Neural Correlates of Satisfaction of an Information Need

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Abstract. Knowing when a searcher's information needs (IN) are satisfied is one of the ultimate goals in information retrieval. However, the psycho-physiological manifestation of the phenomenon remains unclear. In this study, we investigate brain manifestations of the moment when an IN is satisfied compared to when an IN is not satisfied. To achieve this, we used functional Magnetic Resonance Imaging (fMRI) to measure brain activity during an experimental task. The task was purposefully designed to simulate the information-seeking process and suit the fMRI experimental procedure. Twenty-nine participants engaged in an experimental task designed to represent a search process while being scanned. Our results indicated that both affective and cognitive processes are involved when an information need was being satisfied. These results are in distinction to when satisfaction was not obtained. These results provide insight into features of brain activity that can ultimately be developed to detect satisfaction in search systems with more portable brain imaging devices.

Keywords: Satisfaction, fMRI, Information Need, Neural Correlates, Search, Cognition, Affect, Brain

1 Introduction

Information seeking refers the behaviour of how an individual looks for pieces of information in order to satisfy their needs [5]. From a searcher's perspective, the satisfaction of an information (SAT) can be seen to combine both the accuracy and the completeness of the task that a searcher performs [1]. It can also be thought to be a part of the information seeking process [20, 23]. A searcher who is performing a search will continue their search and examine multiple sources of information repeatedly to gather pieces of relevant information [23]. The search will be successfully terminated when a searcher believes that they no longer have an information need. This is similar to an image puzzle game where a player finds puzzle pieces and the game will end when the puzzle can be solved, i.e., the need for information has been satisfied. In the real world, there are many different ways that information can be gathered and internally represented, which makes the satisfaction of an IN a complex and dynamic process to understand.

Several behavioural studies have been conducted to understand the satisfaction of an information need by observing human search behaviour and conducting surveys [15, 17]. However, these studies are limited in their ability to inform what is happening to the internal states of searchers when their IN is being satisfied. In order to illuminate the internal states of users during search, recent research has increasingly used neuroscience to measure brain activity, using techniques such as electroencephalography (EEG) and functional Magnetic Resonance Imaging (fMRI). This neuroscience research has focused on the topics of relevance [2, 10, 26, 34] and IN [28–30], while SAT has been addressed only in the context of the transition of brain activity between different periods of the search process [27]. More detailed examination of SAT has not yet been performed. Understanding the brain regions involved during the satisfaction of an information need will fundamentally advance our theories of search and add to a growing body of evidence that supports the application of neuroscience to search systems. Thus, in this paper, we aim to investigate the following research questions (RQ) related to SAT in Information Retrieval:

- **RQ1:** What brain regions correspond to the moment of obtaining information that satisfies an information need?
- **RQ2:** What brain regions correspond to the moment of obtaining information that does not satisfy an information need?
- **RQ3:** What differs in brain activity between the moment an IN is satisfied and the moment when it is not satisfied?

To answer our research questions, we used an fMRI technique, which allows us to acquire brain signals of participants during search. The technique of fMRI was chosen as it provides superior spatial resolution of brain signal, particularly in deep regions of the brain that are not readily accessible by other popular neurotechnologies such as EEG and functional Near Infrared Spectroscopy (fNIRS). This is important as previous investigations of IN and satisfaction have revealed that deep brain regions such as the insula and cingulate cortex play an important role [27, 30].

2 Related Work

Information Seeking describes the process of how an individual seeks for information to resolve an information need [5]. The process can be thought of as finding missing pieces of a puzzle in order to solve the puzzle [7, 36]. The behavioural pattern is explained as a searcher purposefully seeking pieces of information as a result of a need of information to fulfil a gap of knowledge or an information need in order to resolve a task [5].

Once the information need is fulfilled by pieces of relevant information, the searcher themselves will express their satisfaction of information need by terminating a search and make use of the information to complete their task [20].

So, the satisfaction of an information need can be considered as an ultimate goal of the information seeking process [20, 23], which could be influenced by both cognitive and affective factors [1]. Recently, many studies in the field of information science have put great effort in developing models of predicting user satisfaction using feedback collected during a web search, for example dwell time and click-though [11, 15, 21].

A new emerging field in Information Science integrating neuroscience techniques in order to understand concepts of information science is called "Neurasearch" [25]. The imaging techniques include fMRI, EEG, and magnetoencephalography (MEG). Previous works in the field have made use of these techniques to explore brain regions associated with several concepts in Information Science, including the realisation of an information need, relevance judgement, and other search behaviours [22, 26–30, 32]. Other related works also investigated graded relevance using EEG [34] as well as attempts to build a prediction model that can predict relevance judgements using EEG [10]. These works have provided clear evidence of neural correlates of the concepts in Information Retrieval driven by the measurement of brain activity of a searcher. However, evidence of the neural correlates of satisfaction and how it differs from the ongoing search still remain unclear.

3 Experimental Procedure

Design: This study used a within-subject design. Participants were first given a caption and then presented with separate image tiles with the task of determining if the caption matched to the image. The independent variable was satisfaction of the information need and had two levels. One level, labelled as **SAT**, corresponded to when participants could determine that the caption shown matched to the image. The other level, labelled as **UNSAT**, corresponded to trials where, despite seeing every tile making up the image, participants could not determine that the caption matched to the image, i.e. an established and ongoing search that is not satisfied. The time-point of tile presentation used to represent the UNSAT condition for the fMRI analysis was obtained based on behavioural task performance. A final condition, labelled as **FIX**, corresponded to the time of seeing a fixation cross at the beginning of a trial. The dependent variable was the brain activity revealed by the fMRI Blood Oxygen Level Dependent (BOLD) signal.

Stimuli: First, we carefully selected a list of images and converted them into gray-scale images and divided into nine tiles based on a 3x3 matrix. Next, we conducted two preliminary studies to generate a proper set of stimuli for the experiment. In the first study, we aimed to distinguish the difficulty levels of the images. In this study, the participants were recruited to view a caption explaining details of a particular image. The participants then viewed each tile of the image individually presented in random order. They were asked to press the button anytime that they recognised that the caption was proper to the image. As a result, the set of images was categorised into three groups based on difficulty including the levels of easy, moderate, and hard. Next, we asked three assessors to provide a rating of relevance on the moderate group of images in order to generate a pre-defined sequence for each image by sorting the tiles from the least relevant tile to the most relevant tile. Consequently, we obtained a total of 24 stimuli for the fMRI experiment.

Task: We applied the idea of an image puzzle to mimic the information seeking scenario when participants were being scanned. This could allow us to overcome some practical limitations of using fMRI. With this idea, participants have to gather pieces information by viewing a sequence of tiles and integrate the pieces of information in order to answer a particular question.

In the task, participants encounter an image puzzle task, where they have to determine whether a presented caption matches to an image or not. In the task, the image was divided into nine pieces. The participants viewed only one piece of the image at a time. Relating to a web search, each piece of the image could be thought of as a document in a web search that might satisfy an information need of a searcher. A piece of the image could contain relevant/irrelevant information to what the searcher is looking for. This experimental design is an imitation of the information search paradigm in the information seeking process, where a searcher has to gather pieces of information to fulfill their information need. Each piece of an image in this experiment can be thought of as a relevant/irrelevant piece of information in the search process. The searcher will terminate their search when they realise that they have enough information to determine that the image matches the caption.

For each trial, participants were first presented with a caption and given the task of deciding whether the caption was an appropriate description of an image, which was presented to them, one-by-one, as a sequence of nine, image tiles. They then viewed the sequence of image tiles, as described in the Stimuli section. Participants were instructed to view the individual tiles as they were presented and to press the response button as soon as they determined that the caption was an appropriate image description (i.e., realised they satisfied their task). After pressing the button, the whole image was shown to participants, and they were asked to validate their response by pressing the button again if the response they had provided was correct.

Procedure: Ethical permission was obtained from the Ethics Committee of the College of Science and Engineering, University of Glasgow. Participants were instructed that the duration of the experiment was around one hour, approximately fifty minutes to perform the task and ten minutes to obtain the anatomical structure of the brain. Participants were informed that they could leave at any point during the experiment and would still receive payment (payment rate of £6/hr). They were then asked to sign a consent form. Before beginning the experiment participants underwent a safety check to guarantee that they did not possess any metal items inside or outside of their body, or had any contraindications for scanning, such as certain tattoo inks. They were then provided with gear (similar to a training suit) to wear for the duration of the experiment to avoid potential interference with the fMRI signal from any metal objects in their clothes.

All participants were then asked to complete an entry questionnaire, which assessed the participants' demographics and online search experience. Following this, participants were given a corresponding set of example trials in order to familiarise themselves with the procedure. Next, they performed the main task, as shown in Figure 1 where each participant encountered the experimental conditions related to information search while being scanned, i.e. information gathering and response validation for each of the 24 stimuli. At the completion of the study an exit questionnaire was given to assess participants' experience of the experiment.

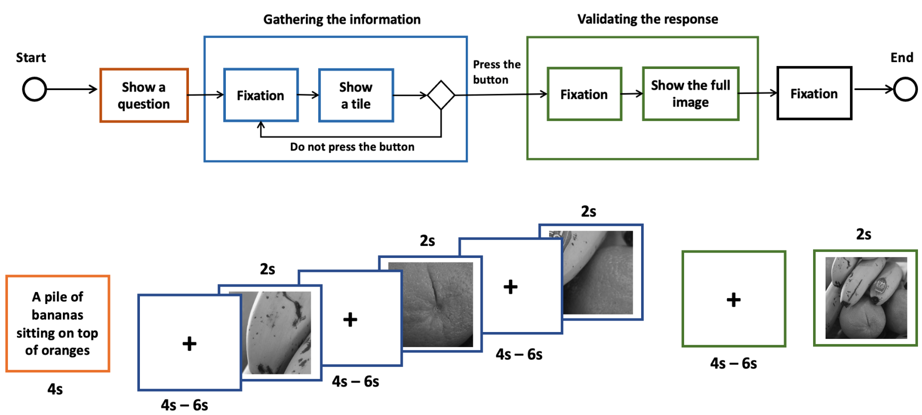


Fig. 1: Experimental procedure shown by both a flowchart and a timeline. Participants were asked to evaluate whether the caption matched to the image. The participants were presented one piece of the image at a time. They would press the button as soon as they were able to make their decision. Then the participants were shown all the tiles together as a single image and asked to press the button again if their judgement was correct.

Image Acquisition: Imaging was performed using a 3T Siemens TIM Trio MRI scanner at the Centre for Cognitive Neuroimaging, University of Glasgow. Functional volumes were acquired using a T2*-weighted gradient echo, echo-planar imaging sequence (68 interleaved slices, TR: 2000ms, TE: 30ms, voxel size: 3 x 3 x 3 mm, FOV: 210mm, matrix size: 70 x 70). Also, a high-resolution anatomical volume was acquired at the end of the scanning using a T1-weighted sequence (192 slices, TR: 1900ms, TE: 2.52ms, voxel size: 1 x 1 x 1 mm, FOV: 210mm, matrix size: 256 x 256).

fMRI Preprocessing: The fMRI data were analysed using Brain Voyager 20. A standard pipeline of preprocessing of the data was performed for each participant [12]. This included slice scan time correction using trilinear interpolation. Three-dimensional motion correction was performed to detect and correct for small head movements by spatial alignment of all the volumes to the first volume by rigid body transformation. In addition, linear trends in the data were removed, and high pass filtering with a cutoff of 0.0025 Hz performed to reduce artefact from low-frequency physiological noise. The functional data were then co-registered with the anatomic data and spatially normalised into the Montreal

Neurological Institute (MNI) space. Finally, the functional data of each individual underwent spatial smoothing using a Gaussian kernel of 6mm to facilitate analysis of group data.

General Linear Model (GLM) Analysis: Analysis began with first-level modeling of the data of individual participants using multiple linear regression of the BOLD-signal response in every voxel. Predictor time courses were adjusted by convolution with a hemodynamic response function. Group data were tested with a second-level analysis using a random effects analysis of variance, using search condition as a within-participants factor. Three contrasts of brain activity included examination of satisfaction vs fixation, no-satisfaction vs fixation and satisfaction vs no-satisfaction. To address the issue of multiple statistical comparisons across all voxels, cluster thresholding was used. This included first using a cluster determining threshold of $p < 0.0005$ and submitting these results to a cluster threshold algorithm that determined chance level for voxels to form a contiguous cluster. MNI coordinates of the peak value of the contrasts were used to identify brain regions and Brodmann areas using Harvard-Oxford cortical and subcortical structural atlases[3][4] and Bioimage Suite[5].

4 Results

Twenty-nine healthy participants joined in the study (16 females and 13 male). All participants were right handed and had normal or corrected-to-normal vision. Participants were under the age of 44, with the largest group between the ages of 18-23 (51.72%) followed by a group between the ages of 24-29 (31.03%). The occupation of most participants was student (89.66%), followed by unemployed (6.9%) and researcher (3.45%). A majority of participants were native English speakers (58.62%) followed by participants with advanced English proficiency (37.93%). On average, participants had around 14 years experience in online searching, often using search services for website browsing, followed by videos and images.

Out of 29 participants, seven participants had head motion exceeding 3mm or 3 degrees while being scanned and therefore we had to exclude them from the analysis due to data artefacts in the Blood Oxygen Level Dependent (BOLD) signal that arises from head movement. Three participants did not correctly follow the instructions. Thus, the fMRI data captured from nineteen participants were used for the final analysis.

Task Perception: To assess participants task perception two questions were asked in the exit questionnaire: (i) "The task we asked you to perform was: [easy/stressful/simple/satisfying]" (with the answer being a 5-point Likert scale (1. Strongly agree to 5. Strongly disagree") and (ii) "I believe I have succeeded in my performance of this task" (with the answer being from a 5-point Likert scale (1-Never to 5-Always). The responses of the participants to this questionnaire

[3] `https://people.cas.sc.edu/rorden/mricron/index.html`
[4] `https://fsl.fmrib.ox.ac.uk/fsl/fslwiki/Atlases`
[5] `https://bioimagesuiteweb.github.io/webapp/`

are shown in Figure 2. The results show that the participants found the tasks moderately easy, simple, satisfying, and not stressful. They also reported that they were very successful in performing the task.

Behavioural Performance: On average, the 19 participants responded correctly on 20 (SD 2.2) of a possible 24 trials to report that the caption matched the image. The distribution of these satisfaction responses are shown in Figure 3. Trials where participants were able to match the caption to the image were subsequently used in the fMRI analysis to represent the SAT condition. There were 3 participants who reported that the caption was matched to the image on all possible trials leaving only 16 participants with UNSAT trials. The UNSAT condition included trials where participants could not match the caption to the image, even after seeing all the tiles.

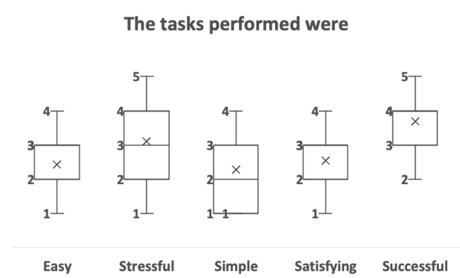


Fig. 2: Task perception results gathered from the exit questionnaire of the participants.

Based on the behavioural results for SAT judgments during the information gathering phase we wished to choose a step of information gathering for the UNSAT condition that would be a suitable for comparison to SAT. For the UNSAT condition we wanted a representative time for an ongoing and established search process that is not satisfied. We choose the seventh step of information gathering (tile 7) to represent the UNSAT condition for several reasons. These included that it had the largest number of responses and corresponded to the time of roughly 75% of the cumulative SAT responses. This choice reduced the difference in time spent searching between SAT and UNSAT. It also reduced fatigue effects that might arise if we used the final step.

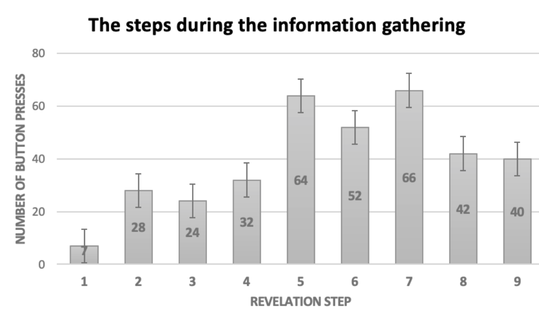
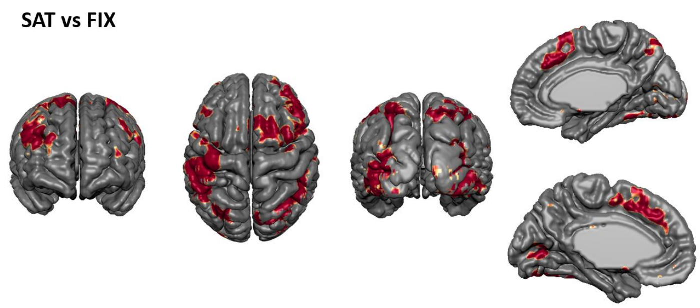


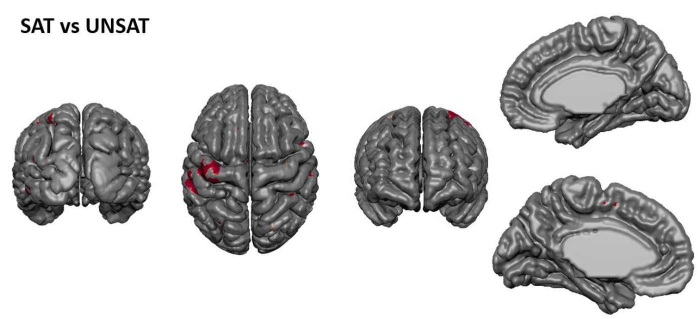
Fig. 3: Results of the nineteen participants during information gathering shown as a bar chart to display the number of button presses indicating satisfaction for each step (termed revelation step) for trials at which satisfaction occurred.

Analysis of the Contrast of SAT vs FIX: In this analysis, we compared brain activity between the SAT and FIX conditions. We hypothesised that this contrast would include brain regions associated with the moment of satisfaction of an information need. In addition, given that SAT contained a button press and complex visual processing, it was expected that the contrast would also reveal



(a) Brain activation maps obtained from contrasting SAT vs FIX, projected on to the surface of the human brain

(b) Brain activation maps obtained from contrasting UNSAT vs FIX, projected on to the surface of the human brain



(c) Brain activation maps obtained from contrasting SAT vs UNSAT projected on to the surface of the human brain

Fig. 4: The figures illustrate three different contrasts (including SAT vs FIX, UNSAT vs FIX, and SAT vs UNSAT) projected on to the three-dimensional surface of a human brain. Each figure also shows four different perspectives of the brain including front view, top view, back view, and medial view.

brain activity related to the planning and execution of the button press as well as possibly increased visual processing.

The results revealed 13 clusters and their activity was higher during SAT than FIX (shown in Figure 4a and Table 1). These regions included postcentral gyrus, insula, superior frontal gyrus, middle frontal gyrus, inferior frontal gyrus, superior temporal gyrus, and basal ganglia. Activity centred in the postcentral gyrus is consistent with our prediction of increased motor activity in the SAT condition. The postcentral gyrus is associated with the somatosensory system and this large cluster in the left hemisphere extended into related motor cortex, which would have been active in the planning and execution of the button press. Similarly, the middle temporal gyrus is known for visual information processing as well as regulating semantic information retrieval processes [6,42]. Thus, finding a cluster in this region is consistent with increased visual processing due to visually processing a tile rather than a fixation cross.

The remaining brain areas found in the frontal cortex and insula can be associated with higher order cognition and evaluation. For example, the inferior frontal gyrus is known to play an important role in memory retrieval and decision making [3, 9, 24]. It is also implicated with the integrative processing of the low-level sensory information in decision making [16, 33]. The superior frontal gyrus is known to be involved in a network of high-level processing areas for working memory and higher order cognitive functions [4]. This region has also been found to be activated during judgments of relevance [30]. The insula has been shown to play a role in affective processing [35, 40]. It has also been implicated in the salience network, which is involved in the identification of stimulus properties of behavioural relevance [39]. As such, the results of this contrast reveal SAT to be a multilayered response suggesting processing in both cognitive and affective domains.

Table 1: Results for the contrast of SAT vs FIX, including the anatomic label, location (MNI coordinates), Brodmann Area (BA), effect size as indicated by F statistic and p-value, and volume for the different brain regions.

	Brain Area	**H**	MNI Coordinates X	Y	Z	BA	Effect size F(1,21)	p-value	Voxels mm^3
SAT > FIX	Postcentral Gyrus	R	63.0	-16.0	28.0	3	30.07	0.000033	701
	Postcentral Gyrus	L	-42.0	-25.0	46.0	2	102.89	<0.000001	133206
	Superior Frontal Gyrus	R	36.0	47.0	34.0	9	63.17	<0.000001	38645
	Insula	R	33.0	26.0	-5.0	13	72.12	<0.000001	4537
	Superior Temporal Gyrus	R	54.0	-25.0	-11.0	21	40.30	0.000006	503
	Lentiform Nucleus	R	18.0	-1.0	4.0	*	51.48	0.000001	994
	Lentiform Nucleus	R	21.0	8.0	1.0	*	32.07	0.000023	767
	Lentiform Nucleus	L	-18.0	-1.0	4.0	*	38.59	0.000007	4195
	Claustrum	L	-30.0	20.0	4.0	48	53.16	0.000001	3836
	Middle Frontal Gyrus	L	-33.0	50.0	16.0	10	29.44	0.000037	575
	Insula	L	-36.0	-1.0	13.0	13	32.34	0.000022	391
	Middle Frontal Gyrus	L	-42.0	29.0	43.0	8	36.68	0.00001	1581
	Inferior Frontal Gyrus	L	-51.0	8.0	25.0	9	63.40	<0.000001	4260

Analysis of the Contrast of UNSAT vs FIX: In this analysis we compared brain activity in the UNSAT and FIX conditions. We hypothesised that this contrast would reveal brain regions associated with cognition related to the ongoing process of search. In addition, given that UNSAT included complex visual processing, it was expected that the contrast would reveal evidence of increased visual processing.

Results obtained six clusters, shown in Figure 4b and Table 2 and all were found to have higher activation during the UNSAT condition than FIX. The results included middle occipital gyrus, inferior frontal gyrus, medial frontal gyrus, and cuneus. Consistent with our expectation that the UNSAT condition would include higher activation in visual areas we found activation in the region of middle occipital gyrus which is typically known for visual perception and object recognition [41, 44]. As well, the activation in the cuneus can be related to visual processing. The remaining brain areas, which were all located in frontal cortex can be associated more with higher order cognition than with affective processing. For example, the inferior frontal gyrus region has been reported to be responsible for processes of memory retrieval and integrating information from sensory regions in the decision making process [3, 9, 24]. The left medial frontal gyrus is known for executive functions and decision-related processes [37].

Table 2: Results for the contrast of UNSAT vs FIX, including the anatomic label, location (MNI coordinates), Brodmann Area (BA), effect size as indicated by F statistic and p-value, and volume for the different brain regions.

	Brain Area	**H**	MNI Coordinates X	Y	Z	BA	Effect size F(1,21)	p-value	Voxels mm^3
UNSAT > FIX	Middle Occipital Gyrus	R	27.0	-97.0	-2.0	18	43.63	0.000008	396
	Cuneus	R	9.0	-85.0	4.0	17	55.78	0.000002	1119
	Cuneus	L	-6.0	-73.0	4.0	30	36.60	0.000022	900
	Medial Frontal Gyrus	L	-3.0	20.0	49.0	8	44.50	0.000007	388
	Medial Frontal Gyrus	L	-3.0	29.0	40.0	6	41.26	0.000011	203
	Inferior Frontal Gyrus	L	-39.0	20.0	-11.0	47	37.81	0.000019	502

Analysis of the Contrast of SAT vs UNSAT: This analysis examined differences in brain activity between SAT and UNSAT conditions. We hypothesised that this contrast would reveal brain regions that differ between these two cognitive states, as well as differences in motor activity due to the presence of the button press in the SAT condition.

Results, based on contrast of the nineteen participants in the SAT condition versus the sixteen participants in the UNSAT condition revealed six clusters. The results are shown in Figure 4c and Table 3. All six clusters had higher activation during SAT than UNSAT, which included postcentral gyrus, precentral gyrus, inferior frontal gyrus, superior parietal lobule, declive, and middle occipital gyrus. The postcentral and precentral regions are associated with primary somatosensory functions and motor planning. Thus, these regions were likely involved in the motor planning of the button press during the SAT condition. The remaining brain areas included the right inferior frontal gyrus, which is known to be involved in working memory and attentional control [14, 38]. It also included the superior parietal lobule, a region implicated in manipulating information in working memory [19]. It is also known for regulating visuospatial attention as part of frontoparietal attention network [43].

Table 3: Results for the contrast of SAT vs UNSAT, including the anatomic label, location (MNI coordinates), Brodmann Area (BA), effect size as indicated by F statistic and p-value, and volume for the different brain regions.

	Brain Area	H	MNI Coordinates X	Y	Z	BA	Effect size F(1,21)	p-value	Voxels mm^3
SAT > UNSAT	Postcentral Gyrus	R	51.0	-25.0	52.0	2	31.04	0.000053	527
	Inferior Frontal Gyrus	R	45.0	8.0	25.0	9	42.85	0.000009	654
	Declive	R	33.0	-64.0	-17.0	*	45.89	0.000006	457
	Superior Parietal Lobule	L	-30.0	-61.0	46.0	7	33.04	0.000039	908
	Precentral Gyrus	L	-42.0	-16.0	61.0	4	43.24	0.000009	6384
	Middle Occipital Gyrus	L	-42.0	-73.0	-2.0	19	39.42	0.000015	1965

5 Discussion and Conclusion

In this paper, we aimed to understand how the satisfaction of information need physically emerges inside the human brain. Satisfaction of information need is a topic of crucial importance in the information retrieval and information science communities. The field has made great progress in developing systems that can deliver a piece of relevant information to a searcher. However, understanding the internal mechanisms of how searchers determine that they have enough information for their task remains unclear. To advance our understanding of the satisfaction of information need, we conducted an experiment to measure the brain activity of nineteen participants while they performed an experimental task scenario that simulated information seeking.

The contrast of brain activity between the moment of satisfaction and the baseline measurement of fixation helps us to answer **RQ1**. Results of this comparison of brain activity, SAT>FIX, revealed activity in 13 brain regions. Of particular interest are two regions of activity that include bilateral regions of both the frontal cortex and the insula. The regions of the frontal cortex include the left inferior frontal gyrus (BA9). This region is associated with a variety of cognitive functions and would likely have been included in the large cluster previously reported in a study of information need [30] that was centred in the left dorsolateral prefrontal cortex. This previous region was found to be more active when a question could be answered than when it could not. This provides converging evidence that the left inferior frontal gyrus plays an important role when an information need is satisfied. This region has been widely suggested to be involved in selection demands when performing semantic tasks [13, 31] along with the controlled retrieval of semantic information [31]. Interestingly, the previous result [30] was obtained with a text-based task, while the current task was image-based, raising the possibility that the involvement of the left inferior frontal gyrus might be independent of modality. The finding of insula involvement is interesting from the standpoint of its general role in affective and other evaluative aspects of brain response. In particular, the insula is part of the salience network, which is activated when items in the world are determined to have behavioural relevance. The salience network has also been found to be active in the contrast of brain activity between satisfaction judgments and relevance judgments [27]. Thus, converging evidence points towards involvement of the insula, possibly in its affective capacity of determining behavioural relevance, in the satisfaction of information need.

The contrast of brain activity between a moment of ongoing information search that does not satisfy the information need and a baseline measurement of fixation helps us to answer **RQ2**. This contrast of UNSAT>FIX revealed activity in 6 brain regions. Of particular interest are three regions in the left frontal cortex that have been implicated in complex cognition. Two of these regions were in the medial frontal gyrus, which is a known heterogeneous region associated with many cognitive functions [8]. The other region, the inferior frontal gyrus (BA 47) has been reported to be involved in semantics of language, though it is not clear how language would be involved in the current task. Overall, the results addressing **RQ2** point to areas of the frontal cortex involved in cognition. Though it is possibly difficult to infer more than the involvement of high level cognition, it is notable that the results do not provide evidence to support an affective response.

Brain activity at the moment of satisfaction compared to a moment of ongoing not satisfied information search helps us to answer **RQ3**. In the SAT>UNSAT condition, we found 6 brain regions, which are mainly located in the left superior parietal lobule and the right inferior frontal gyrus (BA9). Potentially, the parietal cortex activation could result from more robust recruitment of attention to items in an image tile that satisfies an IN, compared to an image tile which does not. Finally, the larger activity in the right inferior frontal gyrus is found on the other side of the brain to the inferior frontal gyrus finding from the contrast of SAT vs FIX, making it harder to directly relate the two. The region has been ascribed to higher order cognition and thus we can take the result as indicating a difference in cognitive processing in trials where the information need is satisfied.

Our results addressing **RQ1** provide converging evidence of the importance of the inferior frontal gyrus and the insula in understanding the moment of satisfaction. They further suggest that both cognitive and affective processes are at work during the moment of satisfaction. However, while the data supporting **RQ2** and **RQ3** clearly implicate regions of the frontal cortex, they provide less clear an interpretation of the nature of these cognitive functions. Future research should explore in more detail the ongoing brain activity preceding the moment of satisfaction in order to more fully understand the particular brain processes at work. In the current work we examined this preceding brain activity at a single point in time and future work could benefit from exploring how brain activity might reflect an accumulation of information that leads to satisfaction. One limitation of the current research was that for some of the contrasts, the brain activity found could possibly be related to the button press. Although it is possible to discount these activities, future research might design a task where the effect of the button press is less of an issue.

In conclusion, the results from our study revealed cognitive and affective brain regions involved in satisfying an information need, suggesting differences in brain activation associated with cognitive processing involved in an information search. By investigating SAT alone and the contrast SAT to UNSAT the results go past previous reports [27] that only contrasted relevance to satisfaction. We believe that this study will provide a great contribution to the community. The study revealed the brain regions underlying both the moments of satisfaction and no-satisfaction. These results, particularly for deep brain regions such as the insula, might be helpful in the future with the use of other technologies such as EEG, because knowledge of the activity of deep brain structures can be used to shape interpretation of EEG results [18]. Thus, these results not only advance our theoretical understanding of affective and cognitive processes during satisfaction of search, but they also could be used to advance the effectiveness of more portable brain imaging technology such as EEG and fNIRS.

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