Title
Curiosity, Frontal EEG Asymmetry, and Learning

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Curiosity, Frontal EEG Asymmetry, and Learning

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Abstract

Curiosity plays a critical role in our daily behaviors and interactions. Yet, very little is known about its psychological and neural underpinnings. By reframing curiosity as the motivation to obtain reward – where the reward is information –, and using frequency-based metrics of frontal brain lateralization, we aimed to investigate the neural correlates of curiosity in the frontal cortex and its effects on subsequent learning. Twenty-one undergraduate students participated in this two-day study by answering 35 general interest trivia questions, while EEG data was being recorded, also indicating their curiosity towards the question. One week later, participants were asked to write down the correct answers to each one of the questions. The results of this study suggested that frontal brain asymmetry (FBA) predicts memory recall, but is not directly correlated with self-reported curiosity. Study limitations and future directions are discussed.

Keywords: curiosity; EEG; frontal brain asymmetry; learning; memory

Introduction

Curiosity plays a critical role in many of our daily pursuits, actions, and interactions. It drives learning and promotes discovery, increasing our understanding of the world. Albert Einstein once said, "I have no special talents. I am only passionately curious" (Hoffmann, 1972, p. 7). Yet for something that drives much of our daily behavior and knowledge, very little is known about its psychological and neural underpinnings. Lowenstein (1994) was the first one to propose an information gap theory, suggesting that curiosity arises from a perceived information gap, that is, the disparity between what one knows and what one wants to know. According to him, curiosity seeks a subjective value: information.

Innovating from this theory, Marvin & Shohamy (2016) reframed curiosity as the motivation to obtain reward, where the reward is information. This information-as-reward framework was supported by the fact that curiosity shares behavioral and neurobiological properties with other reward-motivated behaviors, as the same dopaminergic neurons that signal changes in the value of the reward also code changes in the value of information (Hare, O'Doherty, Camerer, Schultz, & Rangel, 2008; Kang et al., 2009). Furthermore, high-curiosity information is associated with activation in brain areas known to respond to reward, which includes the caudate and the nucleus accumbens (Gruber, Gelman, & Ranganath, 2014; Kang et al., 2009), and there is a strong link between how valuable information is and the likelihood of remembering it (Gruber et al., 2014; Kang et al., 2009; Mullaney, Carpenter, Grothehuis, & Burianek, 2014). Research has also found that learning is driven not only by the absolute value of given information but also by an information prediction error (IPE), which is the difference between the reward expected and the reward received (Daw & Doya, 2006; Schultz, 2006; Marvin & Shohamy, 2016).

Although these studies demonstrate that curiosity conforms to basic characteristics of reward-motivated behavior, they leave open critical questions related to the extent to which this analogy is valid at a deeper level. The greatest problem is that almost all current studies that investigate curiosity rely primarily on self-reports as a way to measure it, which, despite being convenient and affordable, is knowingly not the most reliable technique currently available. This is due mainly to the lack of a well-known, comprehensive, and more credible method to investigate and measure curiosity.

Over the last decades, however, neuroscience research has developed significantly, and analyses of EEG data have become much more advanced. One of the more sophisticated frequency-based metrics is frontal EEG asymmetry, or frontal brain asymmetry (FBA). This index is commonly used as a tool to measure engagement and motivation, typically using alpha power (8 – 13 Hz) in electrodes over frontal cortical regions (channels F3 and F4). Previous studies have consistently found that greater activity in the left (F3) versus the right (F4) frontal cortex indicates positive feelings, higher engagement, and motivation (Davidson, 2004; Harmon-Jones & Gable, 2017). Evidence suggests that frontal lateralization can, in fact, be used to analyze people's engagement to media advertisements, market products, and services (Vecchiato et al., 2011; Yilmaz et al., 2014). Furthermore, research findings confirm the idea that frontal brain asymmetry modulates the probability to engage in reward-motivated behavior (Pizzagalli, Sherwood, Henriques, & Davison, 2005; Schmid, Hackel, Jasperse, & Amodio, 2017).

Therefore, our study aimed to expand from previous investigations on both curiosity and frontal brain asymmetry. By using the same information-as-reward approach, and reframing curiosity as the motivation to obtain reward – where reward is information –, we wanted to investigate if the same frameworks and methods currently used to study engagement and motivation can be used to measure curiosity in a more reliable way, serving as an alternative to the current self-reported measures. If this held true, we expected to see higher activation in the left frontal cortex – a greater frontal brain asymmetry – when people were exposed to high-curiosity information. We would also be able to correlate higher FBA scores to a higher likelihood of remembering the information. Hence, we aimed to investigate if frontal EEG alpha left asymmetry is (1) in any way related to self-reported curiosity and (2) a stronger predictor of subsequent learning. Our study may provide an initial framework for future studies on curiosity, as well as help to shed light on the functional significance of frontal EEG asymmetry on curiosity, learning, and other reward-motivated behaviors.

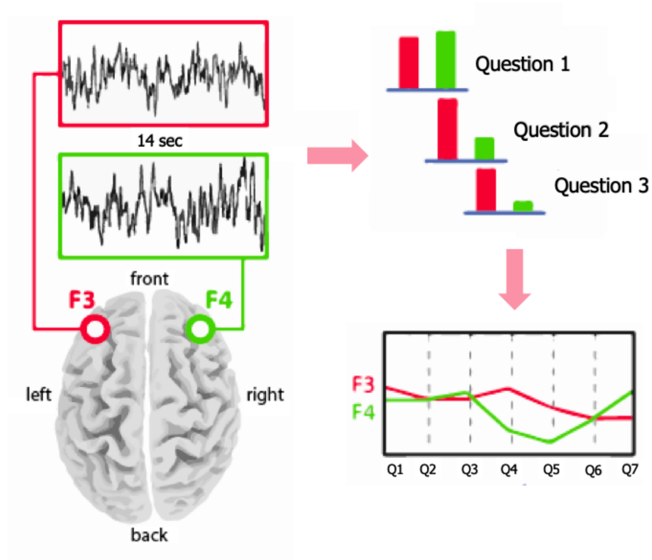

Figure 1: Illustration of EEG data collection. Raw EEG data was extracted from regions F3 and F4 (10/20 System Positioning) during the 14-second period in which each question was presented. The Fast Fourier Transform algorithm (FFT) was used to calculate the alpha power from each raw signal.

Methods

Participants

21 undergraduate students (mean age = 18.8 ± 1.1 year; 12 female, 9 male) at a college of liberal arts in the greater New York City area participated in this two-day study for partial course credit.

Materials & Equipment

Brain electrical data from this experiment was collected using electroencephalography (EEG) equipment, iWorx IX EEG 10-20 (iWorx Systems, Dover, NH) culled from two scalp sites (F3 and F4). The questions were presented on Apple Macintosh computers, using Qualtrics (2013) and the QuickTime Player (Cupertino, CA) to present stimuli and collect responses. The analysis of the EEG data was done on LabScribe Software, and all subsequent statistical analyses were done on R (R Core Team, 2013).

Procedure

The first session was about 45 minutes long, and the second one (a week later) was about 15 minutes long. On the first session, after providing written informed consent and answering a quick demographic questionnaire (which included age, gender, race and/or ethnicity, and handedness), participants were prepared for EEG recording. Before the primary task, two electrodes were placed on the participant's scalp (regions F3 and F4, 10/20 System Positioning; see Figure 1), and two minutes of EEG baseline was recorded. The experiment was a within-subjects design, where all participants were presented with a set of 35 general interest trivia questions culled from Internet sources (e.g., "What is the capital of Brazil?). Each question was presented on the laptop screen for 14 seconds. Participants were instructed to, after reading each question, type the answer down, and indicate their curiosity about the correct answer and their confidence in their guess. Then the question was presented again, followed by the correct answer (Kang et al., 2009). The same procedure was repeated for each and all of the 35 trivia questions, and the order of the questions was the same for all participants. EEG data was recorded for the entirety of the experiment. All participants were expected to come for a follow-up session one week later, although they were not aware of the purpose of the second session. For this session, the same 35 questions from the first day were presented and participants were asked to write down the answer to each one of them.

EEG Data Analysis

Alpha frequency band power was calculated by extracting frequency domain features from both left and right raw EEG signals (channels F3 and F4, respectively; see Figure 1). Since each question was presented for 14 seconds, we extracted the first seven 2-second epochs from each segment, and averaged them. The frequency domain analysis was performed using the Fast Fourier Transform (FFT) algorithm (with a frequency resolution of 1 Hz). The power spectra were reduced to the alpha frequency band, defined as between 8–13 Hz.

The frontal brain asymmetry index was calculated by dividing the alpha power values from the F4 (right) electrode by the values from the F3 (left) electrode. The results were computed using a natural log transformation to normalize the data as frequency power values tend to be severely skewed. This is illustrated by the following formula:

$$FBA\ Index\ = ln\left(\frac{F4\ right\ \alpha\ power}{F3\ left\ \alpha\ power}\right)$$

Since alpha power is inversely related to brain activity, positive asymmetry scores represented relatively greater alpha (less activity) over right than left hemispheres (Coan & Allen, 2004).

Data Preprocessing

The quality of the signal received from each electrode was evaluated during the entire EEG recording in order to make them both comparable and to avoid the influence of artifacts on the analysis. Offline visual artifact rejection was used to remove eye blinks, head movements, muscle activity, and other noise from the data. A subsequent round of artifact rejection was also conducted in which single trials containing voltage deviations of over 50 µV from normal baseline were manually rejected. Therefore, only artifact-free data from electrodes F3 and F4 were extracted and used in the analysis.

In addition to the EEG signal filtering, we also excluded trials based on whether or not the participant already knew the answers to the presented trivia, such that questions that were correctly answered by the participants during session one were not included in the EEG analysis. Therefore, our preprocessing filter yielded a total of 519 trials (332 correctly recalled, 187 not correctly recalled) across all 21 participants of this study.

Results

Self-Reported Curiosity and Frontal Brain Asymmetry

A correlational approach was used to assess links between reported curiosity and frontal brain asymmetry. Pearson's correlation coefficient indicated no statistically significant correlation between self-reported curiosity and FBA, neither for correctly remembered answers, $r(N = 21) = -.008$, $p = .486$, nor for incorrectly remembered answers, $r(N = 21) = -.290$, $p = .101$. Therefore, reported curiosity values were not linked to higher asymmetry values, on average (see Figure 2).

Frontal Brain Asymmetry and Learning

Participants on average remembered 62.1% of the answers correctly (range: 30.2% – 82.7%). A paired-samples t-test was conducted to compare FBA index, self-reported curiosity, and confidence level for both correctly remembered and incorrectly remembered answers (see Table 1). For confidence scores, there was a significant difference between incorrect ($M = 2.14$, $SD = 1.05$) and correct ($M = 2.69$, $SD = 1.17$) answers; $t(20) = 2.97$, $p = .008$. For curiosity scores, on the other hand, there were no statistically significant differences between incorrect ($M = 6.29$, $SD = 1.83$) and correct ($M = 6.63$, $SD = 1.43$) answers; $t(20) = 1.17$, $p = .254$.

Figure 2: Scatterplot of self-reported curiosity and FBA. Each participant is represented by two dots, one orange and one green. Pearson's correlation coefficient indicated no statistically significant correlation between self-reported curiosity and FBA for neither correct nor incorrect answers (p=.486, p = .101).

For frontal brain asymmetry scores, the difference for incorrect ($M = -0.24$, $SD = 0.30$) and correct ($M = 0.40$, $SD = 0.17$) answers was statistically significant; $t(20) = 7.20$, $p < .001$. Specifically, participants' recall was better for trials in which they had higher asymmetry scores than those in which they had lower asymmetry scores (see Figure 3). These results suggest that FBA is linked to whether or not an individual remembered the information from the trivia questions correctly.

Discussion

This experiment investigated if frontal EEG alpha left asymmetry was (1) in any way related to self-reported curiosity and (2) a better predictor of subsequent learning. By using the information-as-reward approach, and after reframing curiosity as the motivation to obtain reward – where reward is information –, we investigated if the same methods currently used to study engagement and motivation can be used to measure curiosity in a more reliable way, serving as an alternative to the current self-reported measures. If asymmetry measurements in EEG recording were indeed a more reliable way to measure curiosity, we expected to see higher neural activity in the left frontal cortex – a greater frontal brain asymmetry – when people were exposed to high-curiosity information. This asymmetry index, then, would be a better predictor of whether or not the participant would remember the correct answer – if compared to the participant's self-reported curiosity levels.

The data indeed showed that there was a relationship between frontal brain asymmetry and subsequent learning:

Table 1

Descriptive Statistics and Paired t-test Results for Confidence, Curiosity, and FBA Index

Measure	Not Correctly Remembered M	Not Correctly Remembered SD	Correctly Remembered M	Correctly Remembered SD	n	95% CI for Mean Difference	t	df
Confidence	2.14	1.05	2.69	1.17	21	0.16, 0.92	2.97*	20
Curiosity	6.29	1.83	6.63	1.43	21	-0.27, 0.95	1.17	20
FBA Index	-0.24	0.30	0.40	0.17	21	0.46, 0.83	7.20*	20

* p < .05.

Table 1: Descriptive statistics and paired t-test results for confidence, curiosity, and FBA index. There are statistically significant differences, at the .05 significance level, in the correctness scores for confidence and frontal brain asymmetry, but not for curiosity. Results show that both confidence levels and FBA scores were higher for correctly remembered answers than for incorrectly remembered answers.

participants were significantly more likely to remember the correct answers for trials in which they had higher FBA scores (see Figure 3). Self-reported curiosity, on the other hand, was not associated with subsequent learning. For the second half of our research question, we utilized a bivariate correlational analysis to investigate whether frontal brain asymmetry and reported curiosity were linked to each other. We found that self-reported curiosity and FBA were not statistically significantly correlated, meaning that higher values of left hemisphere activation were not linked to higher self-given scores of curiosity (see Figure 2).

Because our study did not find any link between self-reported curiosity and frontal brain asymmetry, it is not

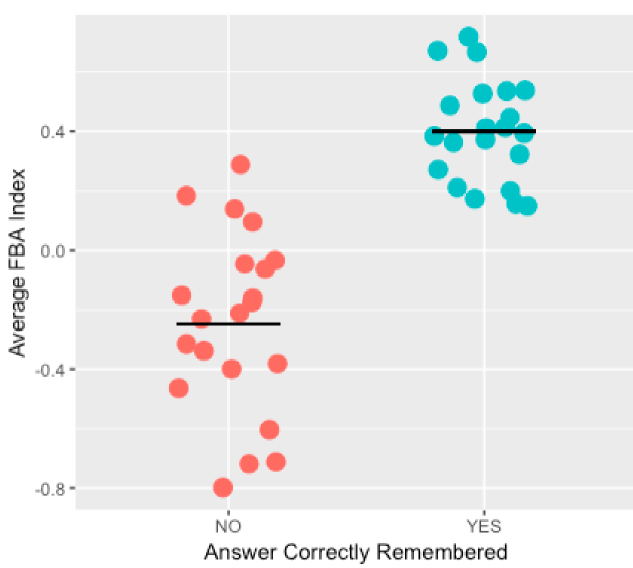

Figure 3: Plot of the mean differences in FBA between questions that were and were not remembered correctly (the black lines indicate the mean for each). Each participant is represented by two dots, one orange and one green. Participants' recall was better for trials in which they had higher asymmetry scores than those in which they had lower asymmetry scores (*p* < .001).

possible to infer any relationship between these two variables. In other words, frontal brain asymmetry might not be a neural correlate of curiosity, as we had initially hypothesized. However, although our experimental study design avoids claiming causality, our results support the idea that frontal brain asymmetry might be a better predictor of subsequent learning and correct information recall than the curiosity scores reported by the participants. Differently from Marvin & Shohamy (2016), self-reported curiosity did not correlate with subsequent learning in our study. These data leave open critical questions related to the reliability of self-reports measures on research investigating curiosity. Given that the current studies on the topic rely primarily on self-reports as a way to measure curiosity due to its convenience and affordability, more research is needed in order to confidently state the effects of curiosity on memory and learning.

Moreover, the variable confidence level showed a significant effect on the correctness of the responses in the retest (p = .008). Subjects were more likely to provide a correct answer during the retest when the same question on the pretest was answered incorrectly but with a high level of confidence. These results are in accordance to previous studies on hypercorrection, which suggest that high-confidence errors tend to be corrected at a higher rate on retests, when compared to low-confidence ones (Metcalfe & Finn, 2011; Metcalfe & Miele, 2014).

Our study also found that there is a positive relationship between frontal brain asymmetry and subsequent learning (see Figure 3). More specifically, correct answers have a significantly higher FBA index than incorrect answers (p < .001). Future research is necessary, however, in order to investigate *why* this relationship exists. Previous studies have suggested that greater activity in the left versus the right frontal cortex indicates positive feelings, higher engagement, and motivation (Davidson, 2004; Harmon-Jones & Gable, 2017). Although these correlates of FBA might play a role in whether a participant will remember the correct answer or not, only future studies might be able to indicate if this is true.

The present study is not without limitations. The number of participants included in the final analysis was relatively small ($N = 21$). Future work should aim to collect and analyze data from a more extensive poll of participants in order to examine if findings will hold true with more data. Furthermore, the equipment used in this study was quite rudimentary if compared to more expensive and sophisticated EEG equipment and software used in first-class clinical settings and research labs.

By any means our study intends to be a definitive verdict or conclusion for the topic. Instead, it aims to provide an initial – but valuable – framework, upon which future studies can be built. Additionally, our study may have implications in the field by providing a helpful framework for more advanced research on the functional significance of frontal EEG asymmetry on learning and other reward-motivated behaviors such as curiosity. More broadly, given the importance of curiosity in our daily decisions and behaviors, these works could have important implications for studies in several different academic areas, including psychology, neuroscience, medicine, marketing, and education, and may contribute to the development of new strategies for improving memory and learning in both school and therapeutic settings.

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