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Conspiracy beliefs are associated with a reduction in frontal beta power and biases in categorizing ambiguous stimuli

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A R T I C L E I N F O

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A B S T R A C T

Prior beliefs, such as conspiracy beliefs, significantly influence our perception of the natural world. However, the brain activity associated with perceptual decision-making in conspiracy beliefs is not well understood. To shed light on this topic, we conducted a study examining the EEG activity of believers, and skeptics during resting state with perceptual decision-making task. Our study shows that conspiracy beliefs are related to the reduced power of beta frequency band. Furthermore, skeptics tended to misclassify ambiguous face stimuli as houses more frequently than believers. These results help to explain the differences in brain activity between believers and skeptics, especially in how conspiracy beliefs impact the categorization of ambiguous stimuli.

1. Introduction

Prior beliefs and acquired information play a substantial role in shaping our perception of natural environments [1–5]. This phenomenon becomes most apparent when observing false patterns, a perceptual inclination strongly connected to the acceptance of conspiracy beliefs [6–12]. Conspiracy beliefs revolve around the notion of concealed plans by powerful, malevolent organizations that withhold information to further their agendas [13]. A central mechanism fostering acceptance of conspiracy and paranormal beliefs is attributed to a skewed understanding of probability and causation, leading to the misinterpretation of patterns and meanings in unrelated events [8,14–16]. This cognitive bias, wherein individuals tend to discern meaningful patterns within uncertain perceptual backgrounds, forms the basis for the development of paranormal and conspiracy beliefs [9,17]. Previous research has confirmed that individuals who embrace conspiracy beliefs often rely on unreliable information when making decisions and exhibit a tendency to identify patterns within insignificant sensory stimuli [9,18–22]. Believers in conspiracy theories have also displayed a propensity for incorrectly identifying faces within chaotic patterns, interpreting ambiguous motion presentations as involving human agents, and attributing face-like qualities to images of environments [19,23,24]. Despite extensive investigations into cognitive biases and their association with belief in conspiracy theories, the underlying neural mechanisms remain inadequately understood.

Resting-state EEG is a widely employed technique in various specialized procedures, offering insights into the brain's electrical activity during resting state [25–27]. Several studies have shown an ongoing link between EEG activity during resting state and

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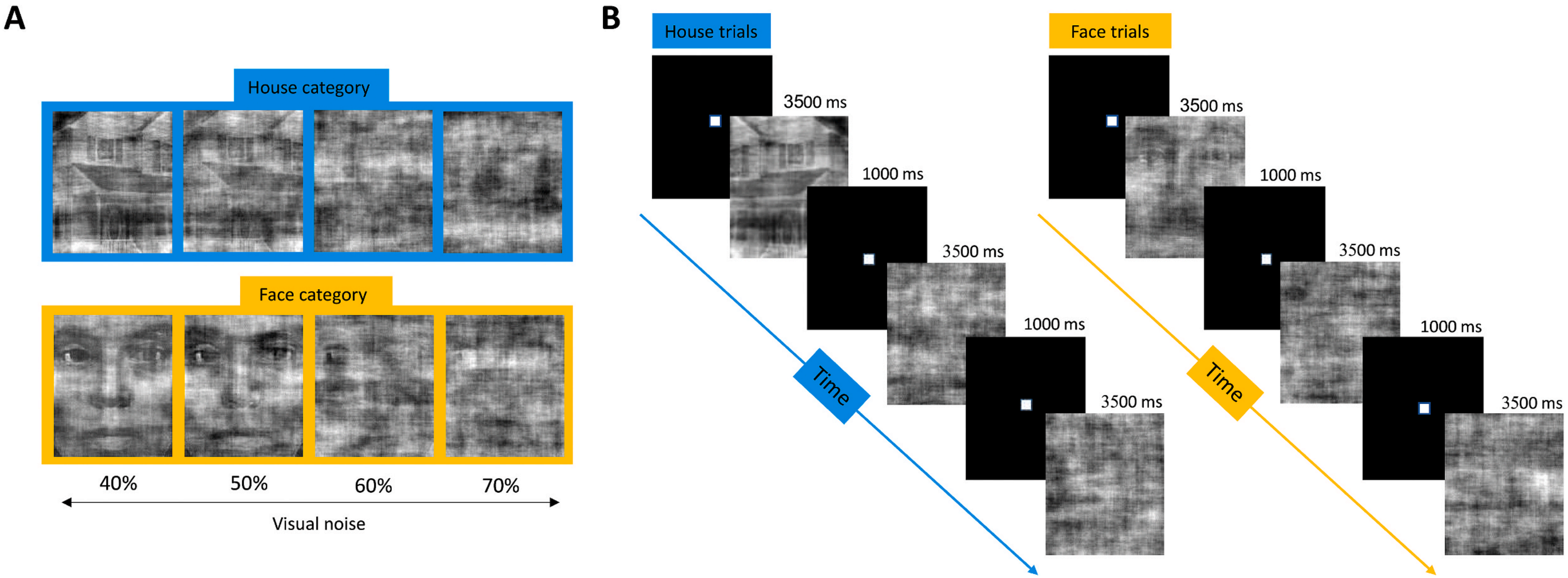

Fig. 1. Overview of the Experimental Design. A) Stimulus examples of houses (top row) and faces (bottom row) with escalating visual noise from left (40%) to right (70%). B) The procedure involved stimulus (face or house trials) presentation lasting for 3500 ms, after which subjects were instructed to press a button to register their response. Throughout the task, subjects were presented with stimuli featuring faces and houses, each with varying levels of visual noise. Their task was to identify and respond to these stimuli by pressing a specified key when they recognized either a house or a face stimulus. The duration between stimuli, known as the inter-stimulus interval (ISI), was configured to be 1000 ms.

performance on cognitive tasks. This stable association over time indicates that resting EEG provides insight into prior neural functioning [28–31]. Consequently, the study of resting-state EEG activity holds the potential to enhance our understanding of core brain functions linked to cognitive processes associated with conspiracy theories and paranormal beliefs [31,32]. The examination of event-related neural oscillations across different frequency bands suggests a means to evaluate brain responses [33]. Each frequency band corresponds to specific cognitive functions [34–37]. When people make perceptual decisions that require lateralized hand movements, frequency beta rhythms in the EEG over motor areas gradually change over the course of the decision. The direction of this beta activity shift depends on whether the eventual hand response is made using the same hand or the opposite hand. This beta signal is believed to represent the progressive preparation for reaction after decisional information has been encoded by EEG signals [38,39]. Existing research has established correlations between beta band oscillation power and prediction errors, decision confidence, and perceptual choices [40–42].

This study aims to delve into the neural underpinnings of belief in conspiracy theories, focusing specifically on perceptual decision-making processes and the beta frequency band. Prior investigations have firmly established a connection between beta oscillations in the frontal cortex and cognitive control, attention, and working memory [43]. These oscillations are also implicated in regulating perceptual decision-making. Moreover, prior research has correlated reduced power within the beta band with diminished cognitive flexibility and impaired performance on tasks requiring the integration of diverse information sources [44]. Building on this foundation, our study hypothesized that conspiracy theories are related to reduced frontal beta oscillations and a proclivity for perceiving meaningful patterns in ambiguous stimuli. To address this hypothesis, we conducted EEG research that compared brain activity between conspiracy theory believers and skeptics during resting state and perceptual decision-making task. By doing so, our study offers new insights into the intricate neural and cognitive mechanisms contributing to belief in conspiracy theories. These insights hold the potential to significantly enhance our comprehension of and approaches to addressing this noteworthy societal phenomenon.

2. Method

2.1. Participants

The research involved the selection of 59 right-handed students who were considered based on the Edinburgh Handedness Inventory. The study aimed to identify students who held either a belief or skepticism towards conspiracy theories. All 59 students initially chosen for the study were included, and their conspiracy theory beliefs were evaluated with the Conspiracy Theory Questionnaire (CTQ) [45]. The average score on the Conspiracy Theory Questionnaire (CTQ) was 64.01 (SD = 8.32). As expected, the distribution of belief in conspiracy theory was not evenly distributed. Based on previous studies [23,46], participants in the upper and lower 30% of the belief spectrum were included in the analysis, which comprised of believers (n = 18; 18 male; mean age (SD) = 27.66 (8.55); mean CTQ score = 53.88, SD = 3.51) and skeptics (n = 17; 9 male, 8 female; mean age (SD) = 25.47 (7.50); mean CTQ score = 36.64, SD = 6.55). All participants in this study were screened for mental illnesses, personality issues, drug or alcohol abuse, neurological disorders, and epilepsy. Our research strictly followed the ethical guidelines outlined in the Declaration of Helsinki. The study protocol obtained approval from the Department for Cognitive Science Ethics Committee (number 93/09/01). Prior to their participation in the study, all participants willingly provided written informed consent.

2.2. Materials

The Conspiracy Theory Questionnaire (CTQ). This questionnaire was specifically designed to assess the level of individuals' endorsement of conspiracy theories [45,47]. Comprising a total of 38 items, respondents are required to rate each item along a continuum ranging from 1 to 10, denoting the extent of their agreement, on a Likert ("extremely unlikely" to "certainly"). The CTQ's reliability was rigorously evaluated through a comprehensive analysis of internal consistency utilizing Cronbach's alpha coefficient (score = 0.963). Notably, this examination demonstrated exceptionally high internal consistency, further affirming the questionnaire's reliability and construct validity in measuring conspiracy beliefs [45].

The Cognitive Failures Questionnaire (CFQ). This questionnaire was employed to assess various aspects of cognitive performance. The CFQ, a self-report measure, is designed to quantify instances of memory lapses, perceptual errors, and motoric mishaps encountered in everyday situations. Comprising a total of 25 items, respondents were tasked with indicating their agreement with each statement using a Likert (0, showing "never," to 4, showing "always"). For example, one question asked was, "Do you forget people's names when you meet them?". Higher composite scores on the CFQ reflect an increased propensity toward cognitive failures [48]. Extensive validation efforts have confirmed the reliability and validity of the CFQ, attesting to its robust test–retest reliability, multidimensional factor structure, and internal consistency [48].

Face/house categorization task. This task was used with stimuli from a prior study [73]. The stimuli consisted of 38 images of houses and faces (black-and-white, 156 × 131 pixels) with varying levels of visual noise. Noise levels of 40%, 50%, 60%, and 70% were chosen based on a previous study showing 82% correct categorization on average at low noise levels. By including a wide range of visual noise, the task was designed so most subjects would correctly categorize the majority of stimuli at low noise levels. Categorization was expected to become more difficult as visual noise increased. This enabled the examination of categorization across a range of noise levels, from easy to more challenging (see Fig. 1A–B for more detail).

2.3. Procedure

Participants were placed in an EEG cabin that provided electrical and acoustic isolation and seated at a computer station. They were then fitted with a 2 Channel EEG System (ProComp2 with EEG-Z, Thought Technology Ltd; Montreal West, Canada). Following written informed consent, EEG recordings were obtained from each participant. Important to mention that although a distinction between conditions (eyes-open and eyes-closed) seems evident, previous studies have yielded inconsistent results [49][50]. To address potential drowsiness artifacts, often associated with early morning EEG recordings, and to facilitate meaningful group comparisons, this study chose to utilize an EEG eyes-open resting state [51–56]. EEG data was recorded as participants observed a blank screen for 5 min, followed by their completion of a face/house categorization task. In this task, subjects were shown stimuli comprising images of either faces or houses, and these stimuli were exhibited with differing degrees of visual noise. They were instructed to press a designated key when they recognized either a house or a face stimulus. Subjects conducted 240 trials with 4 noise levels, 2 stimulus categories, and 30 repetitions per category by subjects. After the task, participants completed the CTQ, and demographic questions in a separate room, and the entire process lasted approximately 30–35 min.

2.4. EEG recording

In a recording room, subjects were seated, and their EEG signals were recorded for a 5-min duration while they had their eyes open, utilizing a 2-channel EEG System. We recorded resting EEG activity at F8/F7 sites using the 10/20 system, with the left ear as the reference. The EEG signal was amplified at 256 Hz with impedance kept below 10 KΩ, and a 50 Hz notch filter removed electrical interference. The data was transformed into four frequency bands using fast Fourier Transform (FFT), band-pass filtering, and notch filtering. We conducted continuous amplitude measurements across delta (2–5 Hz), theta (5–8 Hz), alpha (8–12 Hz), and beta (15–18 Hz) frequencies [57]. To maintain data integrity, we established an artifact rejection threshold to eliminate unwanted interference.

2.5. Statistical analysis

The independent variable is the participants' belief in conspiracy theories. Dependent variables include EEG activity (frequency bands) and sensitivity to pattern recognition in ambiguous stimuli. In this study, our aim was to compare the performance of two groups (believers vs. skeptics) to identify differences in brain activity and pattern recognition in response to ambiguous stimuli. We conducted a comprehensive analysis of the data using various statistical methods. For reaction time (RT) and error rate , we employed a repeated measures ANOVA, considering the type of stimuli and noise levels as within-subjects factors, while also factoring in the CTQ score as a covariate. To compare behavioral variables between believers and skeptics, we employed independent two-sample t-tests. We employed an independent two-sample t-test to compare EEG band powers across groups. Pearson's correlations examined links between resting EEG activities and behavioral performances. Analysis was conducted using IBM SPSS Statistics version 24 with significance set at $p < 0.05$.

3. Results

3.1. Behavioral performance

The believers had higher scores on the CTQ than the skeptics. In addition, the CFQ result showed that believers reported more general cognitive failures.

Fig. 2 depicts the error rates in categorization responses based on stimulus type in the face/house categorization task. We detected a

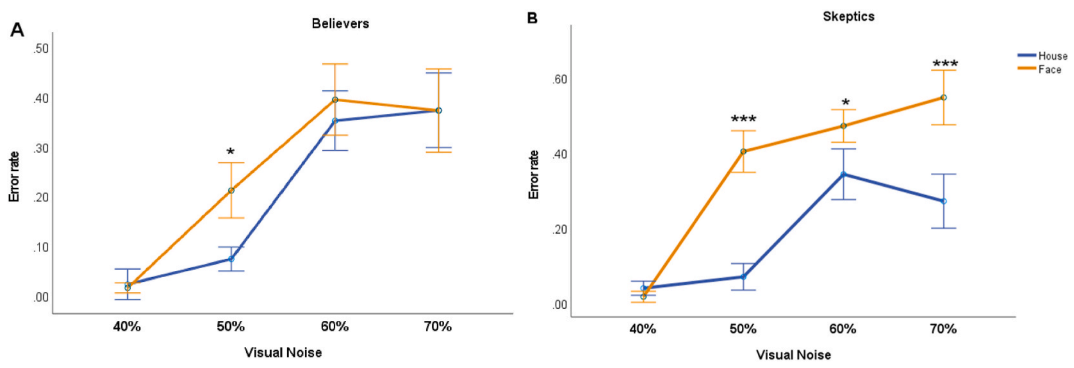

Fig. 2. Behavioral Performance of Groups (Believers and Skeptics) in Error Rate for the Face/House Categorization Task. The panel A) shows results for believers, and the panel B) for skeptics. The x-axis depicts visual noise levels (40%, 50%, 60%, 70%). The y-axis shows the error rate percentage. Orange lines represent errors in face stimuli, blue lines are errors in house stimuli. Error bars are SEM. $p < 0.05$*, $p < 0.01$**, and $p < 0.001$***.

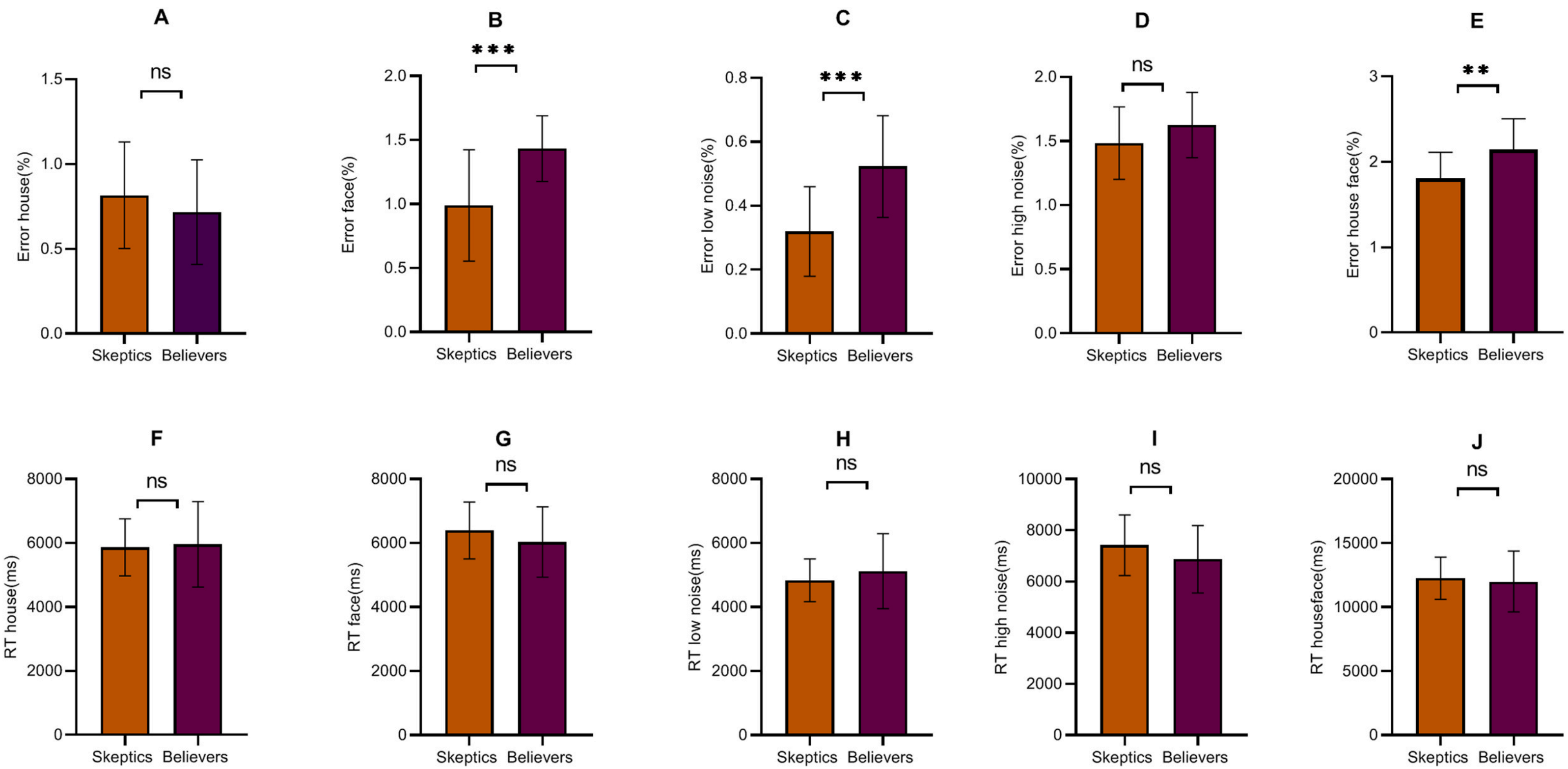

Fig. 3. Behavioral Performance in Face and House Trials: RT and Errors Comparison Between Believers and Skeptics Groups. The figure depicts the error rate (%, top row) and RT (ms, bottom row) for believers and skeptics on the face/house categorization task. Figures show A) Errors on house trials; B) Errors on face trials; C) Errors at low noise levels (40%, 50%); D) Errors at high noise levels (60%, 70%); E) Errors on house/face trials; F) RT on house trials; G) RT on face trials; H) RT at low noise; I) RT at high noise; J) RT on house/face trials. Orange bars represent the group, and purple bars represent the believers' group. Error bars are SEM. $p < 0.05$*, $p < 0.01$**, and $p < 0.001$***.

significant main effect of the stimulus ($F_{1,43} = 26.01$, $p < 0.001$, $\eta 2 = 0.37$), reflecting a higher error rate in categorizing face stimuli compared to house stimuli. Furthermore, there was a stimulus-CTQ score interaction ($F_{1,43} = 9.72$, $p = 0.03$, $\eta 2 = 0.18$), suggesting that the impact of a stimulus on error rates was contingent upon the CTQ score. As expected, a significant main effect of noise was observed ($F_{3,41} = 405.86$, $p < 0.001$, $\eta 2 = 0.96$), reflecting that error rates escalated with higher visual noise levels (Fig. 2). Additionally, there was an interaction between noise and the CTQ score ($F_{3,41} = 3.50$, $p < 0.02$, $\eta 2 = 0.20$). Furthermore, these main effects were clarified by a significant three-way interaction involving stimulus, noise, and the CTQ score ($F_{3,41} = 9.05$, $p < 0.001$, $\eta 2 = 0.39$).

Fig. 2 illustrates a notable three-way interaction. It demonstrates that skeptics' responses varied when faced with stimuli with higher levels of visual noise, particularly between face and house stimuli (Fig. 2B). Conversely, believers exhibited consistent error rates for both face and house stimuli, regardless of visual noise levels (Fig. 2A). To delve into this three-way interaction further, we conducted separate ANOVAs for the groups. This approach allows us to better understand the dynamics at play in the data (for guidelines on interpreting three-way interactions in mixed-design ANOVAs, see Ref. [58]). For skeptics, the analysis unveiled a significant main effect of noise ($F_{3,19} = 4.19$, $p < 0.02$, $\eta 2 = 0.39$) and a notable interaction between stimulus and noise ($F_{3,19} = 8.02$, $p < 0.001$, $\eta 2 = 0.55$). Following post-hoc , it was found that errors were significantly greater for face stimuli than house stimuli in conditions with 50%, 60%, and 70% visual noise. Conversely, for believers, a main effect of stimulus ($F_{1,20} = 7.84$, $p < 0.01$, $\eta 2 = 0.28$) and noise ($F_{3,20} = 5.31$, $p < 0.008$, $\eta 2 = 0.47$) was observed, but the interaction between stimulus and noise did not reach significance. Within this group, post-hoc showed a significant distinction in error rates between house and face stimuli solely in the 50% visual noise condition. This analysis provides insights into the differential responses of skeptics and believers to visual noise levels during the processing of face and house stimuli.

Additionally, the believers showed more errors in face trials ($t_{43} = -4.145$, $p = 0.001$, Fig. 3B), house and face trials with low noise (40% and 50%) ($t_{43} = -4.578$, $p = 0.001$, Fig. 3C), and house and face trials ($t_{43} = -3.470$, $p = 0.001$, Fig. 3E) compared to the skeptics. The results indicated no significant differences between the two groups in error rates and RT for various conditions (Fig. 3A, D, F, G, H, I, and J). Additionally, the skeptics showed more errors in house trials with 70% visual noise ($t_{43} = 2.015$, $p = 0.05$, Fig. 4D) compared to the believers. Additionally, the believers showed more errors in face trials with 50% visual noise ($t_{43} = -4.779$, $p = 0.001$, Fig. 4F), and face trials with 70% visual noise ($t_{43} = -3.227$, $p = 0.002$, Fig. 4H) compared to the skeptics. The findings demonstrated no significant difference between the two groups in error rates for houses at 40% (Figs. 4A), 50% (Fig. 4B), and 60% (Fig. 4C), as well as error rates for faces at 40% (Figs. 4E) and 60% (Fig. 4G).

In RT, as can be seen in Fig. 5, the findings demonstrated a significant difference between the groups for the RT in-house trials with

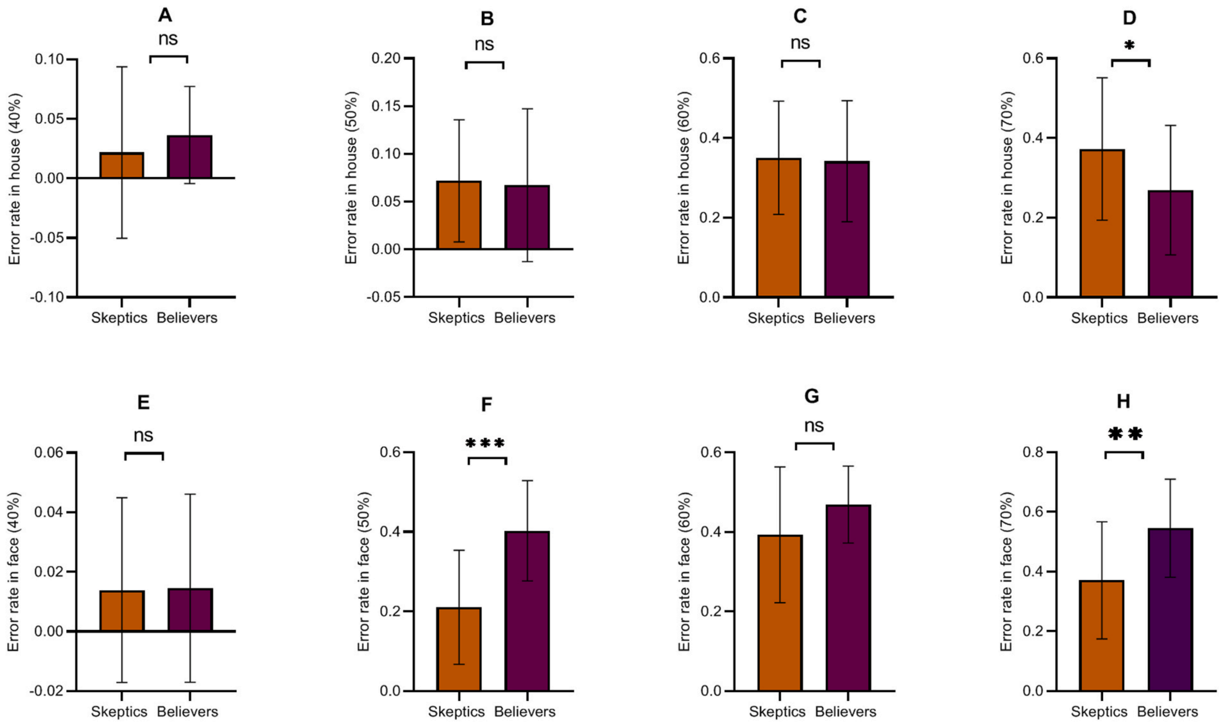

Fig. 4. Behavioral Performance: Error Rates in Face and House Trials for Believers and Skeptics Groups. Figure shows error rates for believers versus skeptics on the house (top row) and face (bottom row) categorization task across different noise levels. Figures depict A) House trial errors at 40% visual noise; B) House trial errors at 50% visual noise; C) House trial errors at 60% visual noise; D) House trial errors at 70% visual noise; E) Face trial errors at 40% visual noise; F) Face trial errors at 50% visual noise; G) Face trial errors at 60% visual noise; H) Face trial errors at 70% noise. Orange bars represent the group, and purple bars represent the believers' group. Error bars are SEM. $p < 0.05$*, $p < 0.01$**, and $p < 0.001$***.

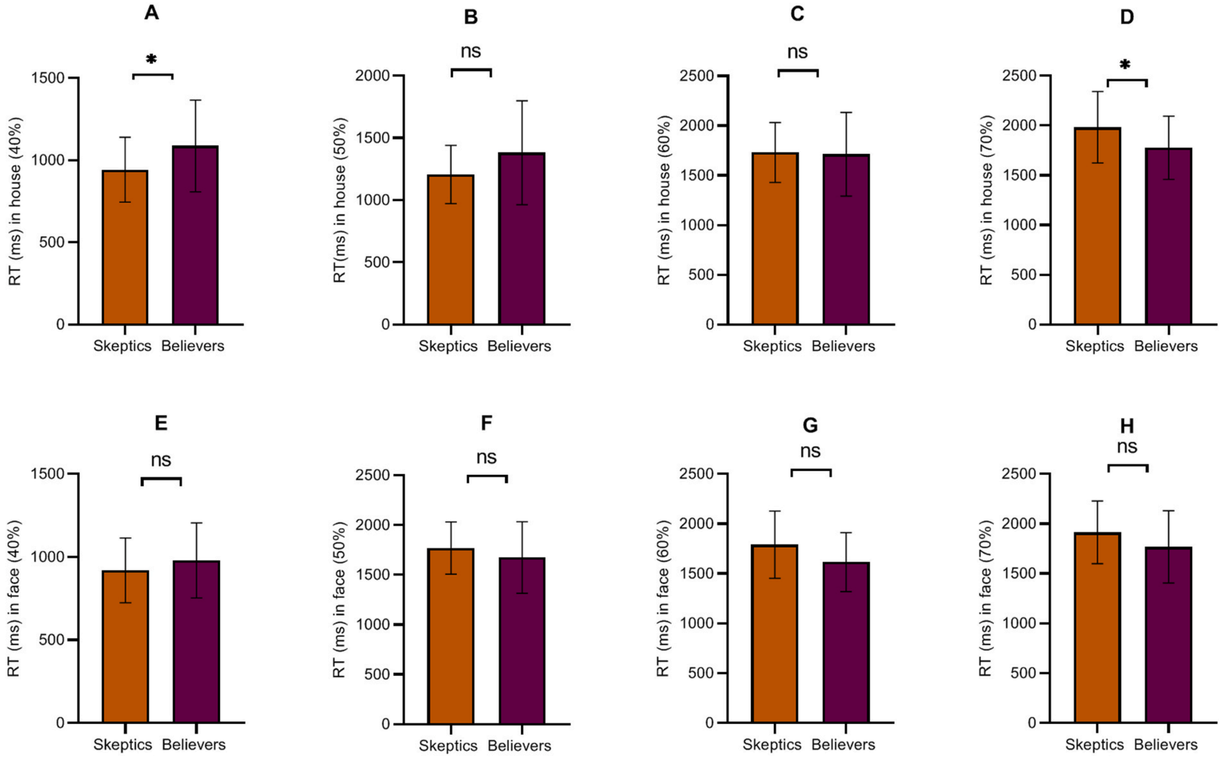

Fig. 5. Behavioral Performance: Reaction Times in Face and House Trials for Believers and Skeptics. Figure displays RT (ms) for believers versus skeptics on the house (top row) and face (bottom row) categorization task across varying noise levels. Figures show A) House trial RT at 40% visual noise; B) House trial RT at 50% visual noise; C) House trial RT at 60% visual noise; D) House trial RT at 70% visual noise; E) Face trial RT at 40% visual noise; F) Face trial RT at 50% visual noise; G) Face trial RT at 60% visual noise; H) Face trial RT at 70% visual noise. Orange bars represent the skeptic's group, and purple bars represent the believers' group. Error bars are SEM. $p < 0.05$*, $p < 0.01$**, and $p < 0.001$***.

40% visual noise ($t_{43} = -2.007$, $p = 0.05$, Fig. 5A), and RT in-house trials with 70% visual noise ($t_{43} = 2.025$, $p = 0.04$, Fig. 5D) compared to the skeptics. Additionally, the findings demonstrated no significant difference between the two groups in RT (ms) for house (50%) (Fig. 5B), RT (ms) for house (60%) (Fig. 5C), RT (ms) for face (40%) (Fig. 5E), RT (ms) for face (50%) (Fig. 5F), RT (ms) for face (60%) (Fig. 5G), and RT (ms) for face (70%) (Fig. 5H).

3.2. EEG oscillatory activity

Fig. 6 compares the absolute power between the two groups across different frequency bands. The findings reveal significant differences in EEG power across various bands between the groups: delta ($t_{33} = 0.115$, $p = 0.909$, Fig. 6A), alpha ($t_{33} = 2.147$, $p = 0.039$, Fig. 6B), and beta ($t_{33} = 2.530$, $p = 0.016$, Fig. 6C). Additionally, there no significant differences in theta band power between the groups ($t_{33} = 0.859$, $p = 0.397$, Fig. 6D).

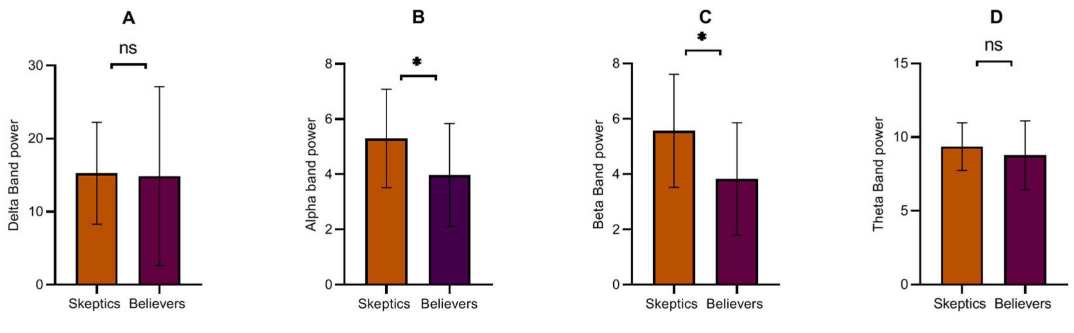

Fig. 6. EEG Band Power Differences Between Believers and Skeptics. The figures display EEG power across frequency bands for skeptics and believers. Charts show power for A) Delta band; B) Alpha band; C) Beta band; and D) Theta band. Orange bars represent the skeptics' group, and purple bars represent the believers' group. Error bars are SEM. $p < 0.05$*, $p < 0.01$**, and $p < 0.001$***.

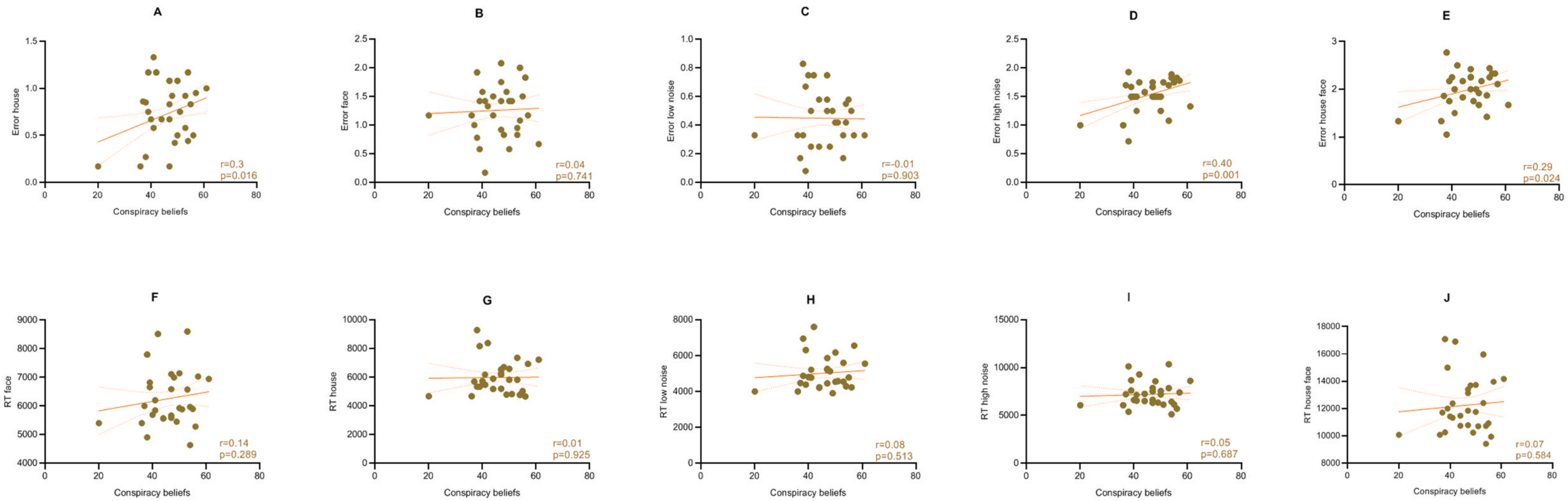

Fig. 7. Correlation Between Severity of Conspiracy Beliefs and RT/Error Rate in Face/House Categorization Task. The x-axis displays the level of conspiracy belief. The y-axis shows A) House trial errors; B) Face trial errors; C) Errors at low noise; D) Errors at high noise; E) House/face errors; F) Face trial RT; G) House trial RT; H) RT at low noise; I) RT at high noise; J) House/face RT. The data points on the plots represent a 95% confidence interval for the best-fit line.

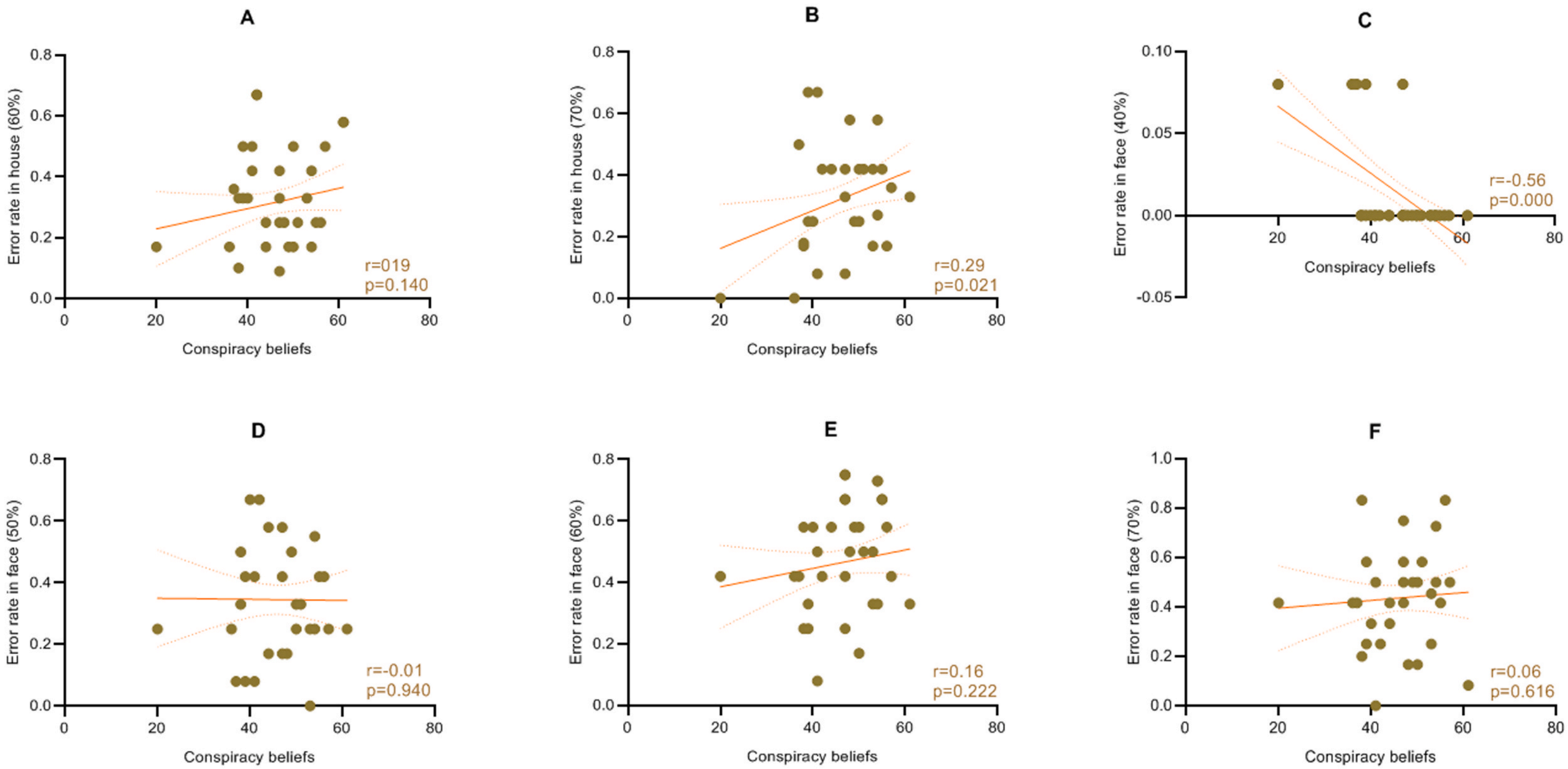

Fig. 8. Correlation between severity of conspiracy beliefs and error rate in face/house categorization task. The x-axis shows the level of conspiracy belief. The y-axis displays: A) House errors at 60% visual noise; B) House errors at 70% visual noise; C) Face errors at 40% visual noise; D) Face errors at 50% visual noise; E) Face errors at 60% visual noise; F) Face errors at 70% visual noise. The data points on the plots represent a 95% confidence interval for the best-fit line.

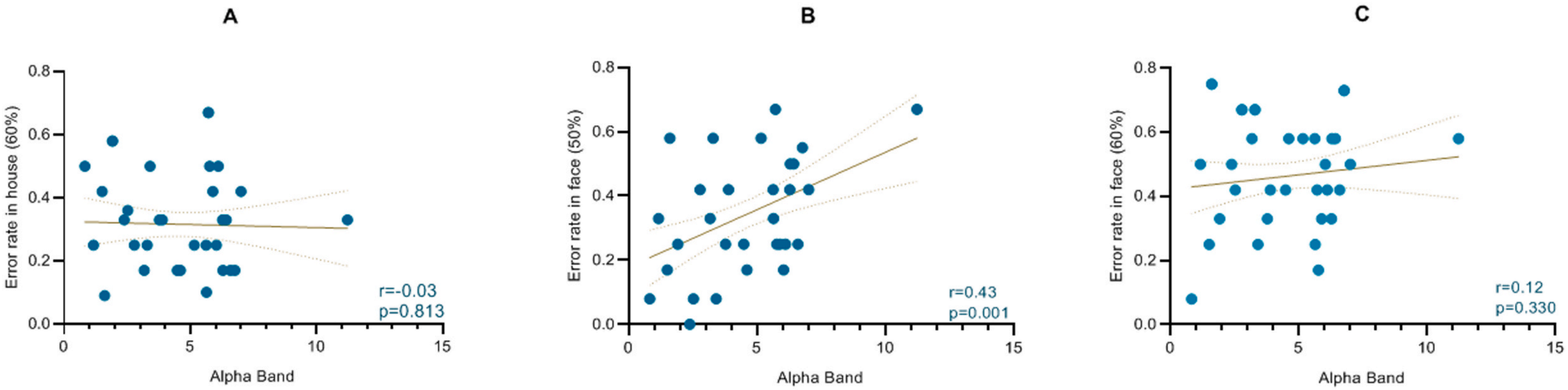

Fig. 9. Correlation between alpha band power and error rate in face/house categorization task. The x-axis displays alpha power. The y-axis shows A) House errors at 60% visual noise; B) Face errors at 50% visual noise; and C) Face errors at 60% visual noise. The data points on the plots represent a 95% confidence interval for the best-fit line.

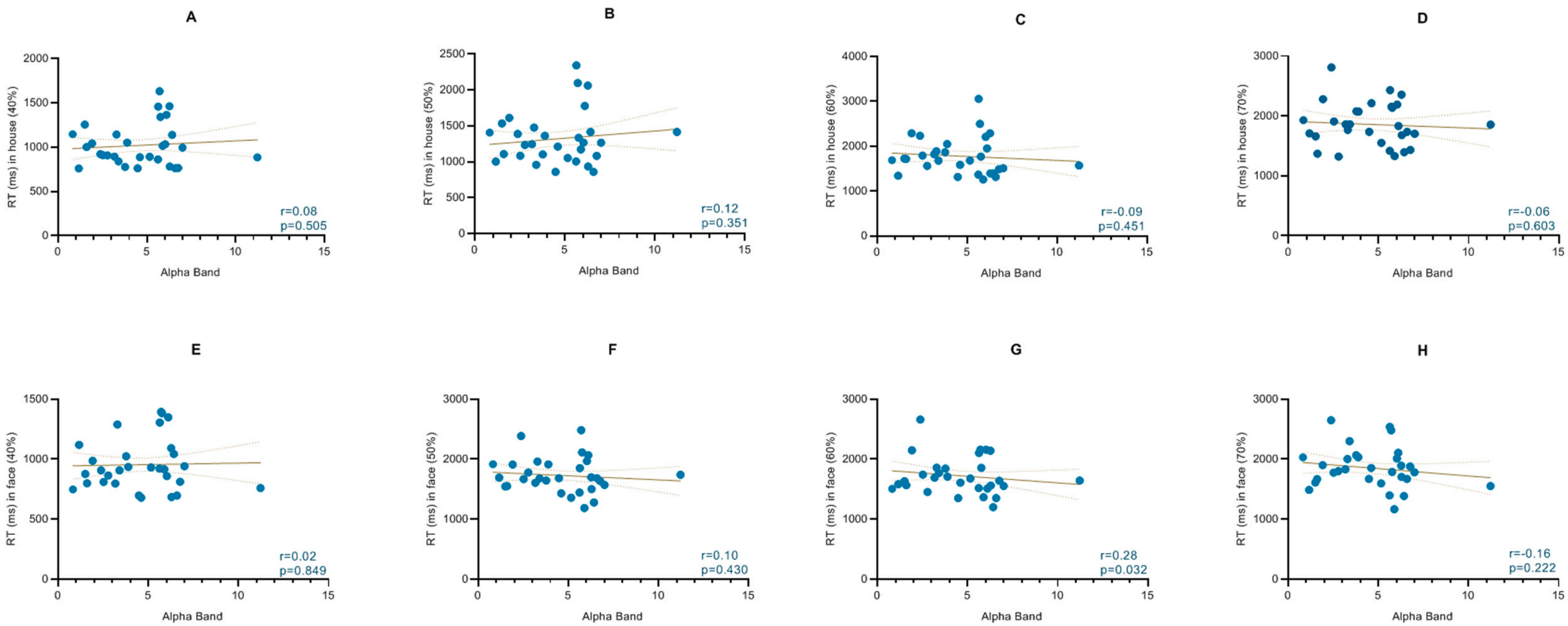

Fig. 10. Correlation between alpha band power and RT in face/house categorization task. The x-axis shows alpha power. The y-axis displays: A) House RT at 40% visual ise; B) House RT at 50% novisual ise; C) House RT at 60% novisual ise; D) House RT at 70% novisual ise; E) Face RT at 40% novisual ise; F) Face RT at 50% novisual ise; G) Face RT at 60% novisual ise; H)and Face RT at 70% novisual ise. The data points on the plots represent a 95% confidence interval for the best-fit line.

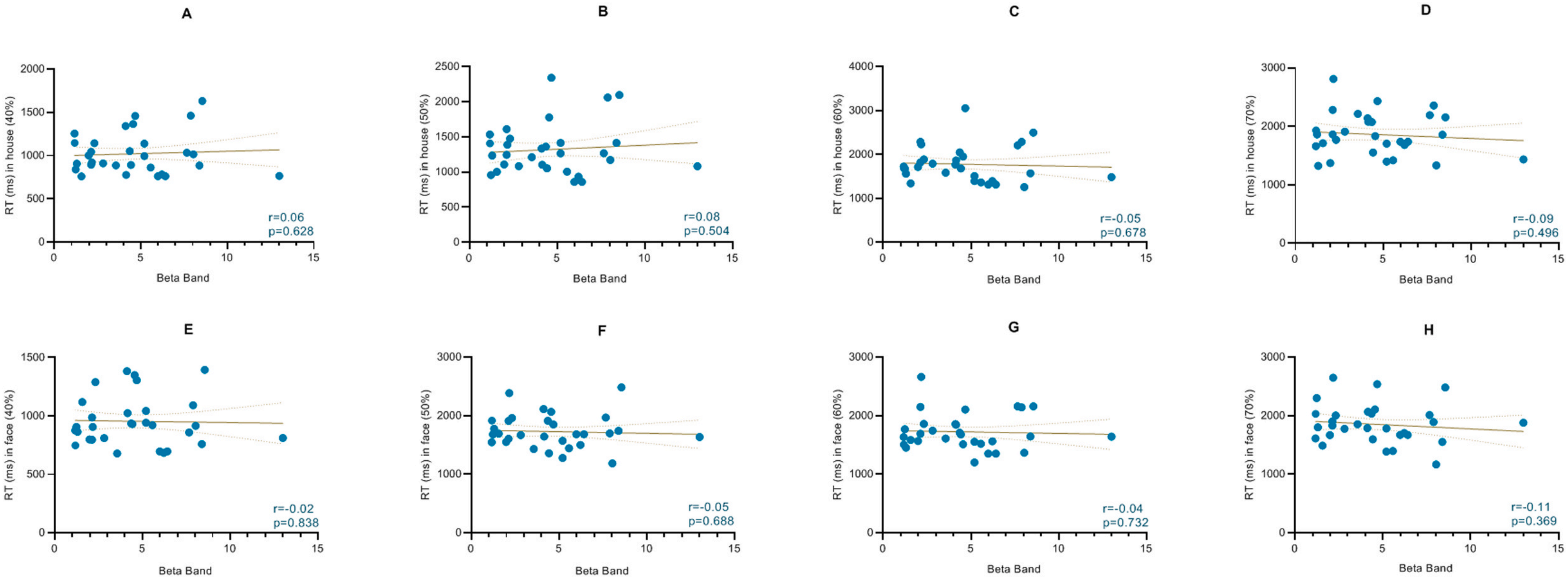

Fig. 11. Correlation between beta band power and RT in face/house categorization task. The x-axis displays beta power. The y-axis shows RT (ms) on house trials at visual noise levels of A) 40%; B) 50%; C) 60%; and D) 70%. It also shows RT on face trials at noise levels of E) 40%; F) 50%; G) 60%; H) 70%. The data points on the plots represent a 95% confidence interval for the best-fit line.

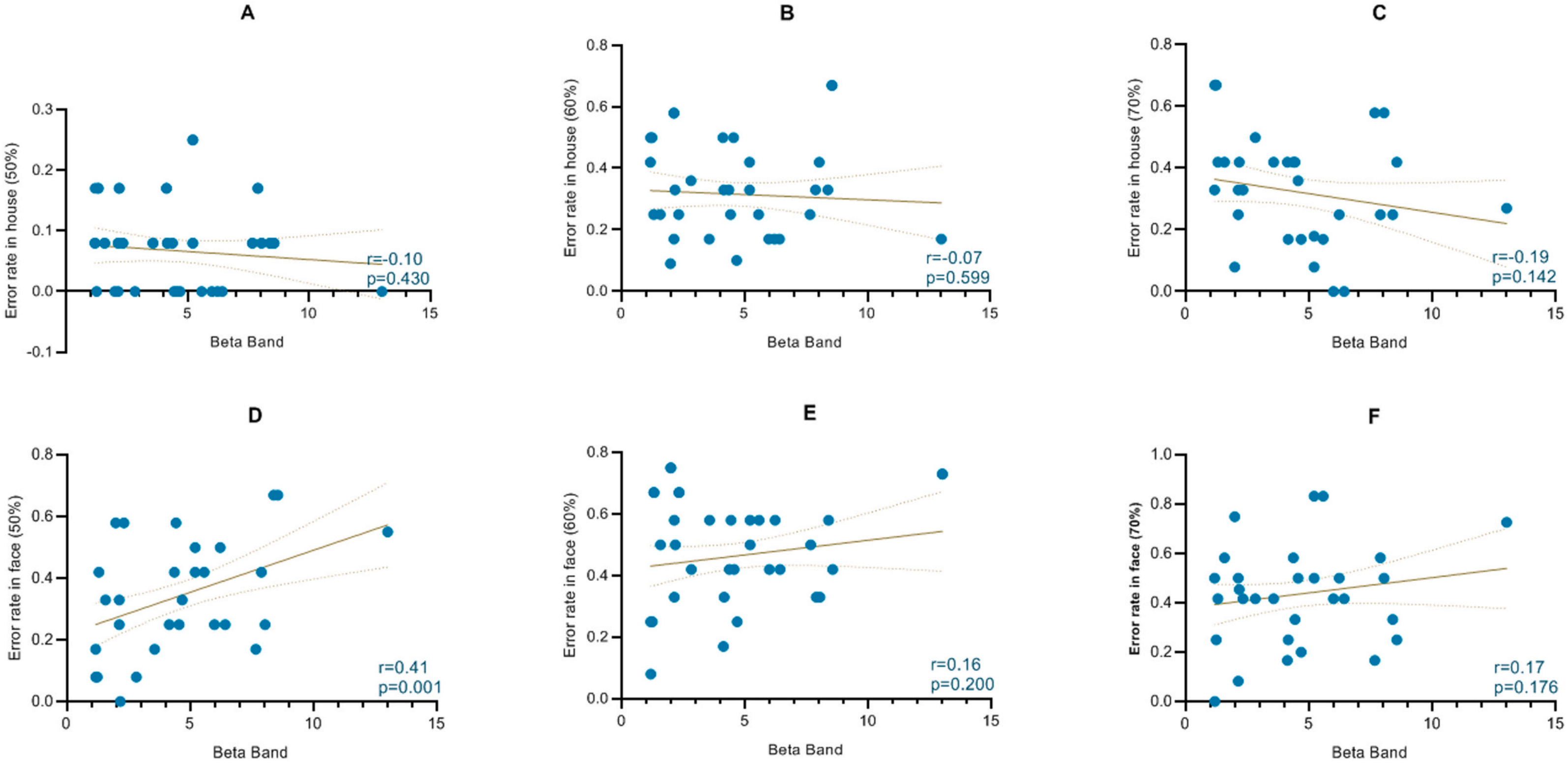

Fig. 12. Correlation between beta band power and Error rate in face/house categorization task. The x-axis illustrates the beta band power, while the y-axis displays the error rates under various conditions: (A) 50% visual noise in a house setting, (B) 60% visual noise in a house setting, (C) 70% visual noise in a house setting, (D) 50% visual noise in a face setting, (E) 60% visual noise in a face setting, and (F) 70% visual noise in a house setting. The data points on the plots represent a 95% confidence interval for the best-fit line.

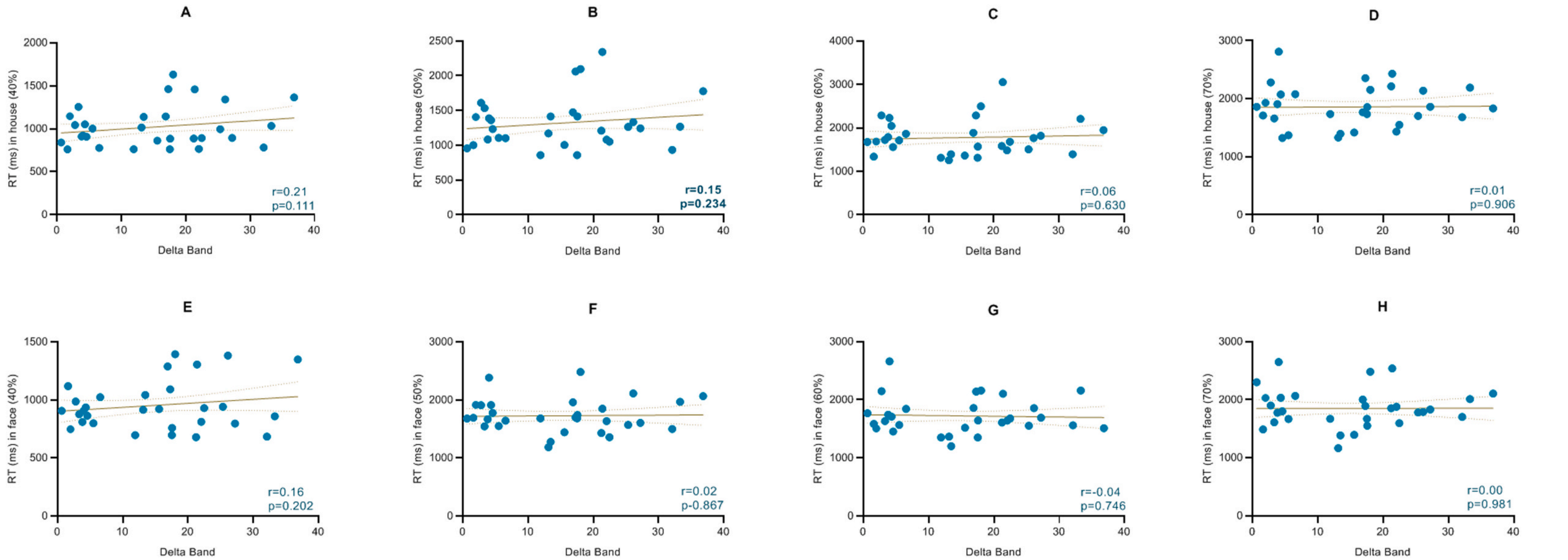

Fig. 13. Correlation between delta band power and RT in face/house categorization task. The x-axis displays the delta band power, while the y-axis depicts the response time (RT) within a household setting under different levels of visual noise: (A) 40%, (B) 50%, (C) 60%, and (D) 70%. The RT in a facial context is also shown with varying visual noise levels: (E) 40%, (F) 50%, (G) 60%, and (H) 70%. The data points on the plots represent a 95% confidence interval for the best-fit line.

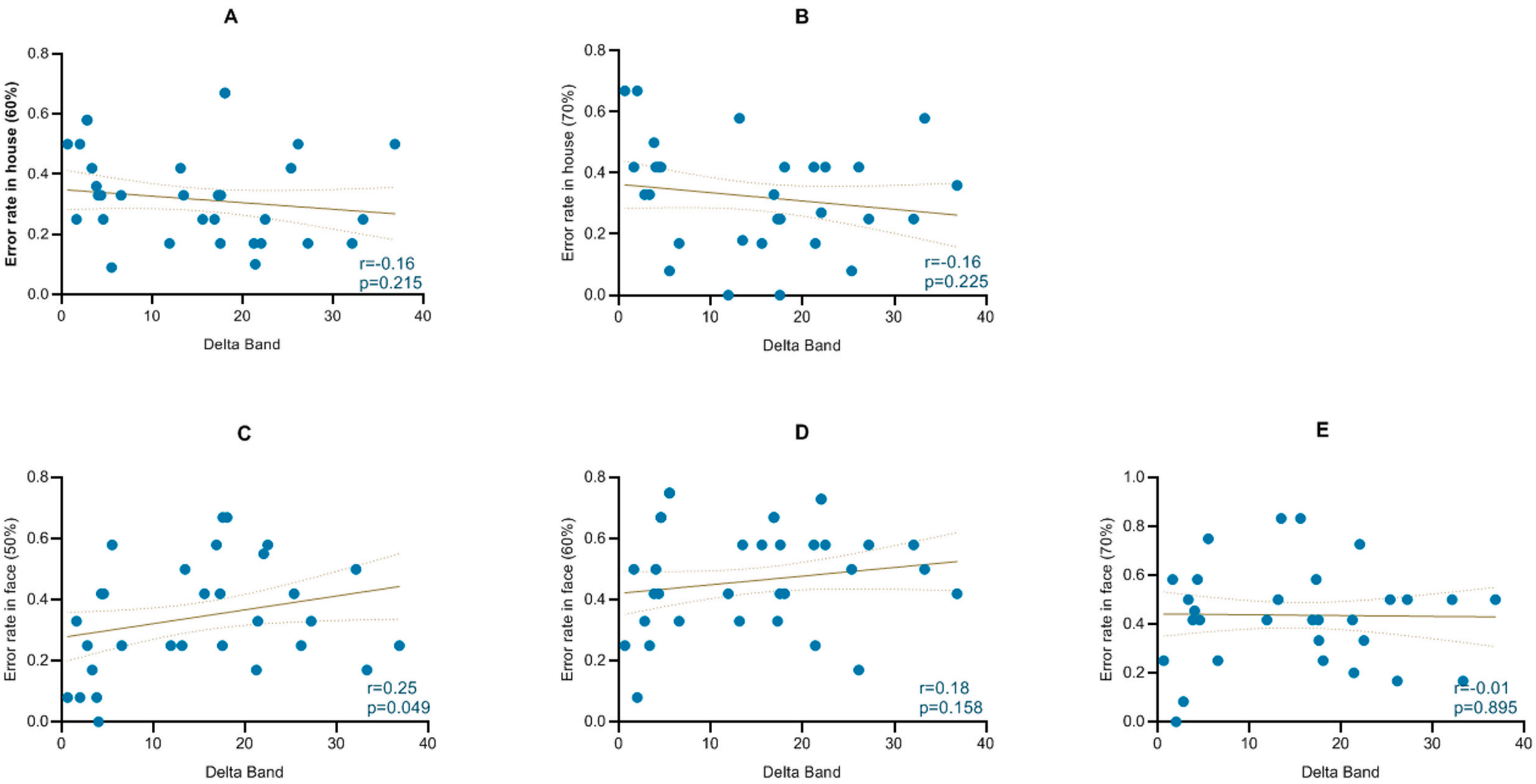

Fig. 14. Correlation between delta band power and error rate in face/house categorization task. The x-axis depicts the delta band power, while the y-axis displays the error rates under different conditions: (A) 60% visual noise in the house, (B) 70% visual noise in the house, (C) 50% visual noise in the face, (D) 60% visual noise in the face, and (E) 70% visual noise in the face. The data points on the plots represent a 95% confidence interval for the best-fit line.

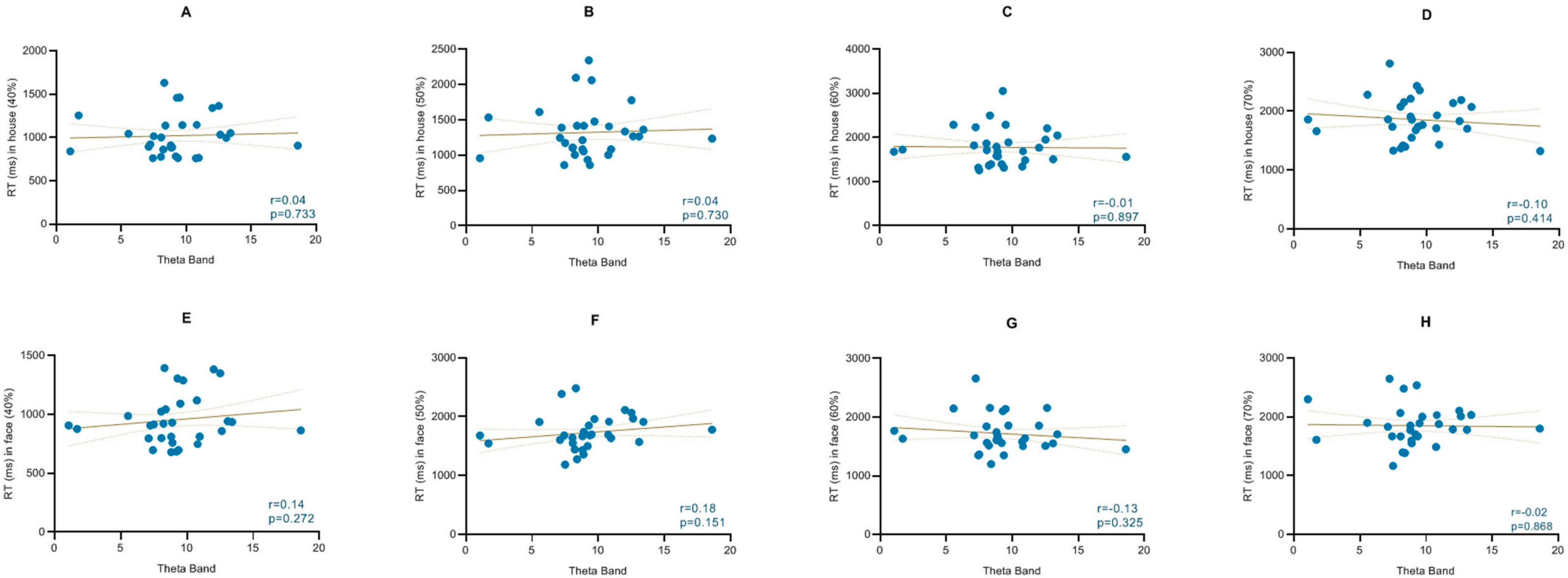

Fig. 15. Correlation between theta band power and RT in face/house categorization task. The theta band power is depicted along the X-axis, while the Y-axis displays RT (ms) within household settings under varying visual noise conditions: (A) 40%, (B) 50%, (C) 60%, and (D) 70%, as well as RT for facial settings with (E) 40%, (F) 50%, (G) 60%, and (H) 70% visual noise. The data points on the plots represent a 95% confidence interval for the best-fit line.

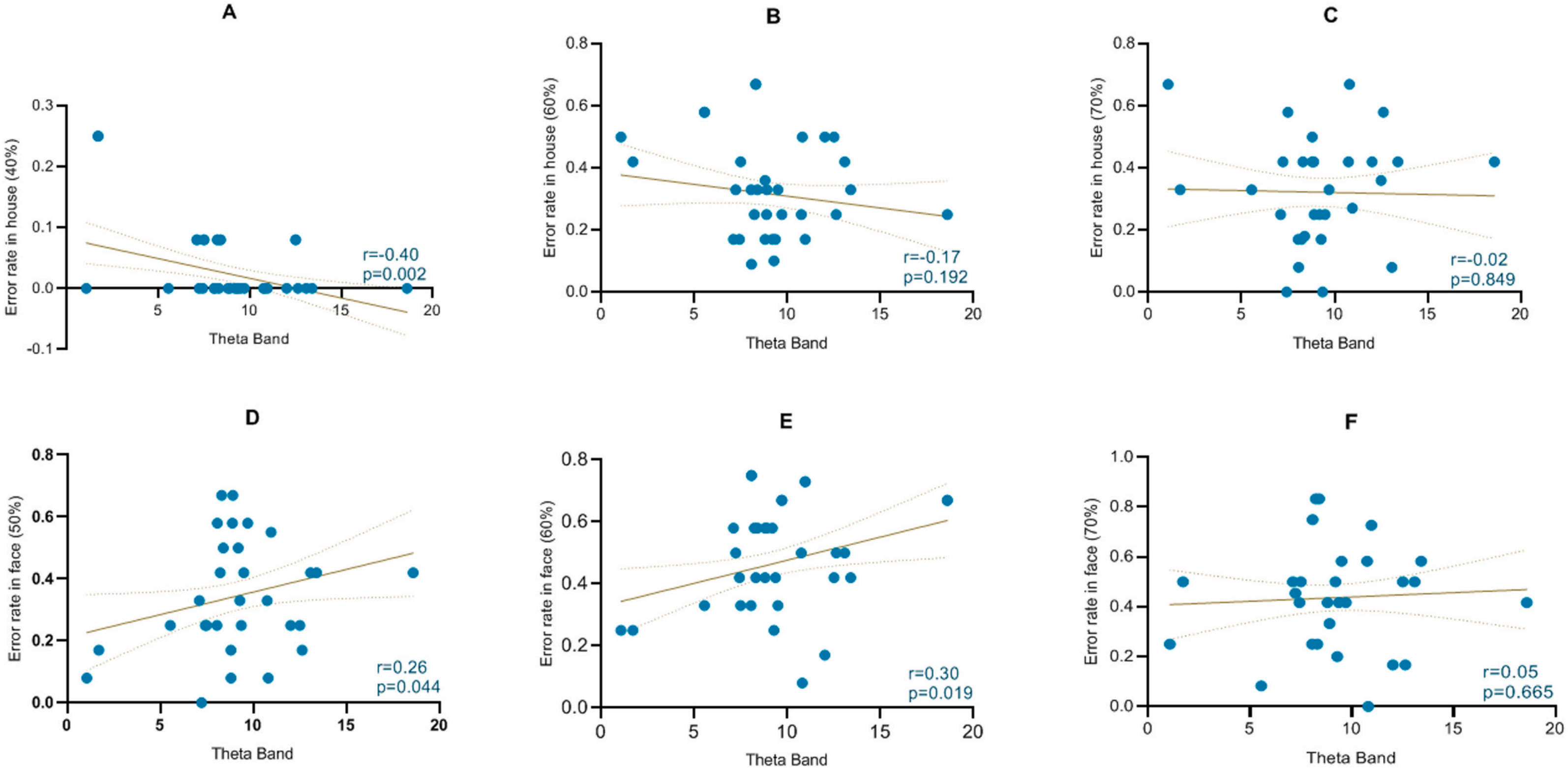

Fig. 16. Correlation between theta band power and Error rate in face/house categorization task. The theta band power is depicted along the X-axis, while the Y-axis displays the following: (A) Error rate in houses with 40% visual noise, (B) Error rate in houses with 60% visual noise, (C) Error rate in houses with 70% visual noise, (D) Error rate in faces with 50% visual noise, (E) Error rate in faces with 60% visual noise, and (F) Error rate in faces with 70% visual noise. The data points on the plots represent a 95% confidence interval for the best-fit line.

3.3. Correlation between severity of beliefs in conspiracy theories and face/house categorization task performance

In our study, we investigated the relationship between the strength of belief in conspiracy theories and performance on the face/house categorization task. We discovered significant positive correlations between belief strength and the following variables: the error rate for identifying houses in conditions with collapsed visual noise ($r = 0.31$, $p = 0.016$, Fig. 7A), the overall error rates in conditions with high collapsed visual noise ($r = 0.40$, $p = 0.001$, Fig. 7D), and the error rate for identifying house/face in conditions with collapsed visual noise ($r = 0.29$, $p = 0.024$, Fig. 7E).

However, it is important to highlight that we did not find any significant connections between the conspiracy theory beliefs and the following variables: error rates for identifying faces (Fig. 7B), error rates in conditions with low noise (Fig. 7C), RT for identifying faces (Fig. 7F), RT for identifying houses (Fig. 7G), RT in conditions with low noise (Fig. 7H), RT in conditions with high noise (Fig. 7I), and RT for identifying house/face (Fig. 7J).

Furthermore, our findings revealed a connection between the conspiracy theory beliefs and the following variables: the error rate in identifying houses with 70% visual noise ($r = 0.29$, $p = 0.021$, Fig. 8B) and the error rate in identifying faces with 40% visual noise ($r = -0.56$, $p = 0.000$, Fig. 8C) . Nevertheless, We did not identify any significant relationships between conspiracy theory beliefs and error rates for identifying houses at 60% visual noise (Fig. 8A), faces at 50% visual noise (Fig. 8D), faces at 60% visual noise (Fig. 8E), or faces at 70% visual noise (Fig. 8F).

3.4. Correlation between RT and error rates in the face/house categorization task and EEG oscillatory activity

3.4.1. Alpha band power

In our investigation, we explored the relationships between alpha band power and the face/house categorization task. Notably, the error rate in faces with 50% visual noise ($r = -0.43$, $p = 0.001$, Fig. 9B) showed a significant relationship with alpha power within the context of the face/house categorization task. However, no significant correlations were found between the error rates for houses at 60% (Fig. 9A) and faces at 60% visual noise levels(Fig. 9C) , and alpha band power.

Furthermore, we observed a significant correlation between RT (ms) for faces at 60% visual noise and alpha band power ($r=0.28$, $p=0.03$, Fig. 10G). Conversely, RT (ms) for houses at various visual noise levels (40% - Fig. 10A and 50% - Fig. 10B and 60% - Fig. 10C, and 70% - Fig. 10D), as well as RT (ms) for faces at different visual noise levels (40% - Fig. 10E and 50% - Fig. 10F, and 70% - Fig. 10H), did not demonstrate a significant correlation with alpha band power.

3.4.2. Beta band power

We examined the relationship between beta band power and the face/house categorization task. The findings demonstrated that RT (ms) for houses at various levels of visual noise - 40% (Fig. 11A), 50% (Fig. 11B), 60% (Fig. 11C), and 70% (Fig. 11D), as well as RT (ms) for faces at different levels of visual noise - 40% (Figs. 11E), 50% (Fig. 11F), 60% (Figs. 11G), and 70% (Fig. 11H), did not exhibit a significant relationship with beta power.

Furthermore, the error rate in face categorization at 50% visual noise significantly correlated with beta band power ($r = 0.41$, $p = 0.001$, Fig. 12D). However, no significant correlations were observed for houses at 50%, 60%, and 70% visual noise (Fig. 12A, B, C), or for faces at 60% and 70% visual noise (Fig. 12E and F), in relation to beta band power.

3.4.3. Delta band power

We investigated the correlation between delta band power and the face/house categorization task. The findings demonstrated that there was no significant correlation observed between delta band power and RT (ms) for houses at different visual noise levels - 40% (Fig. 13A), 50% (Fig. 13B), 60% (Fig. 13C), and 70% (Fig. 13D), as well as RT (ms) for faces at various visual noise levels - 40% (Fig. 13E), 50% (Fig. 13F), 60% (Fig. 13G), and 70% (Fig. 13H).

Furthermore, the error rate for face categorization at 50% visual noise significantly correlated with delta band power ($r = 0.25$, $p = 0.049$, Fig. 14C). However, the results indicated that the error rates for houses at 60% (Fig. 14A) and 70% visual noise levels (Fig. 14B) , as well as the error rates for faces at 60% (Fig. 14D) and 70% visual noise levels (Fig. 14E), were not significantly correlated with delta band power.

3.4.4. Theta band power

In our study, we investigated the correlation between theta band power and the face/house categorization task. The findings demonstrated that there was no significant correlation observed between theta band power and RT (ms) for houses at different visual noise levels - 40% (Fig. 15A), 50% (Figs. 15B), 60% (Fig. 15C), and 70% (Fig. 15D), as well as RT (ms) for faces at corresponding visual noise levels - 40% (Figs. 15E), 50% (Fig. 15F), 60% (Figs. 15G), and 70% (Fig. 15H).

Furthermore, the results indicated a significant correlation between the error rate in houses with 40% visual noise ($r = -0.40$, $p = 0.002$, Fig. 16A), the error rate in faces with 50% visual noise ($r = 0.26$, $p = 0.044$, Fig. 16D), and the error rate in faces with 60% visual noise ($r = 0.30$, $p = 0.019$, Fig. 16E) in the face/house categorization task and theta band power. However, no significant relationship was found between the error rates for houses at 60% (Fig. 16B) and 70% (Fig. 16C) visual noise levels, as well as the error rate for faces at 70% visual noise (Fig. 16F), and theta band power.

4. Discussion

The study aimed to investigate how resting-state EEG activity affects the perceptual decision-making abilities of believers in conspiracy theories who tend to perceive meaningful patterns in noise [6–12,18–24]. This study investigated associations between resting EEG oscillations, endorsement of conspiracy beliefs, and performance on a visual pattern recognition task requiring the identification of faces and houses embedded in visual noise. The findings revealed that believers in conspiracy theories exhibited reduced beta EEG oscillatory activity in the frontal region related to perceptual decision-making compared to skeptics. This is consistent with previous research showing frontal lobe dysfunction in individuals with paranormal phenomena and beliefs in conspiracy theories [74]. The results demonstrate that skeptics tended to misclassify ambiguous face stimuli as houses more frequently than believers. Believers, on the other hand, showed random performance when categorizing ambiguous face and house stimuli. This suggests that the bias in the categorization of ambiguous stimuli is influenced more by disbelief in conspiracy theories than by belief [20,59–62]. The results point to a possible relationship between beta activity in frontal lobe and the enhanced of conspiracy belief holders to find significant patterns in ambiguous information.

The specific neural mechanisms that connect conspiracy beliefs to lower frontal beta power remain unknown, though researchers have suggested several possible accounts for this relationship. One possibility is that an overactive default mode network (DMN) may interfere with other cognitive processes [63,64]. Another theory suggests that biased information processing may contribute to altered brain activity. The heightened sensitivity to identifying meaningful patterns in ambiguous stimuli observed in conspiracy believers may be linked to a cognitive bias known as apophenia. This bias may be related to an overactive pattern recognition system in the brain [65]. However, the mechanisms underlying the relationship between believing conspiracy theories and the reduced power in the beta band, as well as the heightened sensitivity to finding meaningful patterns in ambiguous stimuli, require further research. Effective interventions aimed at reducing belief in conspiracy theories can be developed once these mechanisms are better understood.

Our findings indicate a connection between categorizing ambiguous stimuli processing and frontal beta-band power. Another study also discovered a correlation between beta-band power and ambiguous stimulus processing [66]. This correlation could indicate that individuals are actively processing cognitive information or retaining it in their working memory [67]. Prior studies have suggested that the demands of working memory may impact beta band activity in the frontal region [68]. Based on this, we hypothesize that decreased frontal beta band power may be linked to decision-making processes. Although beta band power is typically linked to motor preparation during decision-making, a recent study indicates that it may also play a role in decision formation, regardless of the specific motor plan [69]. Furthermore, the beta band power outside of sensorimotor regions can form predictions related to decision-making within and between distributed cortical regions, such as front parietal networks. The front parietal network appears to be essential in the process of perceptual decision-making [42,70].

The study had a few limitations. One of them was the use of convenient sampling, which involved selecting university students as participants. Another limitation was that no EEG resting state with closed eyes was recorded. Furthermore, the menstrual cycles of female participants could have affected their cognitive task performance related to the prefrontal cortex [71,72], so future studies should control for this factor. Finally, it was not possible to analyze the performance of female participants separately due to their tendency toward paranormal and conspiracy beliefs. Further research should investigate potential gender differences in these phenomenon.

In summary, this study found that conspiracy beliefs are related to the reduced power of the beta frequency band. Furthermore, skeptics tended to misclassify ambiguous face stimuli as houses more frequently than believers. These results shed light on distinctions in neural functioning between conspiracy theory believers' explanations vs. versus skeptics, especially in how conspiracy beliefs impact the categorization of ambiguous stimuli.

Author contribution statement

Abdolvahed Narmashiri; Fatemeh Akbari; Ahmad Sohrabi; Javad Hatami: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability

The datasets used during the current study are available from the corresponding author upon reasonable request.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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