Brain Activation in Interaction with Multi-modal Data Physicalization

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Physicalization of data is an emerging topic and an area of research that has a lot of potential. The ability to give data a physical shape has practical significance for explaining complex systems and making data accessible. In this research, a standard Brain-Computer Interface (BCI) experiment will be conducted to collect brain data while interacting with data physicalization. This is a within-subject design study that exposes the participant to multiple conditions by performing data exploration tasks. Furthermore, the brain signal of each participant was recorded through an EEG recording kit, and the results were pre-processed to remove noise, and the data was partitioned into four segments that isolate the different experiment conditions for a later comparison. Afterward, data was analyzed to show the brain activity of different frequency bands, and this is done by graph visualizations that plot the voltage potential difference of multiple electrode locations against time. These findings show that the alpha band is mostly active during the resting state. In contrast, during the other conditions, the interaction with the physicalization of the data provoked high levels of beta and gamma waves.

Additional Key Words and Phrases: Data physicalization, EEG, brain activity, cognition, Brain-Computer Interface (BCI), signal processing, Within-study design

1 Introduction

In recent years, data physicalization has emerged as a novel and increasingly important field of research, that aims to extend the human understanding of data by providing a tangible representation that users can interact with. Unlike traditional visualization, which relies primarily on digital screens and two-dimensional graphics, data physicalization encodes abstract data into easily perceivable and interpretable representations [6]. While research into data physicalization is new, the concept in itself is not. Physical models have been used for centuries, already 7000 years ago the Sumerians used clay tokens to quantify data long before script was invented [6]. Modern physicalizations are generally static, yet they can provide perceptual, cognitive, and communicative benefits that are not achievable with either paper or digital screens. For instance, data physicalization is widely used as an aid in educational methods and classrooms to teach basic mathematics and science [6].

Even though it is known that data physicalization has many benefits, there is a need for further exploration into how data can be physically represented and how the choices we make impact the perception and understanding of this data. According to (Jansen et al. 2015) there is currently a lack of empirical studies within the research agenda of the field of data physicalization and there remains a gap in research regarding multi-modal interactions. In this research, we are interested in finding out how the brain is activated when interacting with multi-modal data physicalization. The result may offer valuable insights into the designing and evaluating of multi-modal data physicalization. Yet, there hasn't been much research done in this field, thus the goal of this study is to address a timely question that has good potential in making methodological as well as theoretical contributions to this field.

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2 Research question

From the motivation of this study and the present gap in the research field, the following research question arises:

How is the brain activated when information is perceived multi-modally using a data physicalization?

To answer this research research question we need to conduct a scientific experiment that allows data collection of brain activity of different participants while interacting with the data physicalization. Participants will be given data exploration tasks that allow them to experience the different modalities of the system. Meanwhile, an EEG recording will take place to establish a data set, and times will be monitored throughout this experiment to ensure accurate analysis. In the second part of this research, pre-processing will take place through a specialized Python library that contains functions to pass the data set through. Furthermore, post-analysis will be conducted on the collected data, and results will be provided that give a visual representation of the brain activity. We are mainly interested in monitoring the frequency bands available to locate which section of the brain is activated during the data exploration tasks. These visuals will allow us to make a comparison between the brain's resting state and the state where different tasks are performed while interacting with the data physicalization.

3 Related work

3.1 Data physicalization

According to (Jansen et al. 2015), data physicalization (or simply physicalization) is a physical artifact that can be manipulated by human hands and whose geometry or material properties encode data. This is an approach to make the abstract data more approachable. They also argue that instead of studying individual sensory (e.g., visual or haptic) variables, it is necessary to study how they can be combined in physicalizations, so-called physical variables, or modalities[6]. These variables are not intrinsically haptic or visual; instead, they are typically perceived through active exploration involving movements of the hands, head, and body [6]. Usually, humans have evolved a highly complex sensor motor system that allows them to efficiently extract information from the physical world, therefore a major benefit of data physicalization is that it exploits our active perceptions skills [6]. Current studies measuring brain activity using a multi-modal or on-screen visualization, have provided us with insights into which areas of the brain are simulated [2]. For example, in the research conducted by (Ding et al., 2020), they investigated the User Experience during real-time smartphone usage using a multi-modal approach and analyzed the connection between brainwave signal data and the users' subjective experience[2]. Moreover, data physicalization can convey data inter-modally, and not only multi-modally. The difference is that in a multi-modal approach, multiple output devices address the senses separately, unlike the inter-modal approach which guarantees cohesive and realistic multi-sensory experience [6].

3.2 Recording brain activity

A medical imaging method called electroencephalography measures the electrical activity in the scalp that is produced by brain structures. The term electroencephalogram (EEG) refers to alternating electrical activity detected and recorded by metal electrodes and conductive substances on the scalp surface. [15]. EEG is the most commonly used method for brain wave measurement due to its simplicity and non-invasive nature, eliminating the need for surgery or implants [10, 12]. Nonetheless, the signals obtained are often weak and of low quality because they must traverse multiple tissue layers - including the meninges (dura mater, arachnoid, and pia mater), the skull, and the scalp - before reaching the electrodes [12]. Consequently, multiple electrodes are often required to achieve higher spatial resolution and a more accurate system [12].

To investigate cognitive or effective processes in response to stimuli, five spectral bands are commonly monitored: Delta (0.5–4 Hz), Theta (4–8 Hz), Alpha (8–13 Hz), Beta (13–30 Hz), and Gamma (30–50 Hz) [7, 13]. According to several studies [3, 5, 8, 9, 11], alpha and beta waves are the main indicators for evaluating the user experience when interacting with an interface such as a smartphone. According to their research, beta waves dropped when people were extremely focused and anxious, but alpha waves rose when people were more at ease or exposed to visually pleasing visuals [2].

4 Research Method

4.1 Experiment Design

4.1.1 *Goal of the experiment*

This experiment will be a standard BCI (Brain Computer Interaction) experiment without the use of any Artificial intelligence tools. The target of this experiment is to record the brain activity of different participants while interacting with multi-modal data physicalization. We are mainly interested in collecting data for later analysis on which part of the brain is activated when data is perceived multi-modally.

4.1.2 *Study design*

The experiment will be a within-subjects design, exposing participants to multiple conditions. This approach is chosen to account for individual differences, ensuring that the results reflect the specific brain areas activated by the conditions, rather than variability between participants. Additionally, every participant will be given 3 different sets of questions for each condition of the independent variable. By keeping these variables constant, it is guaranteed that apart from the independent variable, no other factors influence the dependent variables, allowing us to confidently attribute any observed effects to the modalities.

4.1.3 *Variables*

(1) **Independent variables:** As the study follows a within-subject design, there is only a single independent variable. This variable is the combination of modalities that each participant has to go through. This ensures that the results gathered from the evaluation reflect the effect of the modalities on the different dependent variables. In total there are three conditions for the independent variable:
  (a) Temperature
  (b) Temperature and Vibration
  (c) Temperature and Sound

(2) **Dependent variables**: Because participants experience multiple conditions of the independent variables, the effect the modalities have on the dependent variables can be analyzed easily. We list below the dependent variables that are present in our experiment.

Dependent Variable	Measuring technique
Accuracy	The number of correct questions given by the participants
Subjective confidence	After each question the user indicates how confident they are with their answer based on a scale from 1 to 5

4.1.4 *Procedure*

Since we are using an EEG tool to record brain activity, we will be experimenting with the data physicalization in a quiet room. Further below, we explain each step of the procedure of this experiment.

(1) This is the preparation stage of the experiment. First of all, the participants are invited to the computer science lab where the experiment will be conducted. Then the researcher will introduce the experiment and the general target of this research before starting with the EEG measurements. Before the beginning of the experiment, some personal information will be collected about the participants, such as age and gender. This process ensures that there is a level of personal communication between the researcher and the participant which causes the participant to relax and provides reliable data that can be later used for analysis. Then the EEG cap is put on and the researcher needs to ensure that the electrodes are placed perfectly to all the contact points on the scalp
(2) At the second stage of this experiment, EEG signals will be recorded under the first condition which is the resting state. Participants are required to sit down with their eyes open and with both feet on the ground for approximately 3 minutes. The participants mustn't shake their heads or move at all, because the wakefulness state will ensure accuracy when interpreting the EEG signals [14, 16]. Consequently, this method will be used to calibrate the EEG kit and the brain waves will be analyzed in rest state for validation.
(3) In this stage the EEG signals will be recorded during interaction with the data physicalization. The participant is going to perform a set of tasks that allow for data exploration. Those

tasks will be in the form of a data exploration questionnaire that consists of 4 questions that they should answer by interacting with the data physicalization. This step will be repeated 3 times to cover all the conditions of the experiment. Meanwhile, the researcher registers mouse clicks each time the participant provides an answer for the performed task.

4.1.5 *The data exploration tasks*

Before the data exploration tasks take place, the participant needs to sign a written consent form that outlines the goal of the study and the expectations of the participant. This step will be paired with the explanation of the experiment by the researcher including what tools will be used to collect data (In this case, the EEG kit). Participants would receive a short explanation of how to use the data physicalization and perform three to four tasks to get them familiarized with the system. Moreover, the target of these data exploration tasks is to let participants engage with the data physicalization while their brain activity is being recorded. Those tasks are designed to make the users think about the climate change data to make them understand the difference between the regions and the different indicators. The next step is to set up the EEG cap and start with recording brain waves. During this stage, participants engage with the data physicalization to respond to 3 sets of questions (representing each condition of the independent variable), each set has 4 questions regarding climate change and they can answer these questions by interacting with the interface. Since this is a within-subjects study, each set has unique questions that the participant has to go through, so each participant answers all three unique sets of questions that represent multiple conditions. In the appendix below you can find the sets of questions that the participants have been asked to answer while interacting with the data physicalization. Note that between each task question, a confidence question is asked to measure the confidence level. This measurement is based on a scale from 1 being extremely not confident to 5 being extremely confident. The question was phrased as follows: *From your previous answer, how confident do you feel in your answer?*

4.2 Apparatus

4.2.1 *Data physicalization*

The utilized data physicalization represents data related to climate change from 1960 up to 2090. Three distinct climate change indicators were used: air temperature, sea temperature, and land precipitation. Five globally distributed regions with significant differences were selected: Greenland, the North Sea, Antarctica, the Indonesian Sea, and the East Bering Sea. Furthermore, the setup consists of a laser-cut wooden box that serves as the base of the installation with five distinct components, each with its unique functionality: the indicator selector, the temperature modality, the sound and vibration modalities, and the Python program. All these components interact through the Python program running on the PC. When interacting with this interface, users can experience climate change with their own hands as they interact with the temperature and vibration modalities. Also, they can experience the sound modality through the use of headphones during interaction. This setup is relevant to our research as it will be used in our designed experiment to collect brain activity while participants interact with this data physicalization. The data collected will be facilitated by an EEG recording kit that will be worn during the experiment.

Furthermore, we briefly describe the functionality of each component of the setup:

1. Indicator selector: This is an RFID reader that operates by scanning RFID cards representing the 3 different climate change indicators.
2. Temperature modality: This component is responsible for updating the temperature. It uses a heat sink with a heating element placed on top to quickly dissipate heat, reducing the time to reach the desired temperature to 6 seconds.
3. Vibration modality: This part is tasked with updating the vibration based on the current category.
4. Sound modality: The installation uses 3 different sounds, each corresponding to a specific indicator:
   (a) Raindrops for land precipitation
   (b) Ocean waves for sea temperature
   (c) Wind chimes for air temperature

The data of this data physicalization represents historical emission records and projections from the Coupled Model Intercomparison Project Phase 6 (CMIP6) [17]. Data for each region was sourced from the NOAA Physical Sciences Laboratory [17] using three distinct Shared Socioeconomic Pathways (SSPs), representing various climate scenarios of socioeconomic changes up to 2100. The installation design requires categorizing all datasets into three groups: low, medium, and high [17]. The table below displays the data ranges for each category and indicator. The values for each region were mapped to one of the three categories [1].

Category	Air temp	Sea temp	Precipitation (mm/month)
Low	-1.4 to 8.5	-0.8 to 5.4	46.6 to 59.6
Medium	8.6 to 20	5.5 to 12.9	59.7 to 98.4
High	20.1 to 31	13 to 31.8	98.5 to 217.8

4.2.2 *EEG recording*

In this study, the Unicorn Suit Black EEG kit will be employed to capture brain signals. This kit consists of an electrode cap, an amplifier, and a software tool for live visualization and recording of brain signals. The electrodes on the cap are arranged according to the 10-20 system and have 8 channels (Fz, C3, Cz, C4, Pz, O1, Oz, O2). The mastoid bone areas of the scalp (located behind the ears) will be identified, and the cap will be fitted using eight electrodes to gather participants' brain signals. In this experiment, one reference electrode (R) and one ground electrode (L) will be attached to both sides of the mastoid bones. To further validate the accuracy of the kit, participants will be instructed to blink their eyes to confirm the EOG signal artifact and to clench their teeth to confirm the EMG signal artifact.

4.3 Participants

As mentioned before, the goal of this experiment is to collect data and the participants who have no experience in using the data physicalization were recruited. Also, no gender differences were made throughout this study. However, to keep the experiment consistent, we have decided to recruit a total of 4 participants, two male plus two female, with ages ranging from 21 to 26. These participants have been recruited from the university and they were all briefed before the experience about the procedure and what is expected from them. Finally, every participant signed a written consent form and no compensations were in order. Most importantly, the data collected during this experiment will not be used or stored after the period of this study.

4.4 Data analysis

4.4.1 *EEG signals pre-processing*

With the presence of different types of non-physiologic and physiological artifacts, the EEG signals can contain a lot of noise, that sometimes disrupts the the essential features of the EEG. Some well-known artifacts disturbing the EEG signal are eye blinks, muscle activity, sweating, etc. [14]. Hence, removing and de-noising the EEG signal artifacts has been done to further re-format the raw data to be usable by the MNE python [4]. The objective here is to visualize the brain activity of multiple band waves in resting mode and during a moment of high mental load, for example, while interacting with the data physicalization. To visualize this, the EEG signals will be segmented into epochs of rest, task 1 (temperature), task 2 (temperature and vibration), and task 3 (temperature and sound). The EEG data were down-sampled to a sample rate of 250 Hz.

4.4.2 *EEG feature extraction*

After pre-processing we first want to correctly segment the data into the conditions we classified above. To isolate the conditions the participants experienced during the experiment, we tracked the intervals between each set of tasks. We utilized the crop function from MNE, which partitions the recorded data by specifying a start and end time for each participant's interaction. After the segmentation process, we verify this method by plotting the segments separately to ensure correctness. Additionally, we created a marker on the data that will allow us to split it based on the events that occurred in the recordings. Here we created an event object of a fixed length that spans through the whole raw data of a segment. By doing that, we can create epochs that are defined by the marked events in the data. We take the average of all those epochs to create an evoked object which we will be able to plot as will be explained in the result section below.

5 Results

5.1 EEG results

Under the segmentation of each condition of the experiment, and with the time monitoring taken into consideration, we were able to plot the brain activity of each of these conditions by having the signals of each scalp location on the y-axis and time on the x-axis and we plot brain activity based on the different brain bands available. In the appendix below A.3 multiple graphs are listed that showcase the brain activity of each participant based on the following brain bands (Alpha, Beta, Gamma, Delta, Theta). We mainly study the alpha, beta, and gamma signals but we added the delta theta waves for the sake of completeness since they don't say much about the interactions. Additionally, the delta and theta waves are easy to confuse with the artifact signals which are just considered noise in our case. Furthermore, with the help of the monitored time between each condition, we were able to approximate when each task (of the task set) took place and marked it in the graphs below. There are two different types of peaks (or fluctuations in the graph), the small blocks that are surrounded by two green lines, those represent an activity that is not related to interacting with the data physicalization such as writing answers, etc., and the areas marked in red which are potentially identified as when the participants interact with the data physicalization.

In the following three subsections, we showcase those results and explain the difference between each condition.

5.1.1 *EEG results during the rest condition*

In figures 3, 4, 5, 6, 7 we can observe the brain activity within the initial 3 minutes of the experiment, referred to as the resting state. At the beginning of the experiment, the participants were instructed to sit still for about 3 minutes to create a base case for our comparison. In this part of the results, not a lot of changes were noticeable between the participants, and the brain activity of each participant was comparable to that of the other with high alpha band activity from the location of the Pz scalp, which is what we would expect from the resting state. It is important to mention that there was also a lot of beta activity for a couple of the participants; however, this might be caused by the distractions that the participants have experienced during the resting stage, such as a person walking by the room or the fact that they just couldn't sit still.

5.1.2 *Under the Temperature Condition*

In figures 8, 9, 10, 11, 12 we can see the various brain bands under the temperature condition. As expected, the alpha waves, don't seem to be affected much by this stage of the experiment. From 8 we can recognize some differences in peeks, but we can't see a clear separation between the tasks performed. However, when we move to 9 we can immediately see the difference in brain activity much clearer, which indicates a high beta-band activity during the interaction. Specifically in Figure 9b, we can create a separation of the tasks performed by Participant 2 under the temperature condition (those tasks are numbered accordingly). As for the gamma waves, we can distinguish between tasks but not as strong as the beta waves. Gamma is mostly activated when there is a perception of both visual and auditory stimuli [16], which is better seen in the last experimental condition that will be mentioned below.

5.1.3 *Under the Temperature and Vibration Condition*

In figures 13, 14, 15, 16, 17 the various brain bands under the temperature and vibration condition are shown. Similarly, the alpha waves in Figure 13 are not conclusive to show any activity during the task performance. During this phase of the experiment, the participants interact with the vibration modality as well as the temperature one.

As we can see from the data, in Figure 14 and for most participants, it is not very visible at which point of time the interaction with the data physicalization is taking place. For participant 4 we can derive the activities that are mostly not related to the interaction with the data physicalization which are highlighted in the green sections. It was observed during the experiment that the vibration modality generated a significant amount of sound while it was activated, due to the rotation of the vibration motor attached to where the participant put their left hand. Here, the results are not entirely clear on which wave is mostly activated. However, we can see that the gamma and the beta waves were mostly activated, because of the presence of auditory stimulus. As shown in figure 15, we can see a relatively clear separation of the interactions with the data physicalization highlighted in red.

5.1.4 *Under the Temperature and Sound Condition*

In Figures 18, 19, 20, 21, 22 the various brain bands under the temperature and sound condition are shown. Here we can see only a beta and a gamma activation. From Figures 19d and 20c we can see the different tasks each participant has performed. The sound modality here was consistent and concentrated through the headphones the participant was wearing. As expected, the gamma waves in this condition were slightly more activated and easier to read than the beta waves, which again reflects the effect of the sound modality on brain activity.

5.2 Accuracy

Here, we define accuracy as the number of correct answers per condition. This reflects well on how the combination of modalities works and how data is perceived by the participants. In Figure 1, we show the sum of all the tasks performed, there are 12 tasks in total per participant. The temperature holds the highest accuracy with 16 correct answers through all 4 participants. While Temperature and Vibration hold the lowest accuracy with 3 wrong answers by different participants. The results can be seen below.

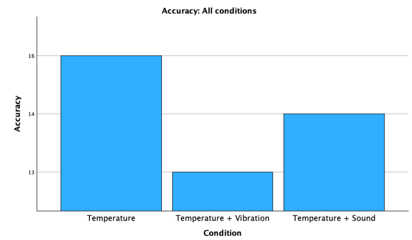

Fig. 1. Accuracy of all conditions

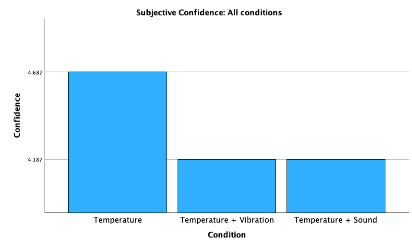

Fig. 2. Confidence of all conditions

5.3 Subjective Confidence

Subjective confidence was assessed by asking participants about their confidence level in their responses after each question, using a scale from Extremely not confident to Extremely confident. The average confidence for each condition was then calculated. On average, the temperature condition got a confidence average of 4.687 which is considered to be the condition where participants were the most confident of their answers. Conversely, when sound is involved, participants tend to lose some confidence in giving the correct answers, the average was 4.187. Figure 2, illustrates the bar graph representing subjective confidence across all conditions.

6 Discussion

6.1 Answering the Research question

In this part, we address the research question in section 2 answered by conducting the experiment mentioned in section 4. The findings of the experiment provided us with the needed insights to locate brain activity. The alpha, beta, and gamma waves were most active during interactions with the data physicalization. Additionally, the graphs indicated the precise regions on the scalp where brain activity occurred, leading us to determine that the central region of the brain, particularly around the electrodes Fz, C3, Cz, and C4, showed the highest levels of brain activity. Therefore, it is clear that the most activated area of the brain when information is perceived multimodally, is mostly around the Parietal lobe and a part of the Frontal lobe which correspond to sensory perception, cognition, and motor control.

6.2 Shortcomings

(1) *The experimental setup was not ideal:* The data physicalization used in this experiment is rather large and not easily portable. This imposed restrictions on the choice of room for experimenting, and ultimately, we opted for the computer science lab because everything was already arranged there. However, the presence of other people working in the lab introduced some noise, creating a less-than-ideal testing environment. Additionally, the Unicorn Hybrid Black kit software is available only for the Windows operating system, which posed challenges during the experiment setup. Consequently, a Windows Desktop had to be utilized instead of a laptop, further restricting the control over the settings. These constraints are evident in the Resting state data shown in figure 3.

(2) *Data collection happened twice:* When four participants were recruited for the experiment, they were invited to the experiment location, and their brain data was recorded. However, times were not monitored between each condition that the participants went through. This resulted in not knowing precisely how to segment the data into the conditions we wanted to test, which made our dataset unusable. To solve this issue, four new participants were invited and the experiment was repeated with all conditions being monitored.

(3) *No time recording was made between each task:* When the data collection happened the second time, the times between each task were not monitored. This meant that after isolating the conditions, we could not pinpoint exactly whether the participant was interacting with the data physicalization or writing down their answer after each task. However, after looking at the data, we managed to make an approximation at which point in time the participant was busy with the data physicalization.
(4) *The time constraint:* Due to the restricted time frame allocated for this research, many design choices, particularly concerning the analysis of the collected data, had to be made. Understanding and working with the MNE library was particularly difficult due to its complexity, which limited us from using other and potentially more effective data analysis methods that might have offered greater advantages for this study.

7 Future Works

Due to the exploratory nature of this paper, we did not present highly conclusive results because of the aforementioned limitations. Nevertheless, this study has provided significant insights by presenting some open questions. This section will list the suggestions and the open questions during this research.

(1) *Choose a suitable experimental setting:* To enhance future research based on this study, it is essential to adjust the experimental setup for improved consistency and precision. This entails selecting a different room for the experiment where noise is limited to the minimum.
(2) *Increase the number of participants:* Four participants were invited to participate in this study. However, it would be of significant statistical importance if more participants were available to partake in a bigger-scale experiment than the one conducted in this research.
(3) *Dive deeper into the MNE-python library:* This is a comprehensive Python library that supports extensive brain data analysis. A significant portion of the research time was devoted to understanding the tools available to achieve our objectives. Therefore, it is crucial to invest adequate time in understanding the library to guarantee precise and reliable results.
(4) *How does gender affect the results of this study?* Exploring this open-ended question could uncover how gender influences the perception of data in a multi-modal context. This study included two male and two female participants, and no significant differences were observed between them in the results. However, in experimental settings specifically designed to examine gender differences, potential findings might emerge.

8 Conclusion

The lack of empirical studies within the data physicalization research field has allowed us to investigate more into how the brain reacts to information that is perceived multi-modally. In this research, we have conducted a scientific experiment that facilitated data collection of various participants to set up a dataset for further analysis of brain waves while interacting with the data physicalization. Data analysis was used on the available data to give a visual representation for a comparison between the different experimental conditions. We discovered the interaction with a data physicalization evokes a strong activity of Beta and Gamma signals, but weaker Alpha, Delta, and theta. The results revealed that the middle and front part of the brain is activated. Our study can help designers understand the way data physicalization works in relation to the human brain, and this work can be further used to fill the gap of research in the data physicalization field

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A Appendix

A.1 Data exploration tasks

A.1.1 Temperature modality

Rank question 1: *Rank the Indonesian Sea, East Bering Sea, and Greenland in order from low to high based on sea temperature in the year 2090.*
Rank question 2: *Rank the Indonesian sea, North sea, and Antartica in order from low to high based on land precipitation in the year 2050.*
Compare question 1: *Which regions (North Sea and East Bering Sea) have the higher air temperature in 2050?*
Compare question 2: *Which of the following regions (Antartica and Greenland) has the higher land precipitation in 2060?*

A.1.2 Temperature and vibration modality

Rank question 1: *Rank the Indonesian Sea, North Sea, and Greenland in order from low to high based on sea temperature in the year 2000.*
Rank question 2: *Rank the North Sea, East Bering Sea, and Greenland in order from low to high based on air temperature in the year 1990.*
Compare question 1: *Which regions (Antartica, Greenland) have the higher land percipitation in 1960?*
Compare question 2: *Which regions (Indonesian Sea, Antartica) have the higher air temperature in 2040?*

A.1.3 Temperature and sound modality

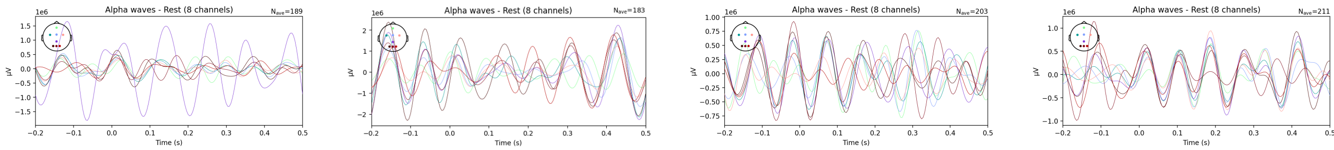
Rank question 1: *Rank the Indonesian Sea, Antartica, and Greenland in order from low to high based on land precipitation in the year 1980.*
Rank question 2: *Rank the Indonesian Sea, East Bering Sea, and Antartica in order from low to high based on air temperature in the year 2090.*
Compare question 1: *Which regions (East Bering Sea, Antartica) have the higher sea temperature in 2010?*
Compare question 2: *Which regions (Indonesian Sea, East Bering Sea) have the higher sea temperature in 2040?*

A.2 The Use of AI tools

During the preparation of this work, Hayel Akel used chatGPT, Quillbot, Grammarly, and TextGPT to paraphrase several pieces of text and to generate code to work with MNE-python. After using this tool/service, Hayel Akel reviewed and edited the content as needed and took full responsibility for the content of the work.

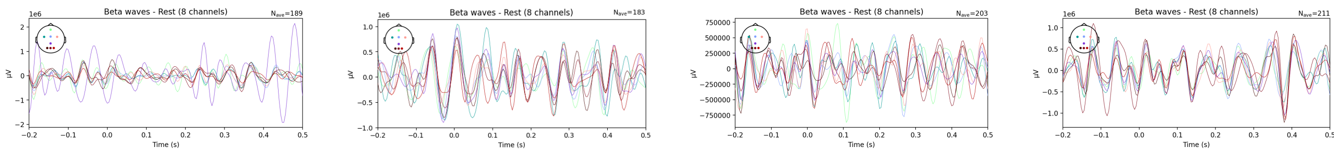
A.3 The graph results

The results of the experiment performed for data collection are shown on the next page of this paper. For the completeness of this research, we have added all the brain waves that can be analyzed and we attach that into the appendix. The reason here is that we have 80 sub-graphs that represent the various participants' mental states during the experiment



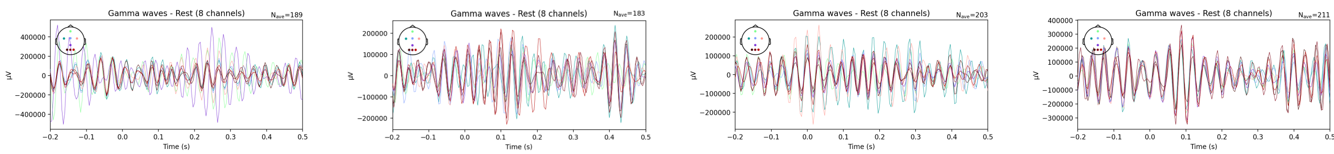
(a) Participant 1 (b) Participant 2 (c) Participant 3 (d) Participant 4

Fig. 3. **The Alpha-band under the Rest condition of 4 participants**



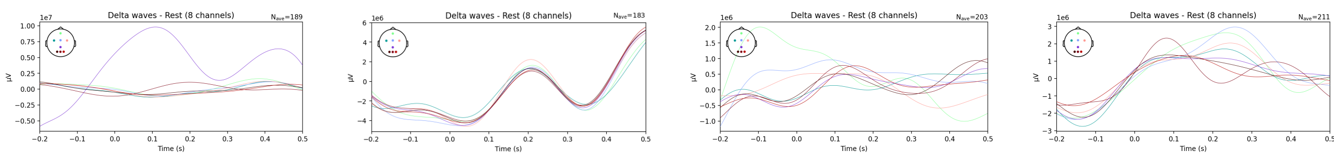
(a) Participant 1 (b) Participant 2 (c) Participant 3 (d) Participant 4

Fig. 4. **The Beta-band under the Rest condition of 4 participants**



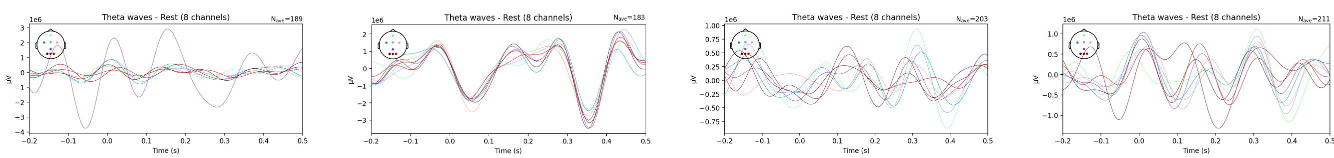
(a) Participant 1 (b) Participant 2 (c) Participant 3 (d) Participant 4

Fig. 5. **The Gamma-band under the Rest condition of 4 participants**



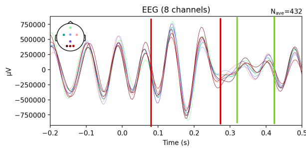
(a) Participant 1 (b) Participant 2 (c) Participant 3 (d) Participant 4

Fig. 6. **The Delta-band under the Rest condition of 4 participants**

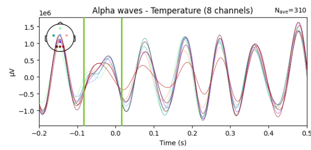


(a) Participant 1 (b) Participant 2 (c) Participant 3 (d) Participant 4

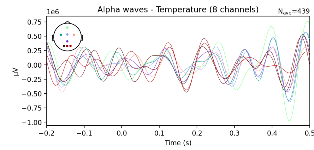
Fig. 7. **The Theta-band under the Rest condition of 4 participants**



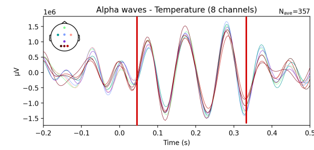
(a) Participant 1



(b) Participant 2

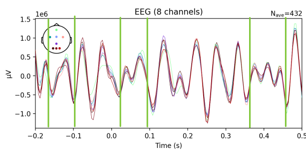


(c) Participant 3

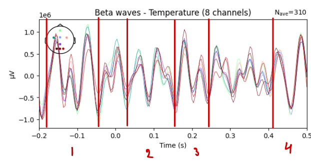


(d) Participant 4

Fig. 8. **The Alpha-band under the Temperature condition of 4 participants**



(a) Participant 1



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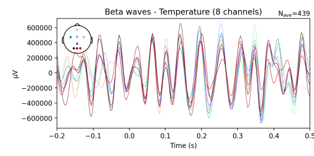
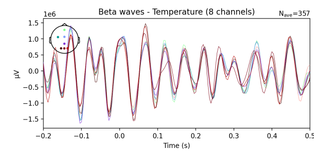
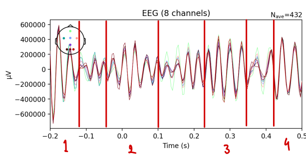


(c) Participant 3

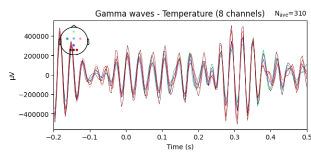


(d) Participant 4

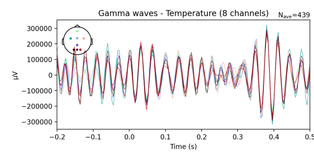
Fig. 9. **The Beta-band under the Temperature condition of 4 participants**



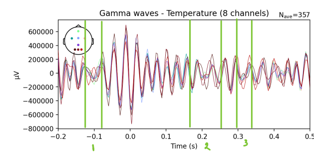
(a) Participant 1



(b) Participant 2

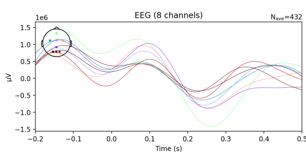


(c) Participant 3

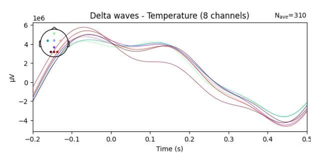


(d) Participant 4

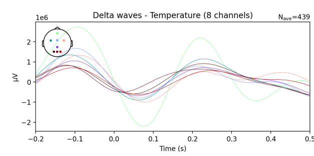
Fig. 10. **The Gamma-band under the Temperature condition of 4 participants**



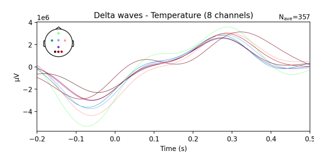
(a) Participant 1



(b) Participant 2

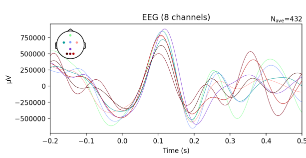


(c) Participant 3

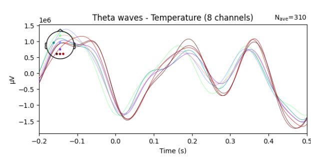


(d) Participant 4

Fig. 11. **The delta-band under the Temperature condition of 4 participants**



(a) Participant 1



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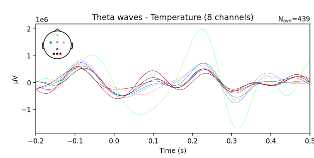
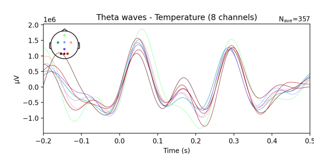
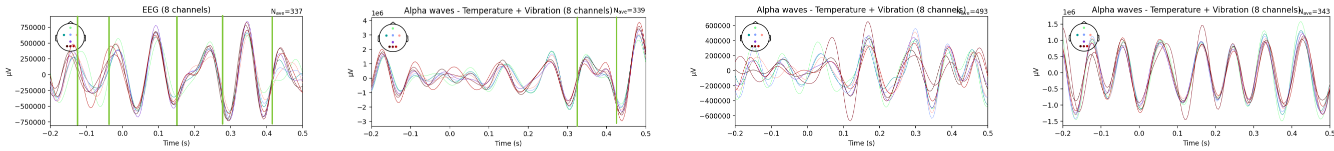


(c) Participant 3



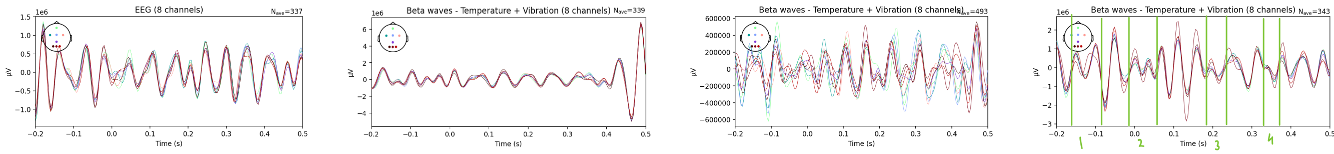
(d) Participant 4

Fig. 12. **The Theta-band under the Temperature condition of 4 participants**



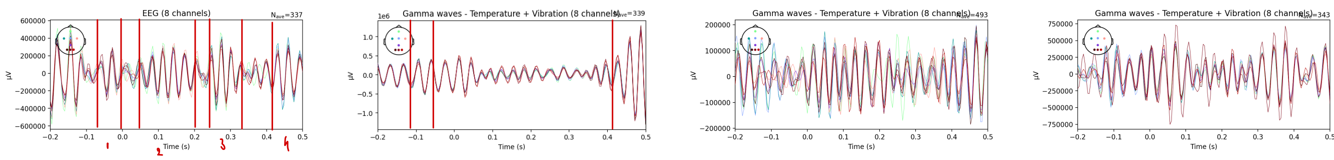
(a) Participant 1 (b) Participant 2 (c) Participant 3 (d) Participant 4

Fig. 13. **The Alpha-band under the Temperature and Vibration condition of 4 participants**



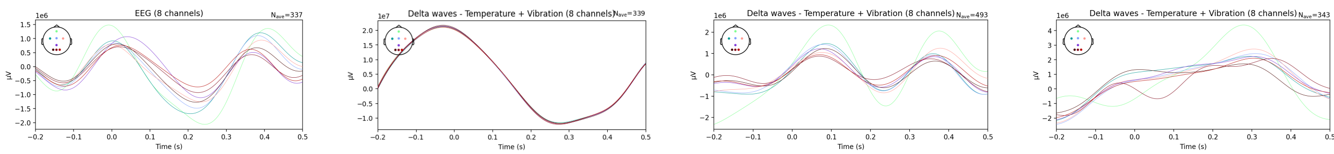
(a) Participant 1 (b) Participant 2 (c) Participant 3 (d) Participant 4

Fig. 14. **The Beta-band under the Temperature and Vibration condition of 4 participants**



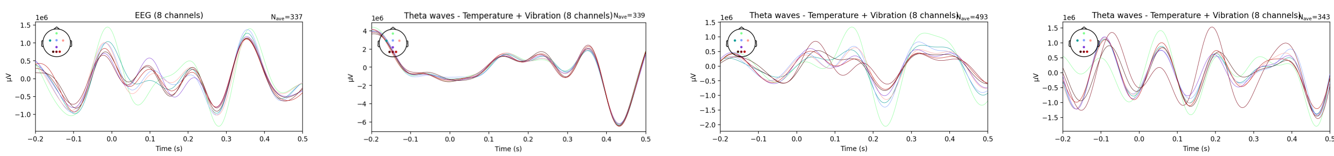
(a) Participant 1 (b) Participant 2 (c) Participant 3 (d) Participant 4

Fig. 15. **The Gamma-band under the Temperature and Vibration condition of 4 participants**



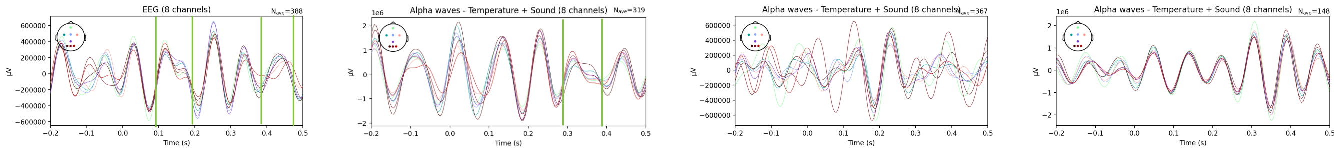
(a) Participant 1 (b) Participant 2 (c) Participant 3 (d) Participant 4

Fig. 16. **The Delta-band under the Temperature and Vibration condition of 4 participants**



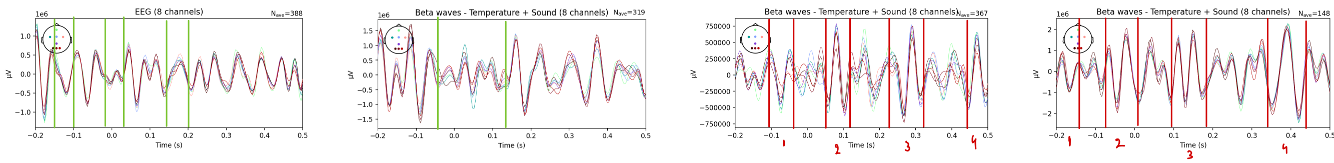
(a) Participant 1 (b) Participant 2 (c) Participant 3 (d) Participant 4

Fig. 17. **The Theta-band under the Temperature and Vibration condition of 4 participants**



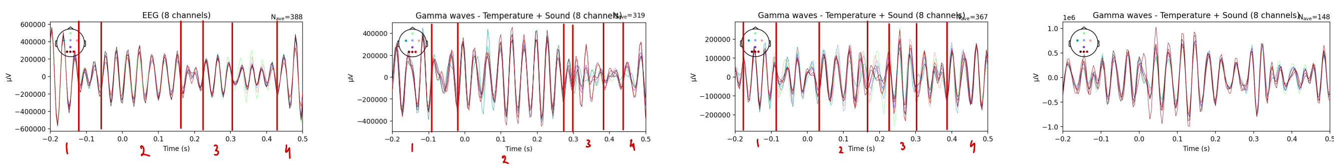
(a) Participant 1 (b) Participant 2 (c) Participant 3 (d) Participant 4

Fig. 18. **The Alpha-band under the Temperature and Sound condition of 4 participants**



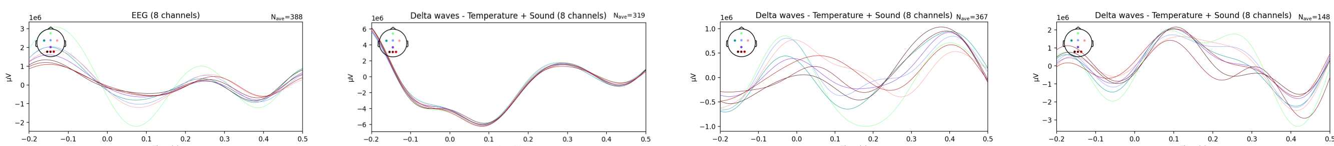
(a) Participant 1 (b) Participant 2 (c) Participant 3 (d) Participant 4

Fig. 19. **The Beta-band under the Temperature and Sound condition of 4 participants**



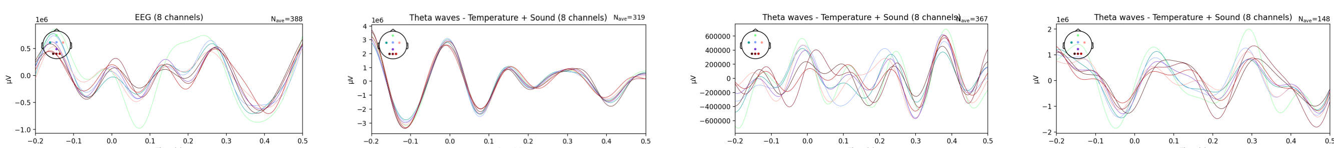
(a) Participant 1 (b) Participant 2 (c) Participant 3 (d) Participant 4

Fig. 20. **The Gamma-band under the Temperature and Sound condition of 4 participants**



(a) Participant 1 (b) Participant 2 (c) Participant 3 (d) Participant 4

Fig. 21. **The Delta-band under the Temperature and Vibration condition of 4 participants**



(a) Participant 1 (b) Participant 2 (c) Participant 3 (d) Participant 4

Fig. 22. **The Theta-band under the Temperature and Sound condition of 4 participants**