MSc Coursework Submission Form

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Title

Evaluation of a functional neuroimaging paper

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Harris, S., Sheth, S. A., & Cohen, M. S. (2008). Functional neuroimaging of belief, disbelief, and uncertainty. Annals of Neurology, 63(2), 141–147. https://doi.org/10.1002/ana.21301

Evaluation of a functional neuroimaging paper

Summary of the paper

Motivation:

Acceptance of a statement is the basis for further human thinking and behavior and regulates human emotions. The main aim of this study is to distinguish between belief, disbelief, and uncertainty at the brain level through fMRI images.

Method:

The experiment used block design, with statements divided into three groups: belief, disbelief, and uncertainty. Each group had 5-7 blocks, interspersed with an occasional one or two other group's operations. In total, there were approximately 100 trials, and each group was subjected to a 7-minute scan. Response is analysed using an event-related manner.

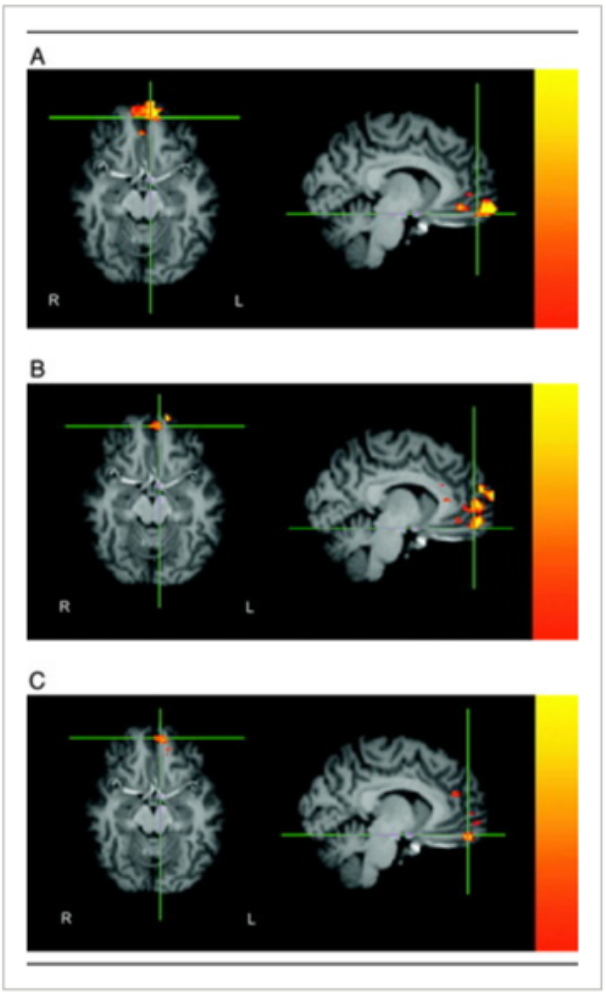
Participants were 14 adults (18-45 years old; 7 males, 7 females) who were all right-handed and native English speakers. The statements used were divided into seven categories: mathematical, geographical, autobiographical, religious, ethical, semantic, and factual.

Result:

1. Belief

In contrast to Belief and disbelief (belief-disbelief), the ventro medial prefrontal cortex (VMPFC) had a significant increase in magnetic resonance imaging signal, especially in the roastal region of gyrus rectus and orbitomedial gyrus. (Fig A Z=3.56)

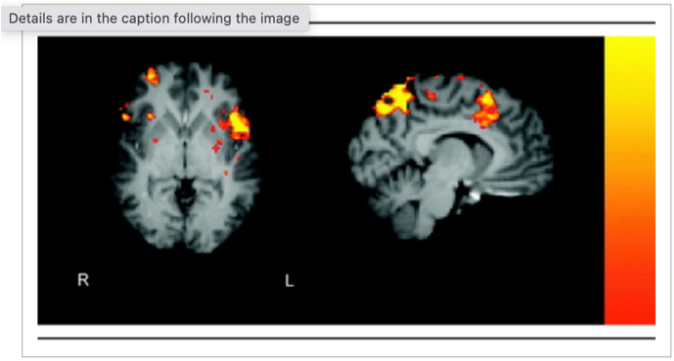
When consider specific categories, most of the specific categories did not show difference significantly, only the ethical (Fig B Z=3.52) and mathematical (Fig C Z=3.00) categories differed significantly.



2. Disbelief:

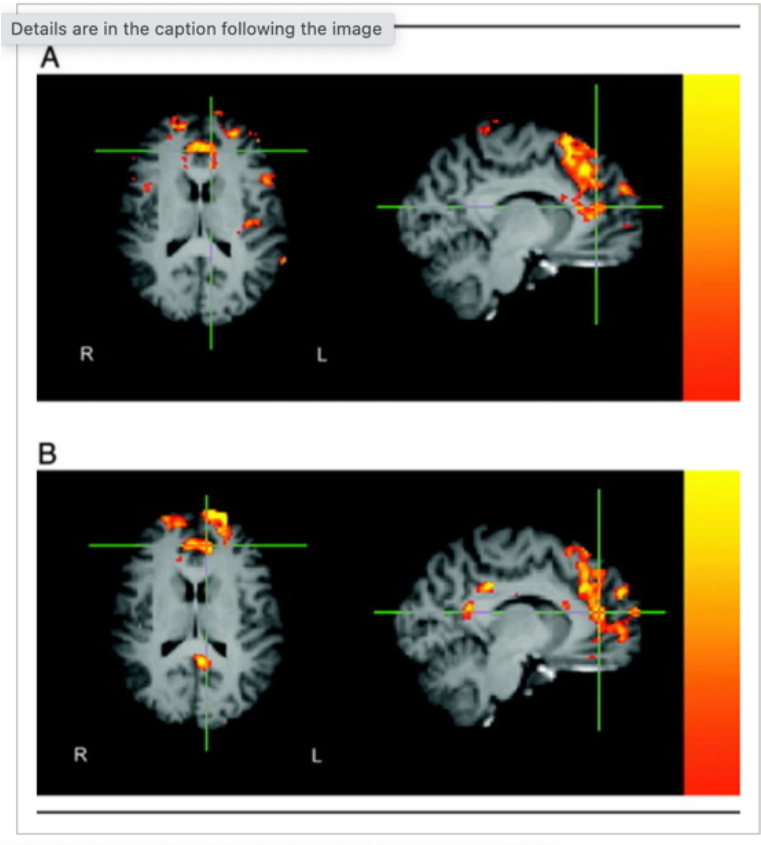
In axial direction images show that disbelief has increased BOLD signal in the inferior frontal gyrus (mainly left), right middle frontal gyrus and anterior insula (bilateral).

Whereas images in the sagittal showed BOLD signal increase in the superior parietal lobule, the cingulate cortex and superior frontal gyrus in the same contrast (Z=3.8).

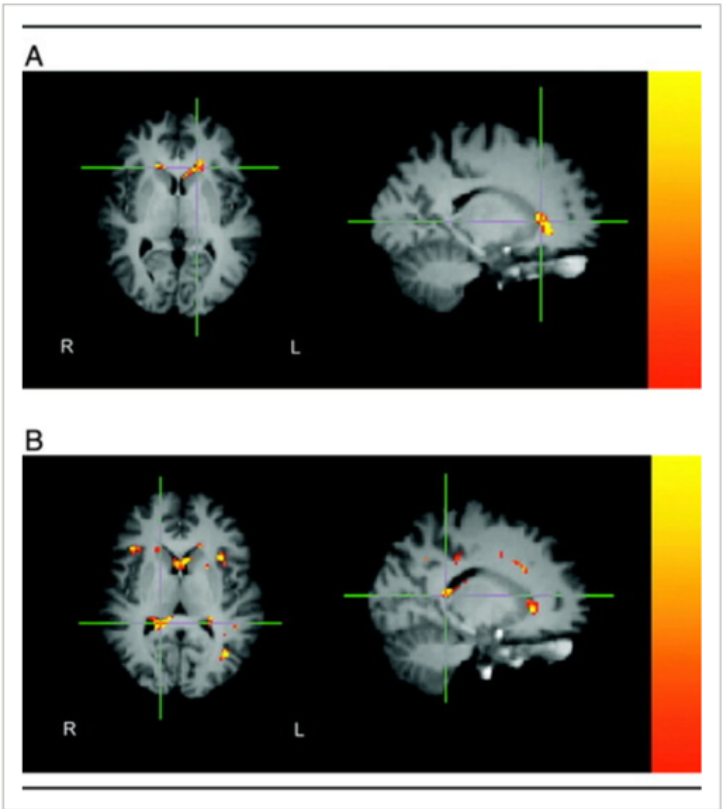


3. Uncertainty:

Figures A and B show uncertainty-belief and uncertainty-disbelief, respectively. Both show increased signals in the anterior cingulate and superior frontal gyrus on these trials. Figure B also shows increased signal in the posterior cingulate. (ZA=3.8, ZB=4.16)



Figures A and B show belief- uncertainty and disbelief-certainty, respectively. Both Figures A and B show increased signals in caudate. The difference is in Figure A for the left hemisphere caudate head and Figure B for the right hemisphere caudate head and tail. And Figure B also shows anterior insula signal enhancement bilaterally. (ZA=3.46, ZB=4.08)



4. Reaction time

The reaction time data from the experimental results showed that both belief < disbelief and belief < uncertainty was significant. While disbelief and uncertainty were not significant difference between each other.

Conclusions:

1. Belief

The VMPFC has a greater signal drop during the disbelief trial compared to the belief trial. This region is associated with reality monitoring (distinguishing between imagination and reality). This seems to imply that disbelief requires more reality monitoring than belief.

At the same time, this region of the VMPFC seems to help linking factual knowledge with relevant emotion for modulating behaviour. This suggests that belief and disbelief may be linked to emotion.

2. Disbelief

The results show increase signal in medial regions of superior parietal lobule, bilaterally in disbelief. This region is related with medial PFC. However, it cannot be explained in the research.

Contrasting beliefs and disbelief, the experimental results show that disbelief is associated with bilateral activation in the anterior insula. This region is associated with pain perception and perceiving pain in others. This region also modulates negatively valanced feeling together with the left frontal operculum. In addition, the left frontal lobe operculum is associated with making active judgements about unpleasant smells. This seems to define the emotional feature of disbelief, like pain and unpleasant smell.

3. Uncertainty

The ACC is distinguished as ventral and dorsal and has been associated with cognitive function and emotion, respectively. Experimental results also found that the ACC had signals detected in both uncertainty - belief and uncertainty - disbelief. Even though there

was a large overlap, the ventral and dorsal sides of the ACC contributed differently to them (dorsal-cognitive-uncertainty-belief, ventral-emotional-uncertainty-disbelief).

The experimental results also show that both belief and disbelief show enhanced signals in the caudate nucleus compared to uncertainty. In particular, the caudate nucleus is often activated in reasoning and guessing tasks with feedback, compared to those without. And a feature of feedback is the elimination of uncertainty. It may therefore be implied that basal ganglia circuits are associated with accepting or rejecting statements about the world.

Critical Thinking

1. Critiques of fMRI

fMRI measures the haemodynamic response, so the temporal resolution is relatively low. Compared to the millisecond resolution of EEG, fMRI has a resolution of a few seconds or a dozen seconds, therefore many temporal details and processes may be missed. For example, some neural events only take several milliseconds, which cannot be measured by fMRI. Therefore, subsequent experiments should try to do EEG experiments based on fMRI to distinguish the time course in more detail. A follow-up study by Douglas et al. (2013) combined EEG and fMRI with ICA. This study found a series of event-locked changes, and these categorized time-frequency changes were separated by about 500 ms. These temporal changes are unlikely to be reflected in the BOLD signal.

Simultaneous haemodynamic responses tend to lag neuronal activity by a few seconds, which means that fMRI cannot measure neural events in real time. It is possible that

unrelated neuronal activity could occur during this delayed time that alters the haemodynamic response, then it could interfere with the neuronal activity we are trying to observe. It is also possible that other physiological activities that cause changes in the haemodynamic response may occur during the delay.

At the same time the relationship between the haemodynamic response and neuronal events is still not very clearly demonstrated. It is questionable whether the experimental results of fMRI are representative of neuronal events compared to invasive techniques like ECoG that directly measure neuronal events.

Also its spatial resolution is lower than that of invasive imaging techniques, which can analyse both a small population of neurons and individual neurons. Therefore, subsequent experiments can continue to do invasive imaging techniques in depth based on this fMRI experiment.

The process of analysing data for functional MRI is complex and involves multiple steps, with its series of assumptions and potential biases, leading to variability in results and interpretation.

The MRI scanner environment may be restrictive and uncomfortable for the participant, which may affect the results leading to conclusions that may not be generalizable to a wider context. For example, subject is required to lie inside the apparatus for a period, which may give them a psychological stress leading to differences in neuronal events. There are also differences in the sensitivity of different subjects to confined spaces. All of these may lead to false positive experimental results.

2. Critiques of Methodology

The age range of the sample is somewhat too large (18-45), so subjects and their neuronal responses may vary in age. The differences would be especially significant with fMRI, an imaging technique with very small expected effects.

Although the sample size is somewhat small, it is reasonable considering the cost of the fMRI experiment. In addition, this was an exploratory experiment, the small sample was sufficient to reveal some new findings. Another study distinguished brain-level differences between testable and non-testable statements (whether they could be verified by experience and evidence) , also had a similar small sample size to the this experiment, which is N=14 (Howlett & Paulus, 2015).

However, it is necessary to increase the sample size for subsequent validation experiments. Because BOLD signals tend to have very small expected effects as the difference between signal of rest and task is small. At the same time there are many complex sources of signals from brain regions interacting with each other and many noises. Except of that, the BOLD signal is an indirect measure of neuronal events. However, given the time and budget costs of fMRI, it can turn to other imaging techniques for validation.

This fMRI experiment used a hybrid design combined block design with event-related analysis manner. It retains the advantages of the block design for easier detection of BOLD signals and the flexibility of event-related analysis for analyzing each individual response. After all, the judgement of statements involves perception, reasoning and other

subdivided processes, which is an extremely complex process. Another advantage of the experiment is that a small number of operations from other groups were added to each group, thus alleviating the adaptation or fatigue of subjects.

This research adopts of two kind of scan, T2*-weighted echo planar scans and magnetization-prepared rapid gradient-echo sequence. T2*-weighted echo planar scans can quickly obtain blurrier images thus capturing changes in neural events over time which form the functional images. While magnetization-prepared rapid gradient-echo sequence are slower but provide with high-resolution images of the brain which regard as anatomic images. Combining the two kinds of scan can better capture and localize the location where neural events differing happen.

The study performed a series of standard pre-processing on the data before analysing the images, such as slice timing correction, motion correction, brain extraction, spatial smoothing, high-pass filtering, and prewhitening. These process have different function: slice timing correction aligns slice acquiring time; motion correction removes some of the noise caused by subject motion; brain extraction preserves brain voxel by removing irrelevant voxel; spatial smoothing improves signal-to-noise ratio; high-pass filtering reduces low-frequency noise such as respiration, cardiac cycles, or slow scanner drifts; prewhitening reduces some autocorrelation of the data, such as the correlation between successive data points, so that each time point is independent of the other.

As the experiment was the first attempt to study beliefs at the brain level without some model to refer for setting a hypothesis. A post hoc analysis was adopted. Although

unexpected patterns may be revealed, there is also a risk of over-interpretation and false correlations.

3. Critiques of Statistic

As mentioned in the paper, due to the preference of the statistical methodology in the research, a more conservative threshold was used. This resulting in a decrease in false positives and an increase in false negatives. Although getting more rigorous significance in certain regions, it would have missed many other regions that were potentially significant. Two locations, the frontal gyrus and the rectal gyrus, may be overlooked due to their inhomogeneous sensitivity to the signal, therefore potentially significant results in these regions may be overlooked.

Also due to the field inhomogeneity, some artefacts caused by slight movements can lead to a rise in false positives. However, this part of the experiment was somewhat resolved by interleaved event-related design (an approach that can help decrease the possibility that motion artefacts occurring simultaneously with stimulus presentation). The experiment also did not control for eye movements, but there is no reason to expect this to influence the results.

4. Critiques related to Further Research

The experiment did not consider within-group differences, such as different degrees or types of uncertainty. Instead, it only considered between-group differences, between belief, disbelief, and uncertainty. Many subsequent experiments have focus on this aspect. The authors of this paper followed up by examining differences in brain processing between the different categories of statements in this experiment (Harris et al., 2009).

Han et al. (2017) focused on the comparison of "believe" and "think" in a self-referential/non-self-referential trait adjective judgment task comparison. Gao et al. (2022) used a similar paradigm to investigate cultural differences in belief processes between Chinese and Danish participants.

On the other hand, Harris' experiment did not examine the different stages of belief processing. In this regard, Gerchen et al. (2024) conducted a similar experiment, but they divided it into three experimental stages which consist of statement presentation, judgment of truth, and certainty judgment. Through this way they separate the different stages of belief processing. Additionally, they used a series of statements which are various difficulty and had participants assess the certainty (0-100%) of their judgment of each statement during the certainty judgment stage. This also compensates for the simple definition of certainty in Harris' experiment.

Overall, this is exploratory research, therefore it is not needy to be overly require its rigor, but rather focuses on its finding. The same criteria can be applied to the fMRI study. Although we cannot interpret the results of fMRI with a high degree of certainty, it still brings a lot of inspiration to subsequent studies, such as some clue to set up psychological model.

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