMF is sufficient to engage physiologically meaningful thermoregulatory changes, and provides indirect support for the view that the RF-EMF effect on the EEG may represent an 'indirect' response to exposure [Perentos et al., 2013].

The possibility that the effect is mediated by direct activation of brain thermoreceptors (TRPM8) was tested in the above [Mai et al., 2020] study, where no support for this proposal was found. Although equivalent research has not been conducted in humans, and although there remains the possibility that different TRP receptors are involved, there is currently no evidence that direct activation of thermoreceptors by RF-EMFs is responsible for the above thermoregulatory changes. Another possibility is that the effect on the EEG is related to the well-established microwave hearing effect, where brief (circa 100 μs), low-level (circa 5 mJ) RF-EMF pulses cause thermoelastic expansion that travels as a wave to the cochlea and is detected as audible sound [Lin and Wang, 2007]. However, there is no evidence that mobile phone-like RF-EMF exposure produces pulses of sufficient specific absorption to generate the microwave hearing effect, and we are not aware of any research conducted to determine whether it can explain the above changes to the human EEG.

CONCLUSION

The present study demonstrated that the RF-EMF-related increase in EEG alpha power is larger in the eyes open than the eyes closed condition, which suggests that the inconsistent results reported in the literature may merely be due to the use of eyes closed resting EEG conditions in some studies, which increases the chance of failing to detect real RF-EMF effects. The present results also show that the EEG alpha power increase due to RF-EMF depends on exposure duration, which suggests that, in addition to eye derivation, exposure duration should be taken into account in order to minimize type II error. That the RF-EEG effect was seen only late in the exposure period also provides evidence that the results are not due to artefactual interference from RF-EMF exposure, as any interference would be present both early and late in the exposure period.

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