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Independent Research: Neuroscience

Introduction

In recent years, there has been an intersection between neuroscience and modern magic as researchers delve deeper into the inner workings of our perceptive systems. In 2008, an article titled “Attention and awareness in stage magic: turning tricks into research” was published in *Nature Reviews Neuroscience*. It details methods used by professional magicians, explains correlation between those methods and phenomenon seen in modern psychology, and suggests that magicians could serve as a unique and powerful tool in studying the function of the brain, and that “magical techniques that manipulate attention and awareness can be exploited to directly study the behavioral and neural basis of consciousness itself”(Macknik et al, 2008).

This is not an entirely new idea - paradigms based in magic techniques have been used in psychological experiments for a number of years. For example, in 2006, Johansson and his research team used palming techniques to change the intended outcome of a subject’s choice without the subject realizing that a change had been made (Johansson et al, 2006). Originally, I had planned to focus my research on the interaction between covert attention and these magic techniques, but after discussion with Dr. Andresen and further research, we came upon another question: What happens in the brain when a subject observes a magic trick?

There are a number of reasons to justify investigation into the interaction between the brain and magic. Magic is inherently impossible - something typically reserved for fiction rather than reality. This seems to be easy to cope with when in a medium where the line between possible and impossible is blurred such as in a book, or a movie. No one batted an eye when Daniel Radcliffe picked up a wand and began casting spells in *Harry Potter*. But when presenting magic in a “real” setting, the brain is presented with an impossible situation that it must be able to rationalize rather than brush aside. In this manner, we hope to try to gain further insight into the human disbelief system.

To explain: the impossibility of a magic trick is not inherent, but rather, arises as a function of what magic appears to be: a violation of physical laws of causality. In other words, a magic trick is an effect without a cause. For example, in normal circumstances, a spoon lying on a table should only move when acted upon, be it by someone pushing the spoon, or tilting the table. In a magic condition, the effect occurs with no perceivable action. This violates a deep-seated belief in the physical laws of causality presumable present in all adults, so any brain activity observed in this case should reflect the activation of a system that governs disbelief.

In 2008, Ben Parris conducted a study titled “Imaging the Impossible” in which he localized the neurological response to impossible causal relationships presented by magic tricks. He found an elevated response in the left dorsolateral prefrontal cortex (DLPFC) and the anterior cingulate cortex (ACC) (Parris et al., 2008). However, one of the major drawbacks of fMRI is that while it’s extremely accurate spatially, it lacks in temporal accuracy due to measuring hemodynamic response rather than the electrical signals. With the assistance of Adam Ganz, Dr. Andresen and I decided to model an experiment after Parris’, using an EEG monitoring the left DLPFC in order to locate the temporal component of the brain’s response to violated impossible causal relationships.

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DLPFC and ACC: Problem Detection and Resolution

The dorsolateral prefrontal cortex is a layer of tissue on the outer area of the lateral anterior brain, thought to have a role in conflict resolution (Parris et al., 2009). It has also been heavily implicated in processing causal relationships, be they physical or otherwise. In 2001, Fletcher saw activation in the DLPFC when he ran patients through a causal-associative learning paradigm (Fletcher et al., 2001). Similarly, Fuselang and Dunbar (2005) linked violation of causal-relationships to activation in the DLPFC in their study, which had patients trying to detect violations in established relationships. Both cases, however, focused on verbal causal relationships, rather than using visual stimuli to violate belief in physical laws. Nonetheless, they show a softer parallel to the findings of Parris. In each case a belief is established, then violated. Upon violation, whether the stimuli is speaking to deep-seated beliefs about the physical world or to newly established beliefs about the relationships between stimuli presented, activation of the DLPFC occurs (Parris et al., 2009. Fuselang and Dunbar, 2005. Fletcher et al, 2001).

Additionally seen in each case is activation of the anterior cingulate cortex. Anterior cingulate cortex is located toward the front of the brain, underlying the DLPFC, and is thought to have a role in error detection and conflict monitoring (Parris et al., 2009). In both Parris' study (2009) and the study conducted by Fuselang and Dunbar (2005), activation was seen in the ACC.

Together, the DLPFC and the ACC are thought to be involved in a "cognitive control loop, in which the ACC is responsible for monitoring the conflict whilst the DLPFC resolves it" (Parris et al., 2009).This is consistent with interpretations by Fuselang and Dunbar (2005), who suggested that ACC activation was caused by recognition of variance between the outcome subjects had been led to expect and the actual outcome they observed, while activations in the DLPFC were thought to be indications of processes used to resolve the observed conflict (Fuselang and Dunbar, 2005).

Ventrolateral Prefrontal Cortex: The Surprise Response

One of the initial concerns we faced was differentiating between a "surprise" condition and one of violated causality. Magic is inherently surprising, and as such, we wanted to be certain that the response we measured was that of disbelief, rather than surprise. However, as Parris states, "Surprise can follow from events in which there are no violations of causality, suggesting that there are at least some brain regions that are specific to its detection." (Parris et al., 2009). The region most commonly implicated in surprise with no violation of causality is the ventrolateral prefrontal cortex (VLPFC) (Braver et al. 2001).

VLPFC is located at the anterior ventral side of the brain, relatively distant from the DLPFC. Due to this distance, we felt we could safely monitor the DLPFC without interference from VLPFC signals. Still, we took measures in order to create stimuli that would allow us the compare surprising events to causality violations. This comparison is meant to allow certainty that data addressing the belief system was not instead a visualization of the brain's response to surprising stimuli. Different forms of stimuli are described and compared in the Methods section.

Methods.

Designing Disbelief: Crafting Stimuli to Suit the Experiment

In order to locate a temporal aspect to the brain's response to impossible causal relationships, stimuli had to be meticulously designed. We established exclusion criteria for our potential stimuli in order to more accurately control testing. First, because EEG is extremely sensitive, particularly to eye movements, blinks, and alpha-waves, stimuli had to be brief enough that subjects would be able to remain fixated and attentive for the duration of each clip. To that end, we decided that all videos should be a maximum of twenty seconds long and preferably under ten. Second, we chose to minimize distracting stimuli within the videos - no faces, no sounds, and the background must be plain. Third, we chose to limit the type of magic trick used to either a change (one card changing into another) or a vanish (an object disappearing). Finally, tricks had to be easy to follow, so tricks with multiple instances of magic were excluded. The tricks that were recorded fell into one of three categories: visual changes, nonvisual changes, and one-step vanishes.

Visual changes were defined as tricks in which one card changed into another while never leaving the spectator's field of view. There were three tricks of this type used, and in each case, a Four of Spades was changed into a Ten of Hearts. The tricks used are referred to as the Ego (Cardini) Change, the Snap Change, and the Duck Change.

The Ego (Cardini) Change involves one card being placed face up on the deck, and changing into another as the performer gestures in the air above it. The Snap Change involves a single card, taken into the right hand, changing into another single card upon being touched by the magician. The Duck Change is an aerial change: a single card is held above the deck and dropped towards it. As it lands on the deck, it changes into another card.

Non-visual changes were defined as tricks in which card changes identity upon leaving the subject's field of vision. There were two tricks of this type, the FD (face-down) Change and the Ambitious Recovery.

The FD Change involved a card being shown, then placed face down on top of the deck. When turned over again, it is shown as having changed into another card. The Ambitious Recovery involves a card being shown, then placed into the middle of the deck. The top card of the deck is immediately revealed and is shown to be the card that was placed into the middle.

Vanishes were defined as tricks in which an object vanished. There were three tricks of this type, known as the Classic Palm, the Retention Vanish, and the Rub Vanish. The Classic Palm and the Retention Vanish were both performed with a camera lens-cap, chosen because of it's size and shape being reminiscent of a large coin. The Rub Vanish was performed with a card.

The Classic Palm and the Retention Vanish both involve an object being passed from one hand into the other, which immediately closes upon receiving it. When the second hand is opened, the object has vanished. The Rub Vanish involves placing a card upon the table and miming the action of rubbing it in. When the rubbing hand is removed, the card is no longer present.

Each magic condition also had a “Non-Magic” counterpart, in which the trick was performed without the magic event occurring. In Vanish tricks, this involved the object remaining where it had been placed. In Changes, this meant that no change occurred. Each magic condition also had a “Surprise” counterpart, in which no magic occurred, but a surprising event did. This could involve objects being dropped to the floor, or cards being spread across the table.

All stimuli were recorded through the combined efforts of myself and Adam Ganz. Due to several years experience as a amateur magician, I was determined to be an adequate actor for the stimuli that we used. Stimuli were also critiqued by a third-party to make certain that magic conditions appeared to be magic and that surprise conditions were suitably surprising.

A total of 150 videos over ten tricks were recorded. Two tricks were discarded because they were unable to meet our exclusion conditions, or because a proper non-magic or surprise condition could not be recorded. In final testing, a total of 120 videos were used over eight tricks, with fifteen videos used per trick. Five videos were of the Magic condition, five were of the Non-Magic condition, and five were of the Surprise condition.

Testing Procedure

Due to time constraints, we were unable to do individual event record for each trick condition. Instead, lump-recording of each overarching (Magic, Non-Magic, or Surprise) condition was used in for frequency-based analysis. Stimuli were randomized within each condition, then shown sequentially, with no more than five seconds delay between stimuli. Once all forty videos within a condition had been shown, the subject was allowed a five minute break before moving on to the next condition. The Magic condition was presented initially, followed by the Non-Magic condition, followed by the surprise condition. While this method does not allow for close investigation into the location of the temporal component of the brain’s response to impossible causal relationships, it does allow us to make judgements about whether or not such a component is observable.

Three electrodes were used in testing, one located on F3 (left DLPFC), one on F4 (right DLPFC), and one on Cz. A fourth electrode was placed on the mastoid to serve as a reference point. Due to the location of the ACC, it could not be monitored.

The subject tested was female and a student recruited on campus. Due to time constraints, we were only able to test one subject.

Data Analysis

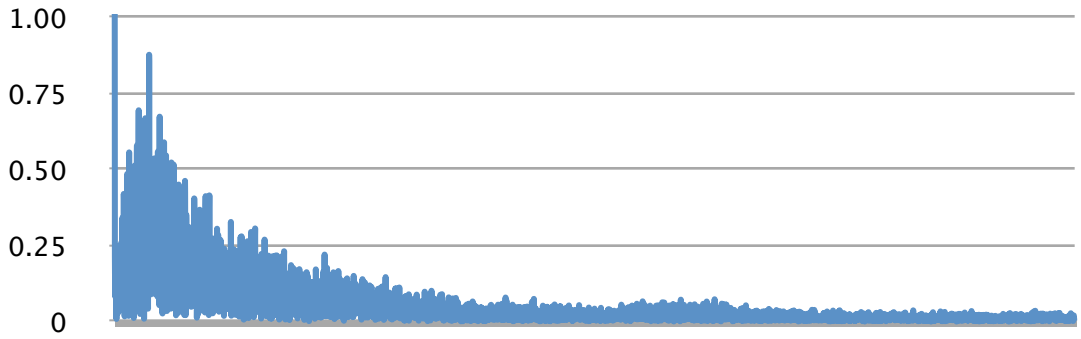
Data obtained were nine EEG waveforms - three for the Magic condition, two for the Non-Magic condition, and two for the Surprise condition. In each case, one corresponded to data obtained from the F3 electrode, one corresponded to data obtained from the F4 electrode, and one corresponded to data from the Cz electrode. Data obtained from F3 and F4 were subjected to further analysis. Data obtained from Cz was discarded.

The waveforms obtained from F3 and F4 were analyzed via Fast Fourier Transform and are compared in the Results and Discussion section.

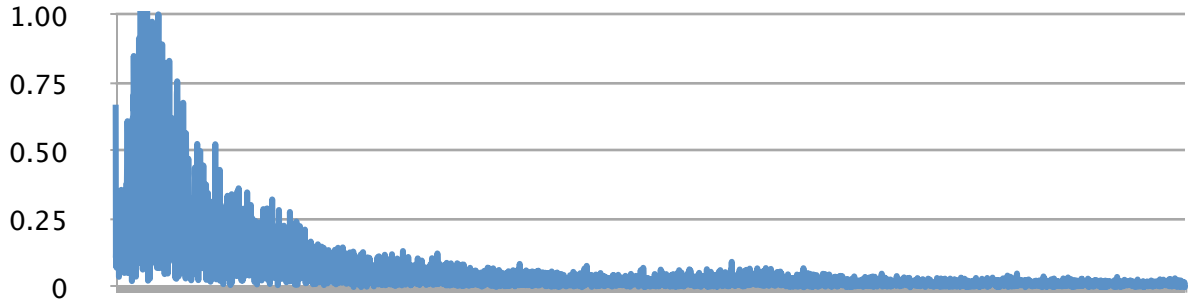
Results and Discussion.

Figure 1 shows the Fast Fouriers obtained from electrodes monitoring F3 in each condition. Comparison shows a solitary peak in the Magic condition and clustered peaks in the Non-Magic and Surprise conditions.

A



B



C

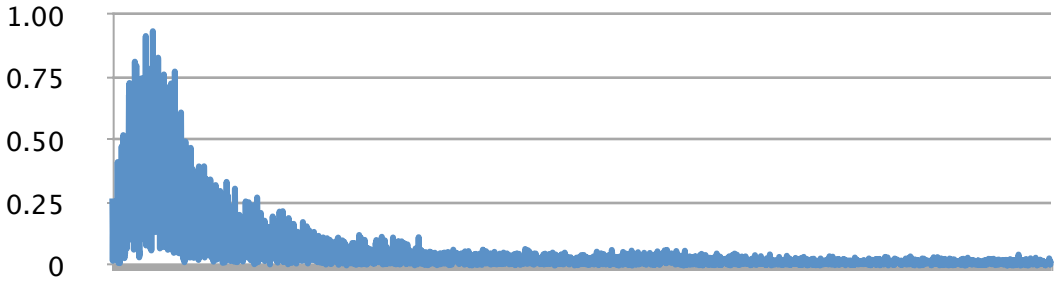
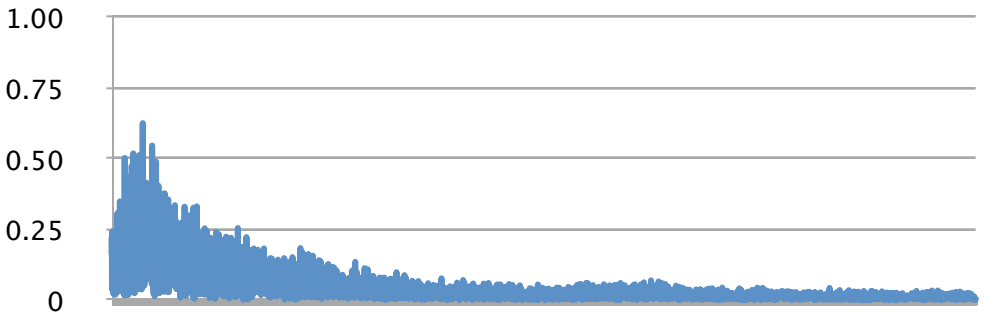


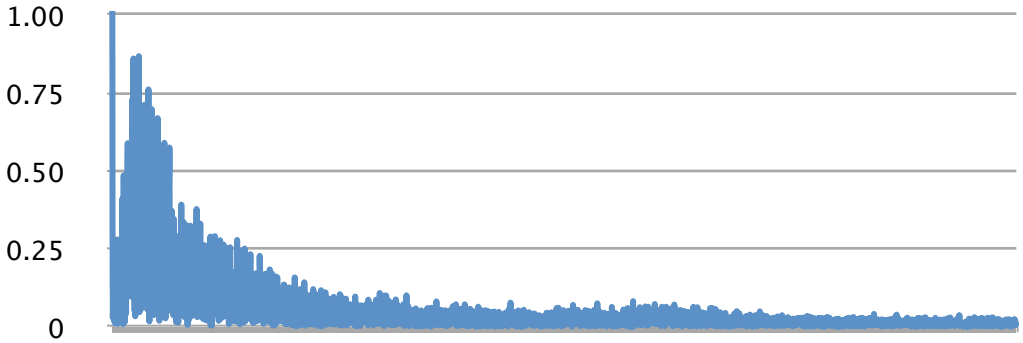
Figure 1. (A) The Fast Fourier Transform obtained for the F3 (left DLPFC) electrode in the Magic Condition. Note the solitary second peak. (B) The Fast Fourier Transform obtained for the F3 (left DLPFC) electrode in the Non-Magic Condition. Rather than the solitary peak seen in the Magic Condition, here we see a cluster of peaks all reaching a similar height as the solitary peak in (A). (C) The Fast Fourier Transform for the F3 (left DLPFC) electrode in the Surprise condition. Again, there is a clustered peak rather than a solitary peak.

Figure 2 shows the Fast Fourier Transforms obtained from the F4 electrons. Again, we see the solitary peak in the Magic Condition and the grouped peaks in the Non-Magic and Surprise conditions. Noteworthy is that in each case, overall activation levels are reduced relative to the F3 electrons.

A



B



C

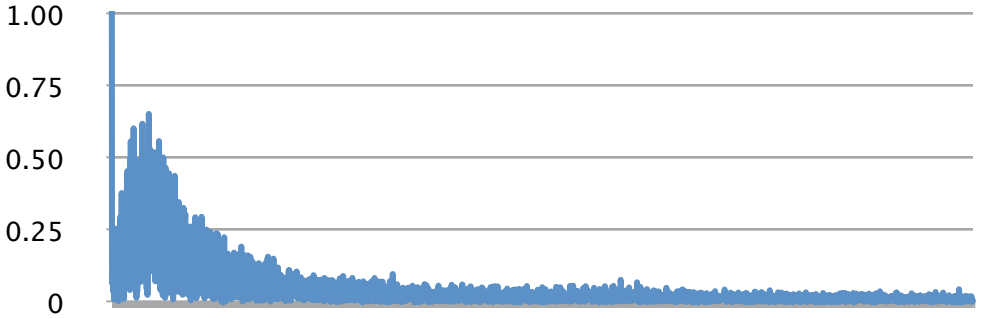


Figure 2. (A) The Fast Fourier Transform obtained from F4 (right DLPFC) electrode during the Magic condition. Again, observable is the single peak in this condition. (B) The Fast Fourier Transform obtained from the F4 (right DLPFC) electrode during the Non-magic condition. (C) The Fast Fourier Transformed obtained from the F4 (right DLPFC) electrode during the surprise condition.

Figure 3 shows the frequency between 8 and 12 hertz at which the maximum discharge was observed for each condition. This functioned as a check for alpha-wave activity.

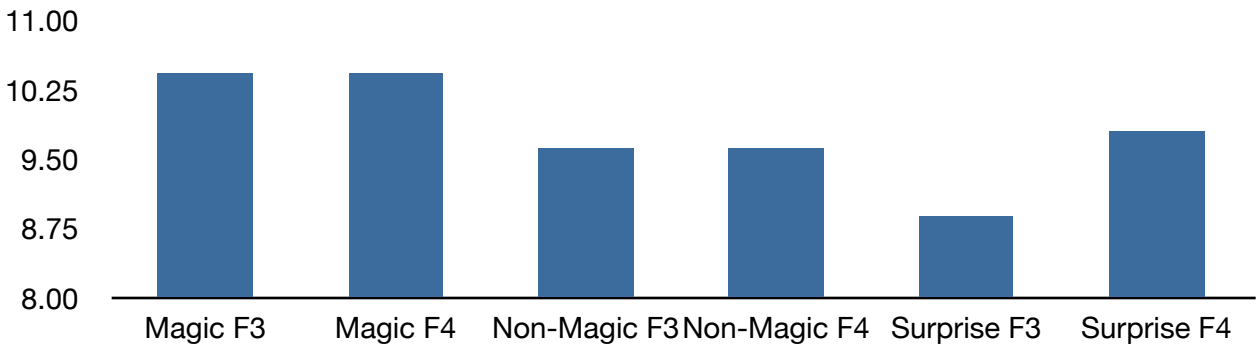
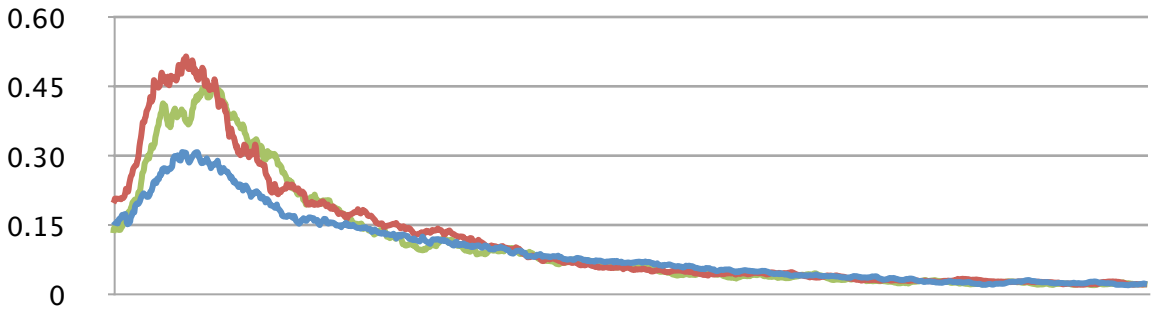


Figure 3. The observed frequency (between 8 and 12 hz) at which maximum discharged occurred. In the Magic condition, frequency was 10.427 hz for both F3 and F4 electrodes. In the Non-Magic condition, frequency was 9.62 hz for both F3 and F4 electrodes. Only the Surprise condition showed any variance between F3 and F4, with the maximum discharge observed at 8.89 hz in F3 and 9.8 hz in F4.

Figure 4 shows a comparison of the smoothened lines formed in by the Fast Fourier Transform in each condition, for each electrode. This figure is of particular interest, because it shows a clear difference between the EEG recorded for the Magic condition and the EEGs recorded for either the Surprise or the Non-Magic conditions.

A



B

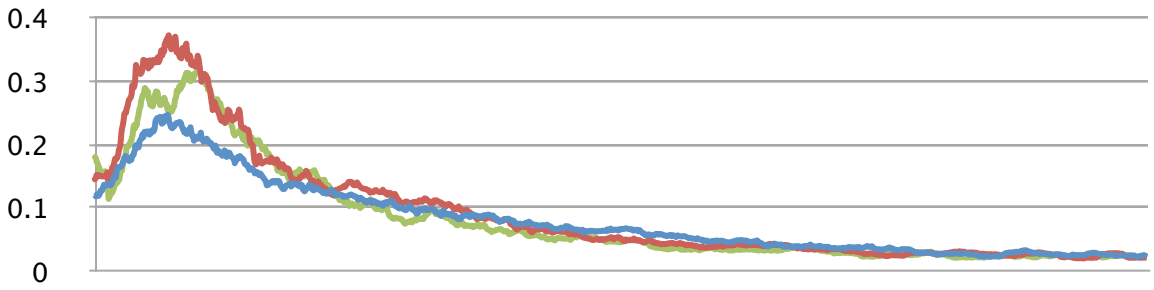


Figure 4. The overlayed lines obtained from each condition. (A) shows data obtained from left DLPFC and (B) shows data obtained from right DLPFC. Blue represents the Magic condition, red represents the Non-Magic condition and Green represents the Surprise condition. Important to note is that not only is the Magic condition consistently lower than the Surprise and Non-Magic conditions, there is a region where it remains isolated while Non-Magic and Surprise intersect.

The decreased activity seen in the Magic condition throughout the experiment could be caused by a number of things. Between 8 and 12 hz, alpha-waves are known to be expressed. Alpha-wave expression occurs when the subject is not focused and is beginning to doze, while alpha-waves are inhibited when the subject is paying close attention. The lowered expression seen in the Magic conditioned could be due to increased attention during recording, or due to order of presentation of stimuli - Magic stimuli were presented first, followed by Non-Magic, followed by Surprise. As the second and third condition were played, the subject may have become tired or bored and paid less attention to the stimuli. The order of presentation doesn't account for the reduced activity seen in the Surprise condition relative to the Non-Magic condition, however, so it may be safer to assume that the lessened presence in the alpha-wave region is due to the Magic condition being viewed as the most interesting and engaging of the three, and the Non-Magic condition being the viewed as the least engaging.

There is a region shown in Figure 4 in which the Surprise and Non-Magic conditions intersect, but the Magic condition does not. This was interpreted to be extremely relevant to the temporal component of the brain's response to impossible causal relationships. Because the Magic condition line remains independent while the Non-Magic and Surprise Conditions converge, it is thought that this region may represent the temporal aspect that we hoped to locate. This region, combined with the single peak activity that was observed in Figures 1 and 2, shows enough of a difference between the Magic condition and the other two to justify further investigation.

The fact that values obtained from the right DLPFC were consistently lower than those obtained from the left DLPFC is in line with our expectations. Previous studies that have investigated the violation of causal relationships have seen similar results,

with left DLPFC being recruited over right DLPFC (Parris et al., 2009, Fuselang and Dunbar, 2005).

Conclusion

Though the temporal component of the neural response to impossible causal relationships and violated beliefs was not located, it is believed that it is observable via EEG. Our inability to locate it was due to a lack of time and a need to switch to a different method of observation, rather than to any particular complication with our paradigm or our hypothesis. There was a clear difference between the Magic condition and either of our control conditions, suggesting that the response we were trying to locate was triggered by our stimuli, and that it was apparent on our EEG waveforms.

As mentioned, time limitations required the changing of our experiment from an event-based EEG to a frequency analysis. In the future, a study could be run using event-specific EEG, where readings are taken from areas directly around the impossible event, allowing researchers to analyze peaks individually. This would allow localization of the particular peak of interest, and comparison with other, known peaks. In particular, a comparison with the change detection peak would allow researchers to analyze ties between belief-related conflict detection and resolution, and the visual system.

There were some drawbacks associated with our method. First, because we had to present each stimuli class as a group, the subject knew before-hand whether or not what they were watching was a magic trick, and by extension, whether or not an impossible event would occur. In an event-specific study, randomization without regard to stimuli class is highly recommended to prevent prior knowledge from interfering with beliefs about what may be seen in the stimuli.

Second, we were only able to analyze one subject. While the subject had no knowledge of magic techniques and so could be viewed as a typical individual, this did prevent us from running statistical analysis. It is entirely possible (though unlikely) that our data is anomalous and further trials would reveal no difference between the Magic, Non-Magic and Surprise conditions.

Future studies should be able to easily correct for these errors. The bulk of the time spent on this experiment was in the planning and preparation phases. At this juncture, we have a small library of stimuli available for further testing. With a programmer available to write software to allow event-based testing, a follow-up experiment to ours could be carried out in order to identify the peak of interest in the localization of the temporal component of impossible causal relationships.

In light of the neuroscience of disbelief: unfortunately, EEG is unable to accurately visualize ACC. While ideally researchers would be able to see the call-and-response mechanism thought to be occurring between ACC and DLPFC (Parris et al. 2009), it is impossible without a more advanced visualization system. It is thought that MEG (magnetic encephalogram) may be able to accomplish this, as it is known to be exceptionally accurate both spatially and temporally. When limited to EEG, however, researchers should still be able to locate the peak of interest and make inferences about how the brain handles impossible causal relationships.

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