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Retrospective confidence judgments: Meta-analysis of fMRI studies

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Abstract

The confidence in our retrieved memories, i.e. retrospective confidence, is a metamemory process we perform daily. There is a wide variety of applied research focused on this metamemory judgements and a very diverse studies including a wide a range of clinical populations. Yet, the neural correlates that support its functioning are not well defined. We used the activation likelihood estimation method (ALE) on the 18 eligible studies in the functional magnetic resonance imaging literature available on the topic. The main analysis of confidence revealed concordant bilateral activation in the parahippocampal gyrus, left middle frontal gyrus, right amygdala and right caudate. These activations support the involvement of a frontoparietal network in metamemory evaluations, and the requirement of the medial temporal lobe. Activations for the exploratory high > low subtraction analysis were also noticed in the main analysis on retrospective confidence, whereas in our exploratory low > high subtraction analyses showed distinctive activations of the right precuneus, previously attributed to low confident evaluations.

Keywords: functional magnetic resonance imaging, brain mapping, activation likelihood estimate, retrospective confidence, metamemory

Retrospective confidence judgments: Meta-analysis of fMRI studies

Metamemory can be defined as the knowledge we have about our memory, how it works and which strategies we need to implement in order to maximize it (Nelson & Narens, 1990). Metamemory is one of the most important superior cognitive functions due to its relevance in our daily life in the selection of encoding and retrieval strategies (Pannu & Kaszniak, 2005). For example, when we are learning new material (e.g., vocabulary of another language) we have to decide whether we have studied enough to remember it later. If we believe that we have invested enough time in learning, we will stop studying, whereas in the contrary case we will continue studying it or try a different approach. Moreover, understanding metamemory is essential for clinical populations: wrong beliefs about how memory works are transformed into a wrong perception of reality (Moritz, Woodward, Jelinek & Klige, 2008). In the rehabilitation of memory processes, awareness of their deficit in the metacognitive processes increases the benefits from rehabilitation (Clare & Woods, 2004).

The seminal works about the neural basis for metamemory comes from neuropsychology studies with clinical patients with Korsakoff syndrome. Korsakoff patients suffer amnesia due to chronic alcohol abuse and malnutrition that derive in a decrease the volume of the prefrontal cortex and thalamus. Shimamura and Squire (1986) compared the performance in semantic memory with general knowledge questions and the metamemory with the use of “feeling of knowing judgments” (confidence in recognizing a current inaccessible information) of Korsakoff patients, control amnesic patients (patients receiving electroconvulsive therapy, which has the side effect of causing amnesia, and amnesic patients for other causes) and an alcoholic control group. Only Korsakoff patients showed an impairment in the metamemory task indicating that these two areas may be involved in the assessment of confidence.

Besides Korsakoff patients, there is also a lot of research done on metamemory with schizophrenia patients. At the neural level, patients with schizophrenia have damage in their medial temporal lobes (hippocampus, amygdala or hippocampal gyrus), prefrontal cortex, lateral temporal cortex, and middle diencephalon (McCarley, Wible, Frumin, Hirayasu, Levitt, Fischer & Shenton, 1999; Powers, 1999). Research on patients with schizophrenia indicates that memory is one of the more severely damaged cognitive functions (see meta-analysis by Heinrichs & Zakzanis, 1998, and by Aleman, Hijman, Haan, & Kahn, 1999), and the results from metamemory measures indicate that the patients are unaware of the damage (Moritz & Woodward, 2006; Moritz, Woodward & Chen, 2006). This unawareness is very important for the patients because knowledge or awareness of their dysfunction leads to implementation of strategies in order to repair the dysfunction or improve performance. In particular, patients with schizophrenia suffer from the so-called “confidence gap”, that is the impairment to distinguish between correct and incorrect answers which is reflected in high confidence ratings for their incorrect answers and low confidence for the correct ones. ~~for which incorrect answers gather higher confidence on their correctness than correct answers.~~ This phenomenon has been observed with remember-known tasks (Moritz & Woodward, 2006), with numeric confidence scales (Moritz, Woodward, Jelinek & Klinge, 2008), and it has been replicated in patients that only suffered from a single schizophrenic episode (Moritz, Woodward, & Chen, 2006). The robustness of this effect with different measures and particularly at different degree levels pointed to the prefrontal cortex as the hub for confidence assessment since it is an area also affected in Korsakoff patients. However, the prefrontal cortex covers a large brain volume with multiple areas some of them rather specialized in particular cognitive processes.

These and other early works with clinical patients were crucial in advancing research on the neural basis of metamemory, and also to understand that it is a process per se independent of the memory performance (Shimamura & Squire, 1986). Yet, from studies with clinical population it is not possible to accurately extract which are the neural basis for metamemory during its normal functioning.

As the access to magnetic resonance imaging scans became more at hand to non-clinical researchers, the number of fMRI studies increased (Logothetis, 2008), including those focused on the neural basis on metamemory. Unfortunately, the variety of experimental tasks to measure metamemory makes it difficult to draw unified conclusions based on the reported results. For example, one can make judgments of metamemory prospectively, that is, estimations of the recallability of an item just presented (judgments of learning) in a later memory test. . In the fMRI study of Kao, Davis, and Gabrieli (2005), participants were presented with scenes and requested to evaluate if they would recognize those images later. Their results point to distinctive activation of the medial temporal lobe, ventromedial prefrontal cortex, as well as lateral and dorsomedial prefrontal cortex associated with the prediction of future memory. However, one can also make judgments monitoring current performance, that is, subjective evaluations of the correctness of an answer- retrospective confidence-, and in this case the anterior and dorsolateral PFC appear to govern these processes (Fleming & Nolan, 2012). Consequently, based on these findings we can infer that while both prospective and retrospective metamemory judgments are metacognitive measures, the disparity of the results suggests that the temporality of the judgments of metamemory recruit different brain structures (Fleming & Nolan, 2012; Le Berre et al., 2016; Pannu, Kaszniak, & Rapcsak, 2005).

Within the metamemory judgments the retrospective confidence judgments have been investigated in the various contexts, such as academic performance (Arnold, Higham, & Martín-Luengo, 2013; Mihalca & Mengelkamp, 2020; Mihalca, Mengelkamp, & Schnotz, 2017; Robey, Dougherty, & Buttacio, 2017), eyewitness testimony and identification (Greenspan & Loftus, 2020; Luna & Martín-Luengo, 2012; Luna, Martín-Luengo, & Brewer, 2015; Semmler, Brewer, & Wells, 2004), as well as various clinical populations (multiple sclerosis: Mazancieux, Souchay, Casez, & Moulin, 2019; psychosis: Dietricheit, Grzella, Nagel & Moritz, 2020; alzheimer: Bertrand, et al., 2019; obsessive compulsive disorder: Moritz & Jaeger, 2018). This variety of study populations and research questions and topics approached by the use of retrospective confidence judgments prove their importance in many different tasks of daily life, and this is the reason why we focus on them in this fMRI meta-analysis.

To date there are two fMRI meta-analyses on metacognition. In White and colleagues' (2015) study, the main objective was to compare and see whether the activation was similar in what they defined as Type-A research and Type-B research. Type A-research focused on the levels of uncertainty given by the environment (e.g., discriminability of perceptual information), while Type-B research oriented to studies where confidence was measured (subjective assessment of confidence or certainty based on a particular experience). This is a very interesting distinction because it allows one to determine to which extent the objective and subjective evaluations share their brain substrates. Despite the value of the conceptualization and results of this seminal fMRI meta-analysis, only nine studies were included in the Type-B category. Recent research indicates that such a low number is insufficient for this type of research and also capable of reporting biased results for the over-influence of a single study (Eickhoff et al., 2017).

More recently, Vaccaro and Fleming (2018) reported an fMRI meta-analysis on metacognition with the main aim of distinguishing between different categories: type of metacognitive evaluations (memory vs. decision-making), analysis type (judgment, confidence, and predictors of metacognitive sensitivity), and metamemory temporality (prospective vs retrospective). The authors presented a cluster mostly for the retrospective confidence judgments, indicating concordant activation of the parahippocampal gyrus and the left inferior frontal gyrus (see Table 5 and Figure 4 in Vaccaro & Fleming, 2018), that is, regions associated with judgments of familiarity in the recognition of novel associations (Du, et al, 2019; Haskins, et al, 2008). In the current meta-analysis, however, we aimed for the most general representation of the brain activation corresponding to confidence judgment, and included quite heterogeneous studies using different experimental tasks, which lead to representation of the activations of confidence assessment less influenced by a particular cognitive processes (Müller, et al, 2017). Vaccaro and Fleming also reported the activations between different confidence levels, but for this contrast all types of metamemory (prospective and retrospective) were collapsed. As mentioned before, the brain activations for different temporal metamemory measures tend to be different (Chua et al, 2009; Fleming & Nolan, 2012; Le Berre et al., 2016; Pannu, Kaszniak, & Rapsak, 2005). Therefore, the results of collapsing different metamemory measures to investigate the differences between high and low evaluations can convey some distortion or lack of clarity.

In the current functional fMRI meta-analysis we aimed to obtain a clear and more complete picture of the neurocognitive brain basis of the retrospective confidence judgements. To this end, the experiments (i.e., contrasts) included in the meta-analysis

are all characterized for being estimations of confidence once the main task has been completed.

Methods

Literature Search and Article Selection. The literature search was performed using Web of Science (<http://apps.webofknowledge.com/>), Scopus (<https://www.scopus.com/home.uri>), and PubMed (<https://pubmed.ncbi.nlm.nih.gov>) search engines on 11.04.2020, with keywords (“confidence” AND “fMRI”, “uncertainty” AND “fMRI”, “unpredictability” AND “fMRI”, “decision-making” AND “fMRI”, “metamemory” AND “fMRI”, “retrospective confidence” AND “fMRI”, “mnemonic confidence” AND “fMRI”, “subjective experience” AND “fMRI”), during years 1998-2020, yielding a total of 11217 articles (see Figure 1 for PRISMA chart on step-by-step analysis procedure). To achieve homogeneity of imaging data, we did not search for articles that reported PET data. Next, we excluded abstracts and non-English text ($n = 40$), yielding 5318 full-text articles eligible for further screening. Thereafter, we excluded articles that did not report whole brain analysis (only ROI) or did not report fMRI coordinates, reported data on patients or with drug administration, and articles with irrelevant topics. Articles meeting these criteria were reviewed by two researchers of the team (O.Z. and A.D.). Next, we did a reference search on the articles included into analysis, yielding two additional articles (see Table 1 for the detailed information on these articles). We included all relevant experiments from each article in the analysis because the ALE algorithm uses a correction to avoid summation of within-group effects (Turkeltaub et al., 2012). Unfortunately, due to the low number of experiments including the contrasts high>low confidence ($n = 14$) and low>high confidence ($n = 11$) (see Eickhoff et al., 2017 for the recommended number of

experiments), the result for these contrasts needs to be cautiously considered by other researchers in the future.

ALE (Activation likelihood estimate). The meta-analysis was performed using Ginger-ALE software, version 3.0.2 (freely available at <http://www.brainmap.org/ale/>) which allows to perform coordinate-based activation likelihood estimation (Eickhoff et al., 2016; 2017). Foci extracted from different experiments across different articles were used to create a probabilistic map comparing the likelihood of activation to random spatial distribution. All coordinates reported in MNI space were converted to Talairach space before the analysis. Significance was assessed using a cluster-level threshold for multiple comparisons at $p = 0.05$ with a cluster-forming threshold set to $p = 0.001$ (Eickhoff et al., 2016, 2017).

In the majority of the studies included in the current meta-analysis, the participants had to indicate the confidence in an old/new memory answer ($n = 11$, De Zubizaray et al, 2019; Fleck, 2005; Hayes et al., 2011; Henson, et al, 2000; Kim & Cambeza, 2009; Kuchinke et al., 2013; Leiker & Johnson, 2015; Pais-Vieira, et al., 2015; Risius, et al, 2013; Woroch, et al., 2019; Yonelinas, 2005), or to report confidence in their answer to other tasks ($n = 18$, Chua, et al., 2004; Chua et al, 2009; Chua et al 2006; De Zubizaray et al, 2019; Fleck, 2005; Hayes et al., 2011; Henson, et al, 2000; Kim & Cambeza, 2007; Kim & Cambeza, 2009; Kuchinke et al., 2013; Leiker & Johnson, 2015; Molenberghs, et al, 2016; Moritz, et al., 2006; Pais-Vieira, et al., 2015; Risius, et al, 2013; Woroch, et al., 2019; Yonelinas, 2005; Yu et al., 2012). Recent meta-analyses (White et al., 2014; Vaccaro and Fleming, 2018) did not include direct contrasts measured confidence (i.e. feeling of knowing, FOK, or JOL, judgment of learning) or non-

parametric contrasts (i.e. «significant correlations with subjective certainty in color trials» in Vaccaro and Fleming, 2018). To keep the methodology consistent, we included only experiments that used subtraction contrasts (i.e., high confidence > low confidence).

Results

Confidence

Articles included in the main analysis reported data on 602 participants. Across articles, which reported gender, 262 were male participants. Across articles, which reported handedness, 529 were right-handed. For the articles where age range was given, the median of age was 27,4 years; (see Table 1 for detailed information). Figure 1 shows number of articles, number of experiments, and foci included in the meta-analysis.

ALE maps for all tasks related to confidence

All tasks related to confidence evaluation show concordance in five clusters (Table 2 and Figure 2). The largest cluster with the highest ALE value is found in the left parahippocampal gyrus (BA 35 and 36). The second cluster is found in the left middle frontal gyrus (BA 46). Subcortical activation is observed in the next three clusters: in the right amygdala, right parahippocampal gyrus (BA 28, 34) and right caudate.

Exploratory analysis: High > Low confidence and Low < High confidence

As an exploratory analysis, we estimated the two conditions included in the meta-analysis: high confidence and low confidence. Previous studies suggest that these two types of confidence are related to different neural substrates, such as parahippocampal gyrus or DLPFC (Kim & Cabeza, 2009). Therefore, we selected 14 studies (foci =

XX) out of the main sample, where participants reported high confidence at the retrieval/recognition stage, and 11 studies (foci = XX) - reporting low confidence (see Table 3 for detailed information on studies included).

ALE maps for the contrast high > low. Three subcortical clusters were identified centered at the right parahippocampal gyrus (BA 28, and amygdala), left parahippocampal gyrus (BA 36), and right caudate.

ALE maps for the contrast low > high. The concordant activation for low confidence versus high confidence was found in three significant clusters centered at the following brain regions: left middle frontal gyrus (BA 46), right precuneus (BA7), and left inferior frontal gyrus (BA 47).

Discussion

Metamemory is the online process, for which we monitor the ongoing activity of memory processes and implement strategies to control its performance depending on our objectives (Nelson & Narens, 1990). This high cognitive process is important for many different processes in both healthy and clinical populations. It is particularly vital in the clinical population, where awareness of the memory may be a prerequisite for the success of the interventions to improve memory (Clare & Woods, 2004). The variety of different measures in assessing the level of metamemory complicates the identification of the underlying brain structures, which makes it crucial to run specific meta-analyses for each main category (i.e., prospective vs retrospective) in which metamemory measures are classified (Chua et al, 2009; Fleming & Nolan, 2012; Le Berre et al., 2016; Pannu, & Kaszniak, 2005).

In this study we examined concordance across studies in brain areas responding to the assessment of confidence. We also ran the analysis for the directionality of

confidence (high > low, low > high), to observe the tendency of the data, which can orient future studies. The main analysis of confidence revealed concordant bilateral activation in the parahippocampal gyrus, left middle frontal gyrus, right amygdala, and right caudate. Notice that the concordant activation we observed in our analysis closely corresponds to the concordant activation of the parahippocampal gyrus reported by Vaccaro and Fleming (2018) for metamemory judgements and, specifically, retrospective metamemory judgements. However, the rest of our results differ from theirs since they only found this concordant bilateral activation in the parahippocampal gyrus and activation of the left inferior frontal gyrus. This is probably due to the different criteria of inclusion used: we only included functional imaging articles based on the whole brain, and only those reporting subtraction contrasts. These criteria guarantee that the analyses only reveal regions associated with retrospective confidence and not other general functions involved (Müller, et al, 2017).

Overall, the results confirm the involvement of a frontoparietal network in the assessment of confidence (Fleming & Dolan, 2014; Metcalfe & Schwartz, 2015; Vaccaro & Fleming, 2018). We also confirm the role of the medial temporal lobe in the processes of recollection of information (Cohen & Eichenbaum, 1993; Eichenbaum & Cohen, 2001), which is undoubtedly required in the assessment of the confidence for retrieved answers (Nelson, 1990). It is worth to note that the activation of structures included in the MTL only appears in the main analyses and the high > low contrast. The absence of activation of the MTL for the contrast low > high may be explained by the fact that low confident judgments are related to the inability to retrieve the information requested.

In both analyses, for the main and low > high confidence analyses, we found an activation of the left middle frontal gyrus (BA 46). This particular area has been suggested to be in charge in the response inhibition and error monitoring in go/no-go tasks (Heitzeg,

et al, 2014; Le, et al, 2020). Hence, the observation of the BA 46 activation in the main and low > high confidence analyses but not in the high > low analysis suggests its involvement in the negative outcome of monitoring, which leads to low confidence assessment of confidence.

Our findings for the low > high contrast are also consistent with previous work that has associated the activation of the right precuneus with low confidence in memory (Ye, Zou, Lau, Hu, & Kwok, 2018). Ye and colleagues disrupted the precuneus by the use of transcranial magnetic stimulation (TMS) to examine its causal role in the meta-cognition of perceptual and memory processes. They found differences in the assessment of confidence, in particular, the impairment to adequately rate low confident answers with low confidence on the memory domain. This result not only corroborates the hypothesis of the involvement of the precuneus in metamemory processes (see work of Simons et al, 2010 on patients with bilateral parietal lesions), but also strengthens the view of a domain-specificity in the assessment of metacognition (Morales, Lau, & Fleming, 2018).

Analysis limitations

Our study focused on the brain structures involved in the evaluation of retrospective confidence. Ideally, we should have run the analyses balancing the perceptual modality of the tasks. We included studies that used diverse type of materials (images or semantic information). Such a variability in cognitive processes presumably recruited may introduce certain bias in the results, since there is an open debate on whether metacognition is a domain-specific or domain-general process, and whether they possibly co-exist (Morales, et al, 2018). Second, as repeatedly mentioned in this study, the results for high > low and low > high contrasts are preliminary and should be considered with caution because none of them reach the recommended minimum number of studies to guarantee enough power (17 studies; see Eickhoff et al., 2016; Müller et al, 2017). Despite

these shortcomings, the current meta-analysis present new knowledge on the topic of confidence judgments, which is more advantageous comparing to standard reviews.

Conclusion

The wider access to MRI scans and the acknowledgment of the relevance of collecting metamemory measures in different type of studies allows implementing more refined selections of studies in order to further clarify the particular brain structures subserving metamemory. With that aim in mind we selected fMRI studies only on retrospective confidence. Our results indicate the involvement of five clusters (see Table 2) required to the assessment of confidence. Some of the brain structures included in these clusters have also been related to memory processes and others to monitoring of errors and inhibition of answers, but all of them consistent with the proposed functioning of metamemory processes (Fleming, & Frith, 2014). Finally, our results can better inform future clinical research focusing on retrospective confidence failures and emphasize the need for similar studies with other types of metamemory measures.

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Figure 1. PRISMA chart illustrating the selection procedure for the articles used.

Figure 2. Brain maps showing significant ALE values for confidence.

Figure 3. ALE results for the high > low contrast.

Figure 4. ALE results for the low > high contrast.

Table 1. Descriptive information of studies used in the main analysis.

////**In excel file Supplementary for 13.08 analyses**////

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Table 2. ALE meta-analysis of all studies on retrospective confidence.

Cluster	Foci (x, y, z)			ALE value	Brain area	BA
	x	y	z			
1	-22	-22	-16	0.024561662	Left Parahippocampal Gyrus	35
1	-28	-32	-12	0.019843556	Left Parahippocampal Gyrus	36
2	-40	18	22	0.02492742	Left Middle Frontal Gyrus	46
3	24	-8	-14	0.017792294	Right Amygdala	
3	16	-2	-12	0.017452436	Right Parahippocampal Gyrus	28
3	16	0	-16	0.017243285	Right Parahippocampal Gyrus	34
4	24	-24	-8	0.023705754	Right Parahippocampal Gyrus	28
5	8	8	-2	0.021724585	Right Caudate Head	

Table 3. Descriptive information of studies used in the contrast high > low.

//////**In excel file Supplementary for high > low 20.08**//////

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Table 4. ALE meta-analysis of the contrast high > low (14 paper).

Cluster	Foci (x, y, z)			ALE value	Brain area	BA
	x	y	z			
1	26	-24	-8	0.022155292	Right Parahippocampal Gyrus	28
1	28	-8	-16	0.01427889	Right Amygdala	
2	-28	-32	-12	0.019816114	Left Parahippocampal Gyrus	36
3	8	8	-2	0.02149668	Right Caudate Head	

Table 5. Descriptive information of studies used in the contrast low > high.

//////**In excel file Supplementary for low > high 19.08**//////

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Table 6. ALE meta-analysis of the contrast low > high (11 papers).

Cluster	Foci (x, y, z)			ALE value	Brain area	BA
	x	y	z			
1	-42	18	24	0.021589866	Left Middle Frontal Gyrus	46
2	12	-66	48	0.020475976	Right Precuneus	7
3	-32	18	-4	0.02492742	Left Inferior Frontal Gyrus	47