Understanding Information Need: an fMRI Study

Yashar Moshfeghi
School of Computing Science
University of Glasgow
Glasgow, UK
Yashar.Moshfeghi@glasgow.ac.uk

Peter Triantafillou
School of Computing Science
University of Glasgow
Glasgow, UK
Peter.Triantafillou@glasgow.ac.uk

Frank E. Pollick
School of Psychology
University of Glasgow
Glasgow, UK
Frank.Pollick@glasgow.ac.uk

ABSTRACT

The raison d'etre of IR is to satisfy human information need. But, do we really understand information need? Despite advances in the past few decades in both the IR and relevant scientific communities, this question is largely unanswered. We do not really understand how an information need emerges and how it is physically manifested. Information need refers to a complex concept: at the very initial state of the phenomenon (i.e. at a visceral level), even the searcher may not be aware of its existence. This renders the measuring of this concept (using traditional behaviour studies) nearly impossible. In this paper, we investigate the connection between an information need and brain activity. Using functional Magnetic Resonance Imaging (fMRI), we measured the brain activity of twenty four participants while they performed a Question Answering (Q/A) Task, where the questions were carefully selected and developed from TREC-8 and TREC 2001 Q/A Track. The results of this experiment revealed a distributed network of brain regions commonly associated with activities related to information need and retrieval and differing brain activity in processing scenarios when participants knew the answer to a given question and when they did not and needed to search. We believe our study and conclusions constitute an important step in unravelling the nature of information need and therefore better satisfying it.

Keywords: Anomalous States of Knowledge, Information Need, Information Retrieval, fMRI Study

1. INTRODUCTION

The main goal of Information Retrieval (IR) systems is to satisfy searchers' information need (IN). Given the core and fundamental role IN plays in an information seeking and retrieval process, over the last several decades much research has been dedicated to better understand this concept in both information retrieval and other relevant scientific communities. As a result of such research, seminal theories, models, and findings have been published, shaping the foundations of current IR systems. A few examples of such influential works are Wilson's Information Seeking Behaviour model [46], Kuhlthau's Information Seeking Process (ISP) model [28], Ingwersen's Cognitive IR Theory [21], and Belkin's Anomalous States of Knowledge (ASK) model [8]. These works are mainly based on *behavioural studies of searchers* while they engaged in an Information Retrieval and Seeking process, mainly through questionnaires/interviews [28], or by observing and studying searchers interaction with IR systems via their submitted queries and their reformulation [26], or via their interaction with retrieved results [44]. Despite their invaluable contributions, they have all investigated the phenomenon of IN indirectly, via some sort of mediator. Therefore, important research questions remain unanswered, such as:

- **RQ1:** "What is the nature of IN from a neuropsycology perspective?";
- **RQ2:** "Is there a clear, detectable, physical manifestation (i.e. neural correlate) of IN in human brains?";
- **RQ3:** "Can such manifestations be identified in an early stage of an information seeking and retrieval process?"; and
- **RQ4:** "Do such manifestations differ when an anomaly in the user's state of knowledge has been experienced? i.e., when searchers choose not to engage in a search process (Don't know – Don't search Scenario), compared to a scenario where they engage in a search process (Don't know – Do Search Scenario)?".

An answer to these questions will definitely improve our understanding and lead to robust definitions of the IN concept. And, fundamentally, it will play a key role in opening new doors to the design and implementations of novel IR techniques which will be enabled to better (and even proactively) satisfy searchers' need. The research described in this paper represents our efforts towards this direction. In particular, in this paper we focus on discovering and mapping the brain mechanisms of IN realisation, within an information retrieval process performed by humans engaged in a Question Answering (Q/A) retrieval task. Our central aims are to identify: (i) the brain regions associated with an IN realisation (in its earliest state) and (ii) contrast the scenarios where individuals engage in search or simply state the

SIGIR '16, July 17–21, 2016, Pisa, Italy.

ACM ISBN 978-1-4503-4069-4/16/07..

DOI: http://dx.doi.org/10.1145/2911451.2911534

need to search. We are focusing on the time period in which the brain exhibits the highest activity with regards to the process of IN realisation, from the moment of observing a question, i.e. recognising an ASK. The identification of the brain regions involved in an IN realisation (in particular in an early state) and observing the period of time in which there is a clear association of the activation of brain regions where there exists an Information Need, can be the basis to detect an IN in a Q/A task.

Our experiments rely on measuring Blood Oxygenation Level Dependent (BOLD) signals and the fact that BOLD signals can be analysed to detect significant brain activities in the process of realising an IN in a Q/A task. In particular, we aim to identify the time frame in which significant activity appears in users' brains, while they are realising an IN. In this spirit, this paper reports the results of an fMRI based user study on Q/A search. In particular, we have monitored, by an MRI device, the brain activities of twenty four participants engaged in a Q/A search task for a predefined set of questions with respect to a predefined set of relevant and non-relevant documents. In order to do so, we devised an experiment consisting of collecting data via a 3T MRI scanner in a lab-based user study, and analysed the collected data off-line. Our hypothesis is that there are brain regions in which the BOLD signals would be different for No-IN scenarios (i.e., "know the answer") versus IN scenarios (i.e., "don't know an answer and need to search"). Moreover, this difference would be sensitive to whether individuals engage in search or simply state the need to search.

The remainder of the paper is organised as follows: Section 2 presents related work and the background. Section 3 discusses at length the experimental methodology. Section 4 presents and analyses our results. Finally, Section 5 presents our key conclusions.

2. RELATED WORK

2.1 IN Complexity and the IN-Query Gap

IN is an essential concept and at the core of the information retrieval processes. When searchers realise an information need, they experience an anomaly in their current state of knowledge (ASK) [8]. As a result, search processes are initiated: Searchers transform their IN into a query and submit it to an IR system. In turn, the IR system retrieves potentially relevant documents, aiming to satisfy the IN. Subsequently, searchers evaluate retrieved documents, accumulating relevant information which leads them to satisfy their IN. Often, however, searchers are not satisfied with the results obtained in response to their initial query formulation [42], and thus must engage in further interaction with the system to resolve their need. Therein lies the complexity associated with the concept of IN.

The complexity of IN rests in its paradoxical nature [12]: Unlike other primary human need (e.g., physiological ones), it is often unknown to the individual beforehand what information is required to satisfy the IN. Research indicates that this is because an IN is "intangible and visceral" and therefore "unknowable and non-specifiable" – thus, how can one express an IN using a query to an IR system? [8, 12] Hence, the very nature of IN inherently makes it nearly impossible for searchers to correctly map their IN to a IR query [8, 9, 20, 12, 40]. This produces a gap between how an IN is represented (i.e. the formulated query) and the actual IN, because the formulated query is not guaranteed to provide an exact description required to retrieve the relevant documents [45]. In other words, expressing an IN using a set of query keywords is considered to be uncertain and noisy [41], as it can only vaguely approximate the actual IN [40]. The problem becomes even more pronounced when an IN is *ill-defined*: i.e., when the searcher only knows "fringes of a gap in [his/her] knowledge" [12] making it extremely difficult for the searcher to identify and describe the IN [7, 8, 11]. Therefore, it is possible that a given query may not sufficiently define the characteristics of relevant documents, or even any relevant information, since a searcher cannot form an appropriate initial state from which to form a query [13].

Taylor's [40] classic four-level theory of IN theorised the complex nature of IN as follows: (i) a search begins with a process based on an area of doubt or a gap in understanding, which is a compromised expression of the need (Taylor calls this the Q4 level). The searcher, as a result of searching, can subsequently frame an IN, borrowing generic knowledge frames from adjacent areas in memory; at a certain point, a transformational event of information use leads to the IN being actualised, resulting in the information search becoming focused. This transformation in the use of information causes the searcher's Q4 compromised level of need to access deeper levels of the need, i.e. the formal expression of the need (Taylor calls this the Q3 level), the conscious "within brain" description of the need (Taylor calls this the Q2 level) and finally the deepest level of the need is the "visceral" (i.e., instinctual) level (Taylor calls the Q1 level) [40, 12]. What is of particular interest to the current paper are the lower levels in Taylor's conceptualisation of IN, namely the unconscious, visceral information need (which the user cannot know and therefore cannot specify to the IR system) leading to the "within brain" description of the IN. Ingwersen [21] in his Cognitive theory of IR explains that, based on the perspective of cognitive science, theories of information and empirical evidence, an appropriate approach to understanding IR is first to examine the mental formation of the information need and use this as the starting point for IR interaction. This formulation is a central issue in IR. This paper takes substantial motivation from this vein of research, arguing that IR systems that can detect and understand INs, starting from their Q1 levels, can better satisfy them.

2.2 Closing the IN-Query Gap

Typically, IR systems rely on a progressive disambiguation of the user's information need through an interactive and iterative process known as the relevance feedback cycle. Relevance feedback is central to the IR system's efforts to construct a better representation of the users' IN. Relevance feedback may be gathered through explicit [27], implicit [43], and/or affective feedback [2]. Explicit feedback is viewed as a robust method to improve retrieval effectiveness [27]. However, it is not always applicable due to the cognitive burden that it places on users [44]. Enter implicit feedback, in which relevance is inferred from the interactional data in an indirect and unobtrusive manner [22]. For example, researchers try to understand how task [43], dwell time [25] and click-through [22] relate to relevance. However, a problem occurs when actions are taken as an indication of relevance without sufficient evidence to support their effectiveness [36]. For example, Kelly and Belkin [24] show that the implicit feedback measures based on user interaction with the full content of documents can often be unreliable, and difficult to measure or interpret. Recently, affective feedback has been proposed [2] which relies on capturing facial expression [5], eye tracking [30], and physiological signals [3, 33] (such as skin temperature) and uses them as implicit relevance judgements. However, these methods can only help researchers to understand the concept of relevance to a certain level and are not considered to be very effective. Implicit feedback IR systems, albeit noisy, can collect several distinct signals of the user's interests through the analysis of both user's actions and user generated contents [44]. Recently, affective and physiological features have been considered as a valid ground to define implicit feedback techniques [2, 35, 33]. For example, Arapakis et al., studied the role of emotions in information retrieval, and introduced a number of models [2, 4]. In their subsequent work, the authors have shown that emotional features can be effectively included in building implicit feedback systems [4], and they can also be used to personalise search [2]. Similarly, the work by Moshfeghi et al. demonstrated that, in addition to emotional features [34], physiological features can also be used to model relevance and they can also be used to predict task types [33].

2.3 Neuropsychology and IR

Recent research has begun to examine IR from a neuroscience perspective, using techniques of brain imaging to reveal the brain activity related to the underlying neural activity of a user. One particular area of emphasis to this research has been to examine the concept of relevance. Results of Moshfeghi et al. [35] showed, using fMRI, that it is possible to identify brain regions activated by the process of judging relevance of an image. The brain regions they reported included the inferior parietal lobe, inferior temporal gyrus and superior frontal gyrus; the activation of these regions during relevance assessment was significantly higher when evaluating relevant items.

Another example is a study conducted by Eugster et al. [17] that used EEG to show that the frequency content of the EEG signal as well as Event Related Potentials (ERPs) can be used effectively as a set of features to decode the relevance of a text. Similarly, Allegretti et al. [1] reported on EEG results that indicated that within 500 ms EEG signals begin to appear that differentiate between viewing a relevant and a non relevant image. Likewise, Kauppi et al. [23] used magnetoencephalography (MEG) to show that the frequency content of the MEG signal, along with eye movement data can be used for decoding relevance of images. These studies have used the relative strength of the different measurement techniques to make great progress and to indicate where in the brain relevance judgments are happening and what the time course is of these neural processes that determine relevance.

However, the above studies have not investigated the wider view of how IN emerges. In this paper we take an important step to understanding the neural processes involved with primary stages when an IN emerges.

3. EXPERIMENTAL METHODOLOGY

3.1 Research Questions and Hypothesis

This paper studies the concept of information need from a neuropsychological perspective by investigating brain activity during periods in which an information need was induced. In particular, we implemented two different scenarios to create information need, in both scenarios participants were asked a multiple choice question, but in the first scenario when participants confronted an ASK they only had the option to acknowledge that they needed to search, they could not act on this IN. In the second scenario when participants confronted an ASK they were able to engage in a search process. Our hypothesis was that there exists brain regions for which the activation levels are different depending on the state of information need and that the regions found for these two scenarios would provide measurement data of brain states to complement our theoretical understanding of IN.

Related to our hypotheses there are several considerations on the design and analysis of fMRI data [35, 14]. Of particular importance are several factors that were critical in guiding our research plans. Firstly, the fMRI scanning environment is restrictive in that a participant must lay supine with their head kept still, and that only limited response/interactive devices can be in this scanning environment without causing signal or safety issues. This constraint led to the use of multiple choice questions for a task since it was possible to provide response using an MRI-compatible button box. Another constraint is that while fMRI provides the ability to localise activity to within millimetres, the temporal resolution of fMRI (the time to take a single measurement of the entire brain) is on the order of around 2 seconds. This relatively slow rate of data acquisition is compounded by the fact that the Blood Oxygenation Level Dependent (BOLD) signal measured is related to the underlying neural signal in a complex way that introduces further delays [18]. To address these delays it was necessary to time the events of the different scenarios at a rate that was compatible with our fMRI measurements. To achieve a suitable design for our questions about IN we adapted the methods used in related work in problem solving [47] which examined neural correlates of insight by comparing brain activity when a multiple choice response showed insight, to brain activity when a multiple choice response did not show insight.

3.2 Design

A "within-subjects" design was used in this study. The independent variable was the information need (with two levels: information need, and no information need), which was controlled by responding to questions viewed on the screen. The set of questions were designed so that averaged across all participants there would be an equal number of responses expressing an answer and expressing a need for search. The dependent variable was brain activity revealed by the BOLD signal.

3.3 Task

Each participant completed two different search scenarios.

Question-Response (QR) Task: In the first scenario, which we term Question-Response (QR), participants were first presented with a question for 4 seconds, then for 4 seconds four possible responses were provided while the question stayed on the screen (Figure 1). Participants could not make a response until after the 4 seconds of observing the possible responses. This was done so that brain activity related to the motor response of pressing the button would not be contained in the model of brain activity, which only considered these first 8 seconds. After the 8 seconds participants were able to respond and in this QR scenario the experiment progressed directly on to the next trial. Of the four possible responses, one was always the correct answer and one of them was always “need to search”. The position of the four alternatives was randomised for each trial and the response given by pressing one of the four buttons available on the button box that each participant had in their right hand. The time to respond was left free so that participants were not under time pressure to respond. The order of the questions was randomised for each participant.

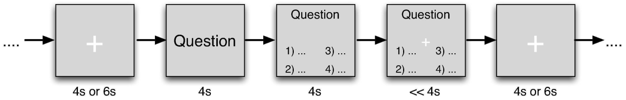

Figure 1: A schematic representation of Scenario 1

Question-Response-Search (QRS) Task: In the second scenario, which we term Question-Response-Search (QRS), participants performed the same task as in the QR scenario except that if the answer ”need to search” was provided then they entered an additional stage where they formulated a search query (and submitted it verbally into a noise-cancelling microphone), received a document and evaluated this document. In the present study we do not investigate brain activity during the search and document evaluation periods. Instead we focus only on the brain activity in response to the the presentation of the question and the possible responses. The difference between the two scenarios is that in Scenario 1 participants do not engage in a search process, while in the second scenario they do engage in a search process. This is important from the conceptual stance that in Scenario 1 stating the need to search is the endpoint of the entire process, while for Scenario 2 it is a transition to the start of a search.

3.4 Question Answering Dataset

In order to perform the two task scenarios mentioned in Section 3.3, we created a Question Answering dataset[1]. To develop this standard set of questions, we used previous runs of TREC Q/A Track, in particular we carefully selected a set of 80 questions from the TREC-8 and TREC-2001 Question Answering Tracks - Main Task[2]. We chose these two Tracks since they were the first and last tracks where the questions presented there were (i) independent from one another, in contrast to other Tracks that share a relationship, and (ii) they also provided the correct answer to the questions.

We then manually examined all the questions presented in these two tracks and selected a subset of questions that (i) were not longer than one line, and (ii) the correct answer to the question was not longer than 5 words. This constraint is due to the limitation of presenting the questions and options to the participants in an fMRI settings. An additional constraint was that there were at least two relevant and non-relevant answers in their QRel. We then removed the questions that were ambiguous or were time dependent, e.g. Who is the president of Stanford University? (TREC-8, Topic 51), making the answers provided in the Track not appropriate. The answers of all these questions were then checked by current search engines to make sure that the answers are still valid and correct. We also created two wrong answers for each question that were in the domain of the question, e.g. ”What is supernova?” (TREC-2001, Topic 1067) the correct answer is “An exploding star” and we created two other wrong answers i.e. “A newborn star” and “A dead star”. We also made sure that the questions covered a wide range of topics, e.g. history, politics, science, etc. This was done in order to reduce any bias that might occur from emphasis of a particular type of question.

Over this set of questions, two annotators separately judged the difficulty of the questions (i.e. hard or easy) and then selected a subset of 80 questions where both annotators agreed upon their difficulties, i.e. 40 of them were hard and 40 were easy questions. For Scenario 1, 40 questions out of these 80 questions were selected where 20 were easy and 20 were hard questions. The remainder of the questions were used for Scenario 2. Since Scenario 2 was divided into two runs, additional care was made to further divide the questions across the runs so that they both had 10 easy and 10 hard questions covering a variety of topics. The goal of this procedure was to control the set of questions such that on average there was an equal chance of experiencing ASK and knowing the answer.

Another extra step for Scenario 2 was to prepare the documents that were shown to the subjects once they engaged in a search process. This took the form of simulating a snippet answer that is returned by current search engine such as Google when a question is submitted. For this purpose we selected two relevant and two non-relevant documents from QRel. The length of the answers provided in TREC-8 and TREC 2001 were incompatible. In order to keep the size of the results consistent, for those answers that were too short, we found the original source file and selected sentences around the answer so that all snippets had the same length. The average length of the answers shown to the participants for first and second run of Scenario 2 were 39.47 words (SD of 3.33) and 39.65 words (SD of 3.285) respectively. This was done in order to reduce any potential confounding effect of snippet size on the brain activity results.

3.5 Procedure

This section outlines the flow of the study, from beginning to end. Ethical permission for the study was obtained from the Ethics Committee of the College of Science and Engineering, University of Glasgow. Participants were recruited from the participant database at Centre for Cognitive Neuroimaging, University of Glasgow. Participants were instructed of the duration of the experiment, which included approximately 50 minutes to perform all tasks examining information need, and approximately 10 minutes to obtain a scan of their anatomical structure. They were informed that they could leave at any point in time during the experiment and would still receive payment (the payment rate was £6/hr). They were then asked to sign a consent form. Before participating, participants underwent a safety check to guarantee that they did not possess any metal items inside or outside of their body, or any other contraindications for scanning, such as certain tattoo inks. They were

---

[1] The Question Answering dataset is available upon request.

[2] For more information please visit http://trec.nist.gov/data/qa/t8_qadata.html and http://trec.nist.gov/data/qa/2001_qadata/main_task.html

then provided with gear (similar to a training suit) to wear for the duration of the experiment to avoid interference from any metal objects in their clothes with the fMRI signal.

Next, as a training process they were given an example task and a corresponding set of example questions in order to familiarise themselves with the procedure. Once they had successfully completed their training task, participants entered the fMRI machine and the experimenter adjusted the settings of the machine to maximise their comfort and vision. While being scanned, each participant first participated in one run of the QR scenario, which contained 40 questions. They then participated in two separate runs of the QRS scenario, with each run comprised of 20 questions. Two runs were chosen to give the participants a further break to relax during the scanning and to prevent fatigue on the QRS task, which consumed more time. After the functional runs were complete the anatomical data of each participant was obtained.

After completion of scanning participants were asked to fill out an exit questionnaire that provided further demographic and qualitative descriptions of their experience during the experiment. They also filled out the Edinburgh handedness questionnaire [37] which provides evaluation of whether the participant was right-, left- or mixed-handed. Handedness information was obtained since lateralization of brain function is influenced by handedness and we wished to ensure that our sample of participants approximated the general population.

Apparatus: The images were presented using Presentation® software[3], and projected using a LCD projector onto a translucent screen, while participants watched them in an angled mirror in the MRI scanner.

fMRI Data Acquisition: All fMRI data was collected using a 3T Tim Trio Siemens scanner and 32-channel head coil at the Centre for Cognitive Neuroimaging, University of Glasgow. A functional T2*-weighted MRI run was acquired for the single run of the QR scenario and the two runs of the QRS scenario (TR 2000ms; TE 30ms; 32 Slices; $3mm^3$ voxel; FOV of 210, imaging matrix of 70 × 70).

An anatomical scan was performed at the end of the scanning session that comprised a high-resolution T1-weighted anatomical scan using a 3D magnetisation prepared rapid acquisition gradient echo (ADNI- MPRAGE) T1-weighted sequence (192 slices; $1mm^3$ voxel; Sagittal Slice; TR = 1900ms; TE = 2.52; 256 × 256 image resolution).

Questionnaires: At the end of the experiment, the participants were introduced to an *exit questionnaire*, which gathered background and demographic information. It also enquired about previous experience with fMRI type user studies as well as participants general comments for the user study. Finally, it also included questions to ascertain participants' subjective experience of performing the experiment.

Pilot Studies: Prior to running the actual user study, a pilot study was performed using two participants to confirm that the process worked correctly and smoothly. A number of changes were made to the experimental paradigm based on feedback from the pilot study. After the pilot, it was determined that the participants were able to complete the user study without problems and that the system was correctly logging participants' interaction data.

4. RESULTS

A study with the procedure explained in Section 3.5 was conducted over 15 days from 7 December, 2015 to 22 December, 2015. Participants consisted of 24 healthy individuals with 11 males and 13 females. All participants were under the age of 44, with the largest group between the ages of 18-23 (54.1%) followed by a group between the ages of 30-35 (20.8%). The handedness survey indicated that 79.1% were right-handed, 12.5% were left-handed and 8.33% were mixed-handed. Participants tended to have a postgraduate degree (20.8%), bachelors (33.33%) or other qualifications (45.8%). They were primarily students (54.1%), though there were a number of individuals who were self-employed (20.8%), not employed (4.16%) or employed by a company or organisation (20.8%). Participants were primarily native speakers (79.1%) or had an advanced level of English (20.8%). They all had experience in searching, with an average of 11.66 years (SD of 3.58) experience.

Task Perception: At the end of the procedure an exit questionnaire was performed that included questions about participants' overall subjective experience of performing the tasks. These questions specifically addressed participants' perception of their performed tasks in terms of the difficulty of the task, the familiarity of the participant with the task and the extent to which they found the task stressful, clear, successful, and satisfactory. Namely, participants were given the following questions *"The tasks we asked you to perform were [easy/stressful/familiar/clear/Satisfactory] (answer: 1: "Strongly Disagree", 2: "Disagree", 3: "Neutral", 4: "Agree", 5: "Strongly Agree")"*. Descriptive statistics of these responses are shown by box plots in Figure 2, which show five key statistics: the minimum, first, second (median), third, and maximum quartiles.[4]. These results indicate that participants found the tasks difficult (not easy) and stressful, familiar, clear, successful, and satisfactory.

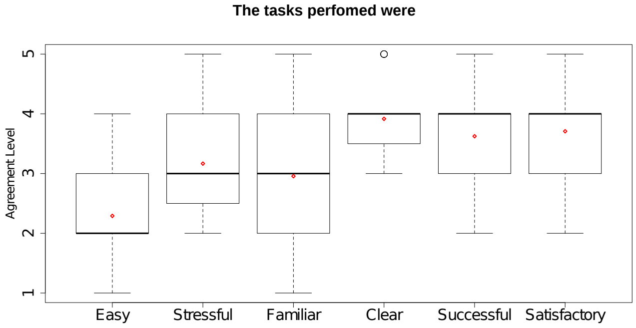

Figure 2: Box plot of the task perception based on the information gathered from the questionnaires of 24 participants. The red diamond represents the mean value.

Log Analysis: The fMRI analysis for both Scenario 1 and Scenario 2 relied upon a participant's response of the question to code whether a trial was IN or No-IN. This raised two considerations: firstly, for examination of brain data within a scenario it is important to have approximately an equal response rate for IN and No-IN responses. Secondly, comparison across scenarios is strengthened by having similar response rates since this argues against the possibility

---

[3] Presentation® software (Neurobehavioral systems, Inc.), http://www.neurobs.com.

[4] Further information can be found in [31].

that any difference found was due to simply response bias. Thus, it was important to examine the average response rates for whether the number of IN and No-IN responses were approximately balanced for each scenario and whether there was a difference between scenarios. In Scenario 1 the average number of IN responses was 18.45 (SD of 4.59) and the average number of No-IN responses was 21.42 (SD of 4.41). A paired t-test revealed that there was no difference between the type of responses (p-value = 0.12). In Scenario 2 the average number of IN responses was 17.5 (SD of 5.91) and the average number of No-IN responses was 22.5 (SD of 5.91). A paired t-test revealed a marginal difference between the type of responses (p-value = 0.05). An examination of the response rates across scenarios using paired t-tests revealed no significant difference between scenarios for either IN responses (p-value = 0.24) or No-IN responses (p-value = 0.19).

fMRI Data Preprocessing: The fMRI data were preprocessed using Brain Voyager QX[5]. A standard pipeline of pre-processing of the data was performed for each participant [19]. This involved slice scan time correction using trilinear interpolation based on information about the TR and the order of slice scanning. Three-dimensional motion correction was performed to detect and correct for small head movements by spatial alignment of all the volumes of a participant to the first volume by rigid body transformations. 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 coregistered with the anatomic data and spatially normalised into the common Talairach space [39]. Finally, the functional data of each individual underwent spatial smoothing using a Gaussian kernel of 6mm to facilitate analysis of group data.

4.1 General Linear Model (GLM) Analysis

Analysis began with a first-level analysis on the data of individual participants using multiple linear regression of the BOLD-response time course in each voxel, using two predictors for the different Response Type (respond need to search, respond with answer). To achieve this, for each participant's data a BrainVoyager protocol file (PRT) was derived that represented the onset and duration of the 8s total time that the question (4s) and question and possible responses (4s) were available. Predictors' time courses were adjusted for the hemodynamic response delay by convolution with a hemodynamic response function. Group data were statistically tested with a second-level analysis using a random effects analysis of variance using Response Type as a within-participants factor. To address the issue of multiple statistical comparisons across all voxels, activations are reported using False Discovery Rate (FDR) at a threshold of $q < 0.01$ [10]. Using FDR we control for the number of false positive voxels among the subset of voxels labelled as significant.

Main Results: The key findings which emerged from the results are that the analysis of fMRI brain data revealed differences in brain activity due to whether participants experienced IN or not. These differences appeared sensitive to whether or not the IN was associated with actually making a search or simply deciding that a search would be necessary. Although several brain regions showed differential activity with IN, our results point to a particular region of the brain known as the posterior cingulate which is known to be a critical hub area involved in coordinating brain activity between the internal and external environment.

Analysis of Scenario 1 (RQ): In Scenario 1 we investigated brain activity when participants were presented with questions and possible responses, and they needed to decide that they knew the answer already or would need to search. For all participants we contrasted brain activity when they provided an answer versus when they provided the response that they needed to search. We hypothesised that this contrast would reveal brain regions associated with successful memory retrieval and working memory when they responded with an answer, signifying No-IN. When the response was that there was a need to search we expected activity in regions associated with IN.

The results, based on all 24 participants, for the effect of the factor Type of Response are shown for Scenario 1 in Figure 3 plotted on an average brain and in Table 1. To evaluate whether the effect of the Type of Response indicated higher or lower activity when a search was requested the average beta weights for each cluster were obtained and these are presented in bar charts for each of the clusters. Results showed that 4 of the 5 clusters had higher activation for the No-IN condition. This included thalamus, extending into the left head of caudate, right head of caudate, the left caudate body and an extensive cluster in the right inferior frontal gyrus (also known as the dorsolateral prefrontal cortex). These regions are known to have anatomical connectivity [16] and have been implicated in processes of memory retrieval [32], working memory [6], and decision making [15]. The only cluster showing greater activation for the ASK condition was found in the the ventral aspect of the posterior cingulate cortex. This region has often been associated with what is known as the default mode network [38] which shows decreased activation when a task is performed and increased activity when mind-wandering. We will return to discussion of the posterior cingulate later in the paper.

An interesting finding is that the situation when an answer could be provided, and thus an information need did not exist, provided 4 of the 5 clusters. Moreover, these clusters can be considered a network involving memory retrieval, information accumulation and working memory, all functions we would expect when a participant can provide an answer to the question. The remaining cluster in ventral posterior cingulate provides us with a putative brain region where activity reflects IN. Activity in this region has been hypothesised [29] to reflect a narrow focus of attention on internal information, and this is consistent with the "need to search" response in Scenario 1. Here, the response can be generated by assessing internally only that it was not possible to provide an answer; for success in the task there is no need to modify behaviour or to broaden the focus of attention.

Analysis of Scenario 2 (RQS): In Scenario 2 we investigated brain activity when participants were presented with questions and possible responses and if they responded that a search was needed then they would subsequently engage in a search. For all participants we contrasted brain activity when they provided an answer versus when they provided the response that they needed to search. Again we hypothesised that this contrast would reveal brain regions associ-

---

[5] http://www.BrainVoyager.com

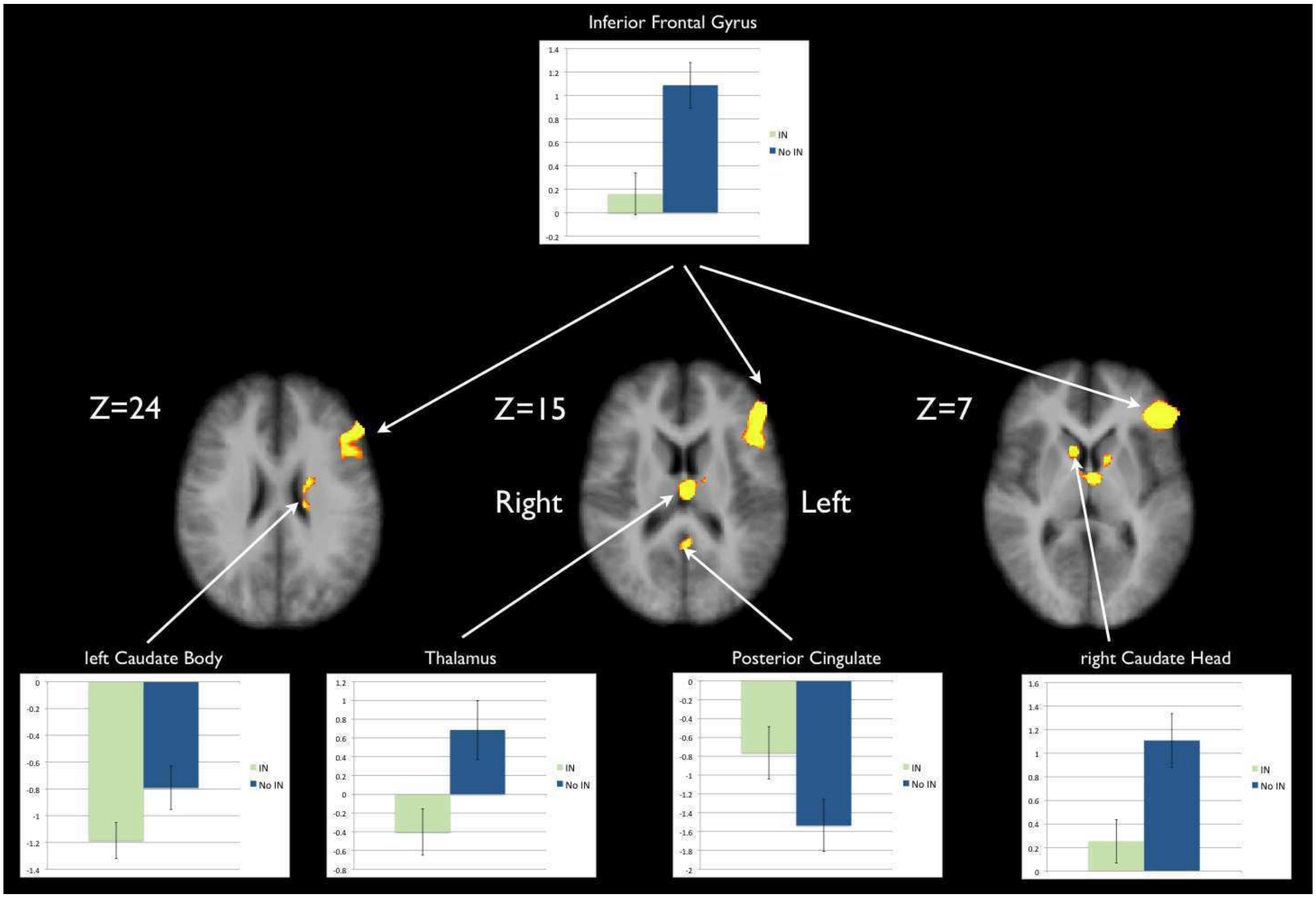

Figure 3: The five activation clusters from Scenario 1 are projected onto the average anatomical structure for three transverse sections. Note that the brains are in radiological format where the left side of the brain is on the right side of the image.

Table 1: Details of Scenario 1 activations, including their anatomic label, location, Brodmann Area (BA), effect size and volume.

		Talairach Coordinates				Effect size		Number of voxels
Brain Area	Hemisphere	X	Y	Z	BA	F(1,23)	p-value	mm^3
Caudate Head	Right	11	10	3	-	42.91	0.000001	427
Thalmus	Left	-1	-11	12	-	52.39	<0.000001	2017
ventral Posterior Cingulate	Left	-4	-44	12	29	33.09	0.000007	263
Caudate Body	Left	-19	-17	21	-	39.03	0.000002	282
Inferior Frontal Gyrus	Left	-46	31	6	46	107.63	<0.000001	8024

ated with successful memory retrieval and working memory when they responded with an answer, signifying No-IN. In contrast to Scenario 1, such a result was not obtained. Instead we only found regions where brain activity was greater for IN, including a region of the posterior cingulate known as the dorsal posterior cingulate.

The results, based on all 24 participants, for the effect of the factor Type of Response are shown for Scenario 2 in Figure 4 plotted on an average brain and in Table 2. Again, to help assess the direction of the effect, parameter estimates are displayed as bar charts for each cluster. All clusters including the fusiform gyrus, the dorsal posterior cingulate and the cuneus (extending into the precuneus) showed greater activation for the IN condition. As both the precuneus and posterior cingulate clusters have been associated with the default mode network, it is perhaps not surprising that deactivations are apparent for these regions. The fusiform gyrus is often associated with high level visual processing and it is possible that this cluster reflects greater visual activity when participants were in the state of IN.

The fact that the posterior cingulate was again identified as a region where activity was greater for the IN condition further raises the possibility that monitoring activity in this area could provide a useful brain signal for identifying information need. The fact that it was the dorsal posterior cingulate is important from a theoretical perspective. It has been hypothesised that the dorsal posterior cingulate is involved when there is brain activity directed towards external sources and broad attention is used [29]. This is consistent with the need to search as the individual must transition from a state of accessing internal information to one where they are engaging with the collection of new information from external sources.

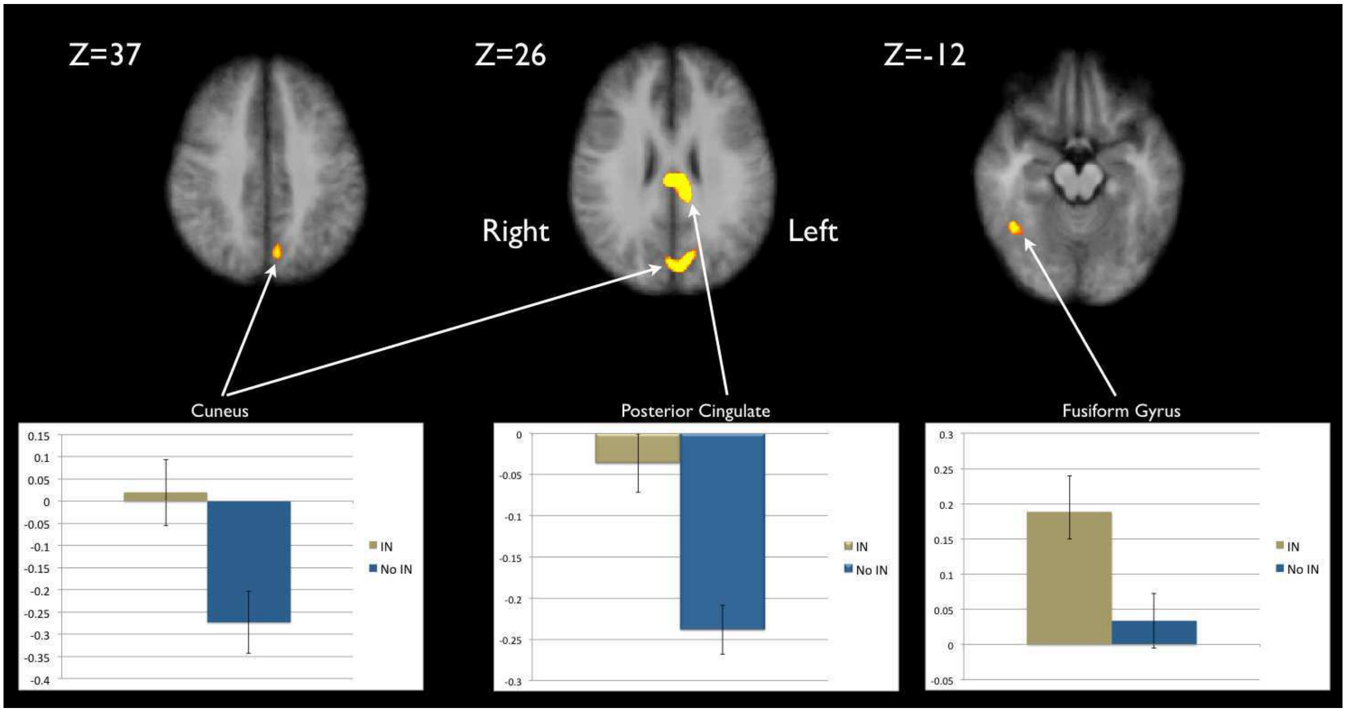

Figure 4: The three activation clusters from Scenario 2 are shown projected onto the average anatomical structure for three transverse sections. Note that the brains are in radiological format where the left side of the brain is on the right side of the image.

Table 2: Details of Scenario 2 activations, including their anatomic label, location, Brodmann Area (BA), effect size and volume.

		Talairach Coordinates				Effect size		Number of voxels
Brain Area	Hemisphere	X	Y	Z	BA	F(1,23)	p-value	mm^3
Fusiform Gyrus	Right	41	-50	-12	37	31.29	0.000011	266
Cuneus	Left	-7	-74	24	18	38.64	0.000002	3453
dorsal Posterior Cingulate	Left	-10	-29	27	23	60.35	<0.000001	2147

Significance of the Posterior Cingulate: As we have discussed in relation to the current results, both the greater activation during IN and the switch between ventral and dorsal regions when an actual search is performed provide a unique signature for IN. In this regard it is useful to review that the posterior cingulate is thought to be what is known as a ”hub” area. Such areas are known to be densely connected with many different brain regions and to be involved in the coordination of large scale brain networks. One function of the posterior cingulate appears to be in the balance between directing brain activity towards either internal or external sources and this role resonates with the requirements of detecting IN in that detecting the switch between internal and external processing is synonymous with search.

5. DISCUSSION AND CONCLUSION

This paper investigated the concept of information need from a neuropsychological perspective by investigating brain activity during periods in which an information need was induced. The raison d'etre of IR is to satisfy human information needs. Despite advances in the past few decades in both the IR and relevant scientific communities, we do not really understand how an information need emerges and how it is physically manifested. Information need refers to a complex concept: at the very initial state of the phenomenon (i.e. at a visceral level), even the searcher may not be aware of its existence. This renders the measuring of this concept (using traditional behaviour studies) nearly impossible. Using functional Magnetic Resonance Imaging (fMRI), we measured the brain activity of twenty four participants while they performed a Question Answering (Q/A) Task. In order to do so, we devised a “within-subjects” design experiment where the independent variable was the information need (with two levels: Information Need, and No-Information Need), which was controlled by responding to questions viewed on the screen. A set of questions were designed for a typical participant to respond equally between expressing an information need to answer the question or expressing a need to search for more information to answer the question using TREC-8 and TREC 2001 Q/A Tracks. The dependent variable was brain activity revealed by the BOLD signal.

We implemented two different task scenarios to create information need, in both scenarios participants were asked a multiple choice question, but in the first scenario when participants confronted an ASK they only had the option to acknowledge that they needed to search, they could not act on this IN (i.e. QR Task). In the second scenario when participants confronted an ASK they were able to engage in a search process (i.e. QRS Task). Our hypothesis was that there exists brain regions for which the activation levels are different depending on the state of information need and that the regions found for these two scenarios would provide measurement data of brain states to complement our theoretical understanding of IN.

The key findings which emerged from the results are that the analysis of fMRI brain data revealed differences in brain activity due to whether participants experienced IN or not (addressing **RQ2**). These differences were obtained from modelling brain activity during the presentation of the question and possible responses and thus precede the actual decision to search (addressing **RQ3**). These differences appeared sensitive to whether or not the IN was associated with actually making a search or simply deciding that a search would be necessary (addressing **RQ4**). Although several brain regions showed differential activity with IN, our results point to a particular region of the brain known as the posterior cingulate which is known to be a critical hub area involved in coordinating brain activity between the internal and external environment. We speculate that this hub nature of switching between large scale brain networks that involve either internal or external processing could be an essential component of IN (addressing some issues raised by **RQ1**).

The results for the QR task of Scenario 1 and the QRS task of Scenario 2 provided strikingly different results. In the QR task of Scenario 1 the contrast of brain activation between the IN and No-IN conditions revealed greater activity for the IN condition in one brain area (posterior cingulate) and greater activity for the No-IN condition in four of the five areas obtained. These four areas can be associated with recalling information and making a decision. Relating this to IR we see evidence for the neural substrate involved with successfully recovering internal knowledge, a situation that relieves the need for information. However, a primary interest of the current research is to explore what brain regions are associated with IN. Thus, the results of the QRS task of Scenario 2 are of interest since we see that all three regions reported had greater activity for the IN condition. In particular, the dorsal posterior cingulate provides results similar to that found for the ventral posterior cingulate found in Scenario 1.

These differences between dorsal and ventral activation of posterior cingulate can be related to theories of the posterior cingulate and its special role in brain function [29]. The posterior cingulate is known to be an area that is metabolically active, using substantial energy and serving as a hub that regulates cognitive activity. It is especially involved in regulating brain resources between engaging in internal or external processes and the Arousal, Balance and Breadth of Attention (ABBA) model provides an explanation of the differences between the IN conditions in Scenarios 1 and 2. The model holds that activation in ventral posterior cingulate is consistent with a narrow internal focus while activation in dorsal posterior cingulate is consistent with a broad external focus. Thus, in Scenario 1, when participants need only to focus on the fact that they need to search (not what they need to search or mechanisms of search) the pattern of results in posterior cingulate shows a narrow and internal focus. However, in Scenario 2, when participants need to engage in a subsequent search task the pattern of results in posterior cingulate shows a broad and external focus. The implication for IR is that the differential patterns of activation in the posterior cingulate provide a window into how cognitive processes are being directed and switching state from a narrow internal focus to a broad external focus can be used as a sign of a searcher needing to gather information from external sources.

Regarding the pattern of activity in posterior cingulate several aspects deserve further investigation. One is whether this general difference of activity found between IN and no-IN is unique, the posterior cingulate is a complicated and densely connected brain region and other differences in cognitive states might reveal similar patterns of BOLD activity. This could be explained by heterogeneity of function in the posterior cingulate, or possibly by some more basic, and yet undetermined, mechanism that is common to IN and other cognitive processes. One possible way forward to studying this would for more detailed analysis of the spatiotemporal pattern of activity in posterior cingulate to determine the encoding of IN. Research in these directions would potentially aid in ways to exploit this neural signal in retrieval systems.

While our present interpretation of brain activity provides a parsimonious account of how IN is represented in the brain, further study is needed to advance this interpretation. One possible way forward is to perform a more detailed analysis of the spatiotemporal pattern of activity in posterior cingulate to see whether multivariate techniques of machine learning could provide a means to decode IN directly from brain activity, rather than to infer it from univariate comparison of brain activity during IN and no-IN states. Such a result could pave the way, as brain measuring technology advances, to monitor the IN state of an individual and to exploit this knowledge in a search engine system. Prerequisites to achieve this would be to confirm that this pattern of activity in posterior cingulate is robust across different IN scenarios as well as being unique to IN.

Our present results indicating differences between the QR and QRS tasks show the importance of task on brain activation. Thus, a meaningful research direction to pursue would be to investigate similar research questions in the context of other information retrieval and interaction tasks. This could provide converging evidence and would advance our neurotheoretical understanding of IN leading to exploitation of such signals in functioning IR systems.

In conclusion, the results of this experiment revealed a distributed network of brain regions commonly associated with information retrieval and produced novel results about the neural bases of information need. These results have implications both for theories explaining information need and the potential to design systems that could detect information need. Finally, we believe our study and conclusions constitute an important step in unravelling the nature of information need and therefore better satisfying it.

Acknowledgement: This work was supported by the Economic and Social Research Council [grant number ES/L011921/1].

6. REFERENCES

[1] M. Allegretti, Y. Moshfeghi, M. Hadjigeorgieva, F. E. Pollick, J. M. Jose, and G. Pasi. When relevance judgement is happening?: An eeg-based study. In *SIGIR '15*, New York, NY, USA, 2015. ACM.

[2] I. Arapakis, K. Athanasakos, and J. M. Jose. A comparison of general vs personalised affective models for the prediction of topical relevance. In *SIGIR '10*, pages 371–378, 2010.

[3] I. Arapakis, I. Konstas, and J. M. Jose. Using facial expressions and peripheral physiological signals as implicit

indicators of topical relevance. In *MM ' 09*, pages 461–470, 2009.

[4] I. Arapakis, Y. Moshfeghi, H. Joho, R. Ren, D. Hannah, and J. M. Jose. Enriching user profiling with affective features for the improvement of a multimodal recommender system. *CIVR '09*, 2009.

[5] I. Arapakis, Y. Moshfeghi, H. Joho, R. Ren, D. Hannah, and J. M. Jose. Integrating facial expressions into user profiling for the improvement of a multimodal recommender system. In *ICME '09*, pages 1440–1443, 2009.

[6] A. K. Barbey, M. Koenigs, and J. Grafman. Dorsolateral prefrontal contributions to human working memory. *Cortex*, 49(5):1195–1205, 2013.

[7] M. J. Bates. Indexing and access for digital libraries and the internet: Human, database, and domain factors. *JASIST*, 49(13):1185–1205, 1998.

[8] N. Belkin, R. Oddy, and H. Brooks. ASK for information retrieval: Part I. Background and theory. *Journal of Documentation*, 38(2):61–71, 1982.

[9] N. J. Belkin, R. N. Oddy, and H. M. Brooks. ASK for information retrieval: Part II. Results of a design study. *Journal of documentation*, 38(3):145–164, 1982.

[10] Y. Benjamini and Y. Hochberg. Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society. Series B (Methodological)*, pages 289–300, 1995.

[11] C. L. Borgman. *From Gutenberg to the global information infrastructure: access to information in the networked world*. Mit Press, 2000.

[12] C. Cole. A theory of information need for information retrieval that connects information to knowledge. *JASIST*, 62(7):1216–1231, 2011.

[13] C. Cole, C.-A. Julien, and J. E. Leide. An associative index model for hypertext internet search based on vannevar bushâĂŹs memex machine: An exploratory case study. *Information Research*, 15(3):15–3, 2010.

[14] A. Dimoka. How to conduct a functional magnetic resonance (fmri) study in social science research. *MIS Quarterly*, 36(3):811–840, 2012.

[15] L. Ding and J. I. Gold. Caudate encodes multiple computations for perceptual decisions. *The Journal of Neuroscience*, 30(47):15747–15759, 2010.

[16] B. Draganski, F. Kherif, S. Klöppel, P. A. Cook, D. C. Alexander, G. J. Parker, R. Deichmann, J. Ashburner, and R. S. Frackowiak. Evidence for segregated and integrative connectivity patterns in the human basal ganglia. *The Journal of Neuroscience*, 28(28):7143–7152, 2008.

[17] M. J. Eugster, T. Ruotsalo, M. M. Spapé, I. Kosunen, O. Barral, N. Ravaja, G. Jacucci, and S. Kaski. Predicting term-relevance from brain signals. In *SIGIR'14*, pages 425–434. ACM, 2014.

[18] K. Friston, C. Buechel, G. Fink, J. Morris, E. Rolls, and R. Dolan. Psychophysiological and modulatory interactions in neuroimaging. *NeuroImage*, 6:218–229, 2007.

[19] R. Goebel. *BrainVoyager QX, Vers.2.1, Brain Innovation B.V.* Maastricht, Netherlands.

[20] B. Hjørland. The foundation of the concept of relevance. *JASIST*, 61(2):217–237, 2010.

[21] P. Ingwersen. Cognitive perspectives of information retrieval interaction: elements of a cognitive ir theory. *Journal of documentation*, 52(1):3–50, 1996.

[22] T. Joachims, L. Granka, B. Pan, H. Hembrooke, and G. Gay. Accurately interpreting clickthrough data as implicit feedback. In *SIGIR '05*, pages 154–161, 2005.

[23] J. P. Kauppi, M. Kandemir, V. M. Saarinen, L. Hirvenkari, L. Parkkonen, A. Klami, R. Hari, and S. Kaski. Towards brain-activity-controlled information retrieval: Decoding image relevance from MEG signals. *NeuroImage, in press*, 2015.

[24] D. Kelly and N. Belkin. A user modeling system for personalized interaction and tailored retrieval in interactive ir. *ASIST*, 39(1):316–325, 2005.

[25] D. Kelly and N. J. Belkin. Display time as implicit feedback: understanding task effects. In *SIGIR '04*, pages 377–384, New York, NY, USA, 2004. ACM.

[26] D. Kelly and X. Fu. Eliciting better information need descriptions from users of information search systems. *Inf. Process. Manage.*, 43(1):30–46, Jan. 2007.

[27] J. Koenemann and N. J. Belkin. A case for interaction: a study of interactive information retrieval behavior and effectiveness. In *SIGCHI '96*, pages 205–212. ACM, 1996.

[28] C. C. Kuhlthau. A principle of uncertainty for information seeking. *Journal of Documentation*, 49(4):339–355, 1993.

[29] R. Leech and D. J. Sharp. The role of the posterior cingulate cortex in cognition and disease. *Brain*, 137(1):12–32, 2014.

[30] L. Lorigo, M. Haridasan, H. Brynjarsdóttir, L. Xia, T. Joachims, G. Gay, L. Granka, F. Pellacini, and B. Pan. Eye tracking and online search: Lessons learned and challenges ahead. *JASIST*, 59(7):1041–1052, 2008.

[31] R. McGill, J. W. Tukey, and W. A. Larsen. Variations of box plots. *American Statistician*, 32(1):12–16, 1978.

[32] A. S. Mitchell and S. Chakraborty. What does the mediodorsal thalamus do? *Frontiers in systems neuroscience*, 7, 2013.

[33] Y. Moshfeghi and J. M. Jose. An effective implicit relevance feedback technique using affective, physiological and behavioural features. In *SIGIR '13*, pages 133–142, 2013.

[34] Y. Moshfeghi and J. M. Jose. On cognition, emotion, and interaction aspects of search tasks with different search intentions. In *WWW*, pages 931–942, 2013.

[35] Y. Moshfeghi, L. R. Pinto, F. E. Pollick, and J. M. Jose. Understanding relevance: An fmri study. In *ECIR*, pages 14–25, 2013.

[36] D. M. Nichols. Implicit rating and filtering. In *Proceedings of the Fifth DELOS Workshop on Filtering and Collaborative Filtering*, pages 31–36, 1997.

[37] R. C. Oldfield. The assessment and analysis of handedness: the edinburgh inventory. *Neuropsychologia*, 9(1):97–113, 1971.

[38] M. E. Raichle, A. M. MacLeod, A. Z. Snyder, W. J. Powers, D. A. Gusnard, and G. L. Shulman. A default mode of brain function. *Proceedings of the National Academy of Sciences*, 98(2):676–682, 2001.

[39] J. Talairach and P. Tournoux. *Co-planar stereotaxic atlas of the human brain*, volume 147. Thieme New York:, 1988.

[40] R. S. Taylor. Question-negotiation and information seeking in libraries. *College & research libraries*, 29(3):178–194, 1968.

[41] P. I. und Kalervo Järvelin. *The Turn: Integration of Information Seeking and Retrieval in Context*. Springer, 2005. xiv, 448 S. ISBN 1-4020-3850-X, 2006.

[42] C. van Rijsbergen. (invited paper) A new theoretical framework for information retrieval. In *SIGIR*, pages 194–200. ACM, 1986.

[43] R. White and D. Kelly. A study on the effects of personalization and task information on implicit feedback performance. In *CIKM*, pages 297–306, 2006.

[44] R. W. White. *Implicit Feedback for Interactive Information Retrieval*. PhD thesis, University of Glasgow, 2004.

[45] R. W. White, J. M. Jose, and I. Ruthven. A task-oriented study on the influencing effects of query-biased summarisation in web searching. *IPM '03*, 39(5):707–733, 2003.

[46] T. D. Wilson. On user studies and information needs. *Journal of documentation*, 37(1):3–15, 1981.

[47] Q. Zhao, Z. Zhou, H. Xu, S. Chen, F. Xu, W. Fan, and L. Han. Dynamic neural network of insight: a functional magnetic resonance imaging study on solving chinese 'chengyu' riddles. *PloS one*, 8(3):e59351, 2013.