Neural correlates of top-down guidance of attention to food: an fMRI study

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Highlights

- Attention is more efficiently drawn to food stimuli when thinking about food;
- Using imaging we show that holding food-related information in mind is less taxing;

Holding food in memory biases perception to food items.

Neural correlates of top-down guidance of attention to food: an fMRI study

Short title: Neural correlates of attention to food

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- Attention is more efficiently drawn to food stimuli when thinking about food;
- Using imaging we show that holding food-related information in mind is less taxing;
- Holding food in memory biases perception to food items.

Abstract

We investigated the neural correlates of working memory guided attentional selection of food versus non-food stimuli in young women. Participants were thirty-two women, aged 20.6y (± 0.5) who were presented with a cue (food or non-food item) to hold in working memory. Subsequently, they had to search for a target in a 2-item display where target and distractor stimuli were each flanked by a picture of a food or a non-food item. The behavioural data showed that attention is particularly efficiently drawn to food stimuli when thinking about food. Using fMRI, we found that holding a non-food versus food stimulus in working memory was associated with increased activity in occipital gyrus, fusiform, inferior and superior frontal gyrus. In the posterior cingulum, retrosplenial cortex, a food item that re-appeared in the search array when it was held in memory led to a reduced response, compared to when it did not re-appear. The reverse effect was found for non-food stimuli. The extent of the reappearance effect correlated with the attentional capture of food as measured behaviourally. In conclusion, these results suggest that holding food in mind may bias attention because thinking of food facilitated neuronal responses to sensory input related to food stimuli and because holding food-related information in mind is less taxing on memory.

Key words: fMRI, neural correlates, attention, food, memory

1. Introduction

Food images are everywhere, from vending machines, to cafes and billboards. Food-related stimuli can promote food intake, as well as enhance our hedonic responses to food when it is eaten [1, 2]. This ubiquitous nature of food stimuli may explain why some people find it difficult to avoid overeating in the current food environment. One reason why exposure to food stimuli can stimulate food intake is because food-related stimuli may capture our attention very easily.

There is now ample evidence that both “bottom-up” reward driven and “top-down” cognitively driven processes are important in determining the attention we pay to objects in the environment, including food-related stimuli [3-6]. Soto and colleagues [7, 8] reported that information held in working memory, caused attention to be drawn to similar stimuli in a search array, even when this information was irrelevant to the search.

fMRI studies showed that this effect was associated with a change in cortical and sub-cortical responses reflecting an interaction between working memory and selective attention processes [9]. In comparison to mere repetition of a stimulus, a stimulus that was held in memory led to two types of effects when it re-appeared in the search array: 1) an enhanced response related to the re-appearance of a stimulus in the array that was unrelated to its proximity to the search target (known as the re-appearance effect); 2) a differential response when the stimulus was in proximity to the search target or the distracter (known as the a validity effect).

These effects were observed in medial orbital frontal cortex, superior frontal cortex, thalamus and lateral occipital areas [10] and were reduced with increased cognitive load of working memory [11]. An fMRI study -[11] showed that a working memory load in the context of the above paradigm, was marked by an increase of the fronto-parietal response when comparing the low to the high memory load condition. The validity effect (valid > invalid) in the left prefrontal cortex was stronger in low relative to high memory load. The reappearance effect was observed in posterior cingulum, but was unaffected by the memory load manipulation.

Using the same paradigm, an ERP study [12] showed a greater response in early spatial attention components (N1PC, N2PC) when the item held in memory appeared next to the target and the reversed pattern when it appeared next to the distracter. We adapted this paradigm to investigate the impact of food information on top-down biases of selective attention. To experimentally induce an increase in food-related thoughts, participants were asked to memorise a food (or non-food) item before completing a search task for a geometrical shape.

Across several behavioural studies, we showed that holding food-related information in working memory biases attention to food stimuli (e.g. [5, 13]). Participants identified the target faster while memorising food stimuli compared with non-food stimuli. This suggests that thinking about food is potentially associated with lower cognitive load than thinking about non-food stimuli [5, 6, 13-15]. We also showed a stronger validity effect to food items. Holding a food item in memory, led to an attentional bias towards a food stimulus when it was presented as a flanker in a search array [5, 6, 13-15].

The attentional bias toward food stimuli (when memorized), was larger than for non-food stimuli. This suggests that top-down guidance of attention to food stimuli is particularly strong [5, 6, 13-15], which may in turn negatively impact the ability to inhibit food (relative to non-food) thoughts and the selective biases to food. In a different experiment, we assessed the real life impact of this bias and showed that the strength of individual's bias toward food stimuli (when held in memory), positively predicted weight gained after 12 months [16].

In a follow up study, we used ERP [6, 14] to study the neural dynamics of the capture of attention by food, when it is held in working memory. Holding food in memory led to an increased response in late ERP components (P3 [250 -450ms], LPP [460-660]) [6]. The P3 also showed the re-appearance effect, with larger responses on neutral than valid and invalid trials. The P3 electrophysiological measure is reported to be stronger under low, compared to high working memory load [17]. P3 was shown to be stronger when the selective attention task was completed under a low versus high cognitive load task [18]. The LPP is typically more positive for emotional relative to non-emotional stimuli (e.g.[19]) and is argued to reflect an increase in arousal which is mediated by the amygdala [20]. Overall, these electrophysiological ERP findings suggest that food may be processed more efficiently and therefore gain privileged access to working memory, which leads to stronger top-down bias, when compared with non-food stimuli. Furthermore, the data also suggest that re-appearance of items held in memory in the search array is associated with reduced cognitive load.

Similar to the behavioural results, the ERP data showed that food modulated the validity effect, i.e. the interaction between working memory content and search target. For non-food [17], early markers of spatial attention (N1PC[120-230ms], N2PC[230-330]) replicated previous findings with geometrical shapes [12]. Both the N1PC and N2PC showed greater negativity during valid than invalid trials, as typically reported in the literature. In contrast, selective attention toward food stimuli when held in memory showed a reverse pattern for N1PC and N2PC.

When food item held in memory was flanked by the search target, N1PC showed increased positivity, followed by N2PC which showed the more common increased negativity. The validity effect was unrelated to whether participants were asked to hold the food in memory or merely view it prior to the search task. This led the authors [14] to suggest that modulation of selective attention by food is driven by bottom rather than top-down up processes. These observations support the enhanced perception hypothesis for affective stimuli, by which perception and attention are facilitated through the increase in arousal and vigilance (e.g. [21]) for food stimuli.

In the present study, we used fMRI to assess the neural correlates of top-down guidance of attention to food stimuli in young women. Based on our previous behavioural findings [5, 6, 13-15], we hypothesised that food stimuli would have privileged access to working memory and that this would be reflected in greater modulation of attentional selection in a visual search task, compared to non-food stimuli. In accordance with earlier studies, we expected to find neural responses that reflect the low cognitive load of storing food content in memory. We also expected that food would modulate the interaction between the content of working memory and selective attention.

2 Materials and methods

2.1 Participants

Thirty-two healthy, right-handed women from the School of Psychology of the University of Birmingham, took part for either course credits or cash. The mean age was 20.6 y (± 0.5) and the mean body mass index (BMI) was 21.3 kg/m^2 (± 0.5). The mean hunger and fullness scores measured using 100 mm visual analogue scales (VAS) were 49 ± 5 mm and 32 ± 5 mm at the start of the experiment, which suggests that participants were neither hungry nor full [22]. Because our previous study [13] showed that dietary success affects top-down guidance of attention to food stimuli, participants were pre-screened to be non-dieters. Participants had low Three Factor Eating Questionnaire (TFEQ) restraint scores (mean score 5.7, range 0-12) and low tendency towards disinhibition of restraint score (mean score 5.8, range 1-13) [23, 24]. Finally, all participants had normal or corrected-to-normal-vision. Written informed consent was obtained from all participants. The study was approved by the Ethics Committee of the University of Birmingham and conformed to the Declaration of Helsinki. Two participants were excluded, post hoc, from the fMRI analysis due to artefacts in the images.

2.2 Procedure

The experiment took place in the morning and participants were asked to refrain from eating before attending the study (overnight fast). Upon arrival, the participants were first asked to report on demographic characteristics and rated feelings of hunger, fullness and desire to eat, using 100mm VAS anchored by word descriptions at each end that express two extreme states of the condition (e.g. "Not Hungry at all", "Very Hungry"). Subsequently, participants were scanned during which they performed a working memory selection task. After the scan, participants completed the VAS once more and had their height (cm) and weight (kg) measured.

2.3 Working memory task

A dual task paradigm was used in which the participant had to hold a stimulus in working memory, while performing a visual search task [5, 6, 13-15, 25]. The stimuli to be held in working memory were pictures of food stimuli and non-food stimuli (household or stationary items). These pictures were presented in black and white, sized 480 x 480 pixels, in the middle of the screen on a black background. Pictures were not presented in colour to prevent attention being drawn due to difference in colour or colour distribution between the food and non-food stimuli. The search target was a circle and the task was to indicate its position relative to fixation; a square was used as a distracter and fell in the opposite field to the target. The search array contained two flanker pictures, one aligned with the target and one with the distracter. The pictures in the search array were irrelevant to the search task but, on two thirds of the trials, one of the pictures was the item held in working memory (Figure 1a).

There were three trial types: 1) valid trials in which the target was flanked by the picture held in working memory and the distracter was flanked by a picture from one of the other stimuli categories, 2) invalid trials, in which the distracter was flanked by the picture held in working memory and the target was flanked by a picture from one of the other stimuli categories, or 3) neutral trials in which both the target and distracter were flanked by pictures from categories different from the picture held in working memory (see Figure 1b for an example of food valid, food neutral, and food invalid trials). A full factorial experiment design was used with the factors; memory stimuli type (food, non-food) and trial type (valid, neutral, invalid). The trials occurred randomly with equal probability.

A trial (Figure 1a) started with a red exclamation mark for 600ms, followed by a picture for 500ms that the participants had to keep in working memory. The search array then appeared. It consisted of a target (circle) and a distracter (square) falling randomly to the left or right of fixation (7.4° visual angle from fixation). Participants responded with their right hand using the index or middle finger to indicate whether the target was on the left or right of fixation with a maximum response time set at 800ms. After the search array, a fixation-cross appeared for 400ms. On 10% of the trials a memory probe followed the search display to test whether participants were memorizing the stimuli. On these trials a picture from the same category as the item in working memory appeared for 3000ms, and participants indicated whether the picture was the same or different to the working memory stimulus. Participants then responded with their right hand using the index or middle finger, to indicate whether the picture in working memory matched the memory probe. Participants were instructed to give equal priority to the search and memory tasks and to perform as quickly and accurately as possible. The inter-trial interval was jittered randomly between 700-2700ms. The task consisted of 384 trials (divided in four blocks), and took 30 minutes to complete. The experiment was implemented using E-prime (Version 1.2 – Psychology Software Tools).

2.4 fMRI data acquisition

Imaging was performed using a Philips 3-T Achieva system (Philips Medical Systems, Eindhoven, the Netherlands) at the Birmingham University Imaging Centre. Structural images were acquired with a T1-weighted sequence. Functional images were acquired with a gradient echoplanar T2*-sequence (36 frontal temporal oblique slices, 3-mm thickness without a gap, acquired in ascending order), with an in-plane resolution of 2.5 × 2.5 mm, 82º flip angle, 35 msec echo time, and 2200 msec slice repetition time. Images were acquired using an eight-channel phase array coil with a sense factor of 2. Data were collected in two waves and we used cohort waves as a covariate in the analyses.

2.5 Behavioural data analysis

For the reaction time (RT) analysis, incorrect responses to the search task, and memory task, as well as reaction times (RTs) that were +/- 3 standard deviations from the search mean were removed. There was no evidence of a speed–accuracy trade off and all further RT analyses included only correct trials. Behavioural response times were analysed using SPSS 22.0 for Windows (Armonk, NY: IBM Corp). We compared the RTs for correct search responses, using repeated measure ANOVA.

2.6 fMRI data analysis

Functional imaging data were analysed using SPM12 (Wellcome Department of Cognitive Neurology, London, UK) run with MATLAB 2015 (Mathworks Inc, Natick, MA) and the WFU

Pickatlas-tool [26], using standard procedures [27, 28]. After motion-correction and realignment, high-resolution T1 images were co-registered to the mean image of the EPI series for each participant. The unified segmentation algorithm was performed to compute a grey matter probability map. These were used subsequently in Diffeomorphic Anatomical Registration through Exponentiated Lie Algebra (DARTEL) for inter-participant registration. The registered images were transformed to Montreal Neurological Institute (MNI) space and then smoothed with a Gaussian kernel (9 mm). Scans that included head movements exceeding 3 mm in any direction during task performance were excluded from further analysis. This resulted in excluding two subjects due to extreme movement.

For data analysis, we used a general linear model. We first estimated the effect size for each participant for each condition across all four fMRI sessions. We modelled the onset of the WM stimuli on each trial separately for each condition, resulting in: food valid, non-food valid, food invalid, non-food invalid, food neutral and non-food neutral trials. We also included a regressor for the onset of error trials. Each event was modelled by a gamma function and convolved with the canonical hemodynamic response function. Additionally, we included 6 movement parameters and a set of harmonic regressors to capture low frequency changes (1 - 128 Hz) in the signal. Finally, for each trial condition we added search RT as a covariate to control for difference in RT. Effects across participants were tested in a group level (second level) analysis.

Summary statistics were used to test the reliability of effects using the general linear model, treating subjects as random variable, assuming dependency between condition and unequal variance. The second level model included the six conditions (averaged across all sessions) and also included a covariate of the scanner software (reflecting the two waves of recruitment). We tested the following contrasts: 1) main effect of memory content (cue type): food versus non-food; 2) validity effect (Interaction-1 between memory and search task, trial type): valid versus invalid; 3) re-appearance effect (Interaction-2 between memory and search task, trial type): valid + invalid versus neutral; 4) Interaction between memory content and validity; 5) interaction between memory content and re-appearance effect.

We report results that survive whole-brain family-wise error (FWE) correction ($P < 0.05$) at cluster or peak levels, with voxel significance ($p < .001$ uncorrected). Anatomical labelling of the results was carried out using the Anatomical Automatic Labelling toolbox (AAL). The charts and scatters were created by extracting the Eigen variate of a 6mm sphere centred at the group peak.

3. Results

Behavioural data

Overall accuracy was high with 90.2% correct responses on the search task and 84.6% correct responses on the memory catch trials. A 3×2 repeated-measures ANOVA with the factors memory stimulus type (food, non-food) and trial type (valid, invalid, neutral) was run with number or error trials as the dependent variable. There was a main effect of trial type, F (2,62) = 34.35, $p < 0.001$, $\eta p^2 = 0.52$. Errors for valid trials (mean=3.42 SD=.51) were smaller than errors for neutral (mean=6.78, SD=.86), which were smaller than errors in invalid trials (9.58, SD=1.1). Error numbers were not different between food and non-food memory stimulus cues ($\eta p^2 = 0.07$).

There was a significant interaction between memory stimulus type and trial type, F (2,62) = 6.84 p = 0.002, $\eta p^2 = 0.18$. To follow up this interaction, we computed the impact of stimulus type in each trial type. For valid trials, accuracy was higher when a food stimulus was held in working memory, compared to a non-food stimulus, t(31) = 2.25, p = 0.003. Similarly for neutral trials, accuracy was higher for food relative to non-food, t(31) = 2.1, p= 0.044. For invalid trials, a tendency for a reversed pattern was observed with lower accuracy for food compared with non-food trials, t(31) = -1.75, p = 0.09.

A 3×2 repeated-measures ANOVA with the factors memory stimulus type (food vs. non-food) and trial type (valid vs. invalid vs. neutral) was run with correct trial RT as dependent variable. Mean reaction times (RT in milliseconds) to food stimuli and non-food stimuli for valid, invalid and neutral trials are presented in Figure 2**.** There was a main effect of trial, F (2,62) = 126.6 $p < 0.001$, $\eta p^2 = 0.8$, whereby RTs for valid trials were faster than RTs for neutral and invalid trials, and RTs for neutral trials were faster than RTs for invalid trials, and a main effect of stimulus type, F (1,31) = 12.0 p = 0.002, $\eta p^2 = 0.29$, whereby participants had a faster RTs for food memory stimuli than or non-food memory stimuli.

There was a significant interaction between stimulus type and trial type F (2,62) = 6.0, p = 0.001, $\eta p^2 = 0.2$. To follow up this interaction, we computed the impact of stimulus type in each trial type. For valid trials, RTs were faster when a food stimulus was held in working memory, compared to a non-food stimulus, t(31) = -9.277, p < 0.001. For neutral trials, there was no effect of stimulus type, t(31) = -1.64, p = 0.96. Similarly for invalid trials, there was no significant effect of stimulus type, t(31) = .049, p = 0.11.

Taken together the results suggest that it is easier to hold food than non-food stimuli in memory; holding food (relative to non-food) in memory was associated with reduced cognitive load. Furthermore, attention is captured by information held in memory, an effect that was larger for food than non-food.

fMRI data

We observed a main effect of stimulus type (Table 1A, Figure 3A): holding a non-food versus food stimulus in working memory was associated with increased activity in middle superior frontal gyrus and posterior occipital cortex, extending to ventral (inferior occipital gyrus and fusiform gyrus) and dorsal (inferior parietal cortex) associative cortex. The reverse contrast was associated with increased response in the posterior calcarine sulcus, though this effect only survived FWE correction at peak level. At a lower threshold we observed regions that are commonly associated with responses to food stimuli (e.g. middle orbital frontal cortex, insula and amygdala). This pattern of results was observed even when we consider only the trials in which food pictures were presented in the search.

We also observed a validity effect (effect of trial type), reflecting the interaction between memory and search that was independent of the working memory content (stimulus type) (see Table 1B, Figure 3B). Specifically, when the item in working memory was flanked by the search distracter (relative to the search target) an increased response was observed in bilateral inferior parietal sulci extending to bilateral superior parietal sulcus; bilateral inferior occipital extending to the fusiform gyrus. We did not find a reverse validity effect (valid > invalid). Neither of the validity effects interacted with the content of working memory.

In contrast, the content of memory affected the second type of interaction between memory and selective attention: aka the re-appearance effect (Figure 4). In comparison to non-food stimuli, we observed decreased responses to a food item that re-appeared in the search array when it was held in memory, compared to when it did not re-appear (food > non-food → [valid + invalid] < neutral). This was observed in the posterior cingulum cortex (MNI: [9 -39 39], z=3.86, cluster size = 113, cluster level P_{FWE} = .015).

To assess the relevance of the interaction effect observed in posterior cingulum to the observed behavioural responses, we computed a correlation between neural responses and behaviour; for the differential impact of holding food and non-food in memory on the selective attention (Figure 4). For the behavioural data, we computed a differential validity effect: Food(valid – invalid) – non-Food(valid – invalid). For accuracy, higher values reflect stronger capture of attention to food than non-food, while the reverse pattern is the case for RT. For fMRI, we computed a differential re-appearance effects: (Food(valid+invalid) – neutral*2) – non-food(valid+invalid) – neutral*2). Here positive values suggest a stronger reactivation for items held in memory that re-appear in the search array, while a negative response, suggests stronger deactivation when the memory item reappears in the search array. We observed a reliable correlation for accuracy (Pearson rho = -50, Spearman rho = -.56, p < .005), the correlation with the RT was not reliable but was in the expected direction (Pearson rho = .14, Spearman rho = .24, p >.21). This association suggests that the capturing of attention by food (relative to non-food) was large in participants who showed stronger deactivation when food item re-appeared in the search array.

4 Discussion

The current study examined the neural correlates of working memory biases for food related stimuli, compared to non-food stimuli, in young women. Our behavioural data matched earlier results [5, 6, 13-15], namely that a food stimulus held in working memory modulated the deployment of visual attention to a search target, benefitting performance on valid trials. In other words, response to a target was facilitated when it was flanked by a food stimulus that was held in working memory. These behavioural data provide further evidence that thinking about food enhances attention to food stimuli in the environment. This top-down bias of attention to food was primarily associated with guidance of attention (valid trials), rather than interference (invalid trials).

At a neural level, we tested whether top-down guidance of attention relates to reduced memory load when holding a food item in memory [6, 14, 17, 18]. We found reduced involvement of associative visual regions in occipital parietal and temporal cortices as well as superior frontal, when holding a food, relative to non-food stimulus, in working memory. Increased response to food, relative to non-food, was observed in posterior calcarine sulcus and less reliably in other regions associated with processing of food pictures. The validity effect was not modulated by memory cue, but when a food re-appeared in the search array independent of its validity to the search task, there was a decreased response in posterior-cingulum cortex (i.e. retrosplenial region). This latter effect was reversed when non-food was held in memory. The reappearance effect in this region correlated with the behavioural results.

Memory for food is suggested to be an important factor in regulating our eating behaviour [29]. It is therefore, not surprising that holding food items in memory is easier than holding non-food items in memory, as our brain is potentially well trained in memorising these type of stimuli. This is aligned with the increase of P3 and LPP ERPs when food stimuli, compared to non-food stimuli were held in memory [6]. It is surprising that we only observed weak reliability for remembering food in regions typically reported to be activated when viewing food than non-food pictures [30]. This might be because in this study visual pictures of food appeared both when remembering food and non-food. It may also be because the analysis focused on the search task, in which the food stimuli were irrelevant. In the search task participants were asked to search for a geometrical shape, and the food stimuli could be in vicinity to the target, or the distracter. It has been suggested that responses to food stimuli depends on task requirement and attention [31].

A novel finding we observed in posterior cingulum (retrosplenial cortex) was that the interaction between memory and the search display is modulated by the content of memory. When a food item was held in memory and re-appeared in the search array, it showed a reduced response compared to when it did not re-appear. The reverse pattern was observed when non-food memory items re-appeared in the search array. Previous studies that used a similar paradigm with simple geometrical shape, reported a re-appearance effect within the posterior cingulum [7, 8, 10, 11]. The re-appearance of simple geometrical shape showed a neural pattern that is similar to the one we observed for non-food items. Similar to the results of the N1PC, ERP study [14], the re-appearance effect was reversed for food relative to non-food.

Posterior cingulate cortex (retrosplenial) is consistently reported to be more involved in processing food than non-food [30] as well as in memory [32], where reduced responses are associated with more efficient processing and better memory [33, 34]. In the context of the current paradigm, it has been suggested that decreased responses to re-appearance reflects implicit sensory priming, while an increase for re-appearance reflects top-down attentional guidance [10]. Hence in line with the ERP results [14], we suggest that the impact of food held in memory on selective attention is mediated through sensory priming processes, supporting the perceptual enhancement hypothesis. Finally, the relevance of the observed interaction in posterior cingulum to behavioural responses was demonstrated by the correlation between the extent of the re-appearance effect and the response accuracy. The correlation showed that with the amount of sensory priming in posterior-cingulate correlated with larger benefits of the valid food cue.

Taken together, the results suggest that thinking of food enhances the natural bias toward food stimuli for two reasons: 1) because thinking of food is less taxing on memory and 2) by facilitation of the responses to sensory input related to food.

There are some limitations and strengths of the present study to be discussed. First, the homogenous nature of the participants (young women only, no dieters) reduces variability in responding due to differences in eating behaviour related to sex and age, but it does not enable us to generalize our findings to the general population. We have previously reported that participants scoring high in restraint and low in tendency towards disinhibition (successful dieters) are less susceptible to the biasing effect of holding food related information in working memory [13], whereas unsuccessful dieters showed a stronger effect [15]. The present data suggest that this may be because successful dieters do not privilege working access to food related stimuli working memory, whereas unsuccessful dieters maintain food stimuli in working memory more easily but this remains to be tested. Similarly, future research should examine the role of emotional eating in attentional bias to food stimuli. Second, it is a limitation that we did not control for menstrual cycle phase which may influence responses to food cues. A final limitation is that we did not control for the impact of finger movement on the brain responses. However, the impact of finger movement is likely limited as participants only responded with the index finger or middle of their right hand on two buttons and the stimuli and trials were randomized. Some strengths are the relatively large sample size studied (>30) and the use of the established and validated memory paradigm.

In summary, these results suggest that holding food in mind may bias attention because thinking of food facilitated neuronal responses to sensory input related to food stimuli and because holding food-related information in mind is less taxing on memory.

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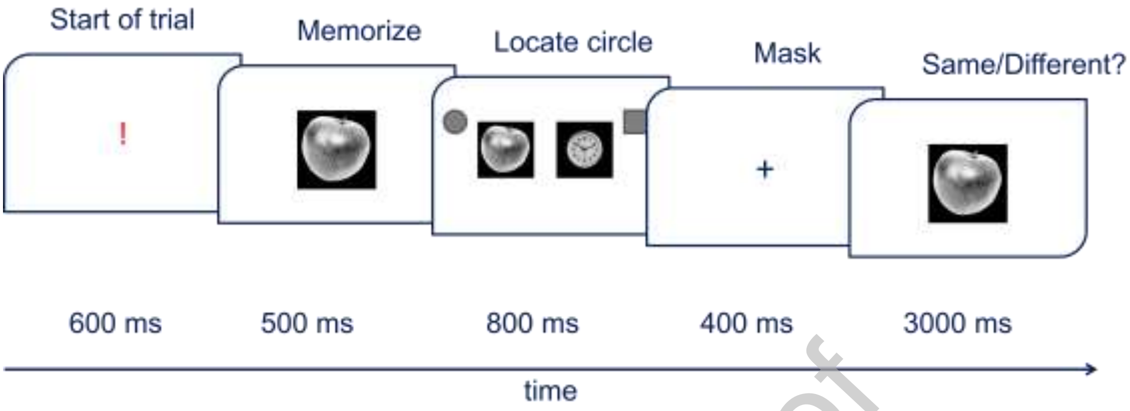
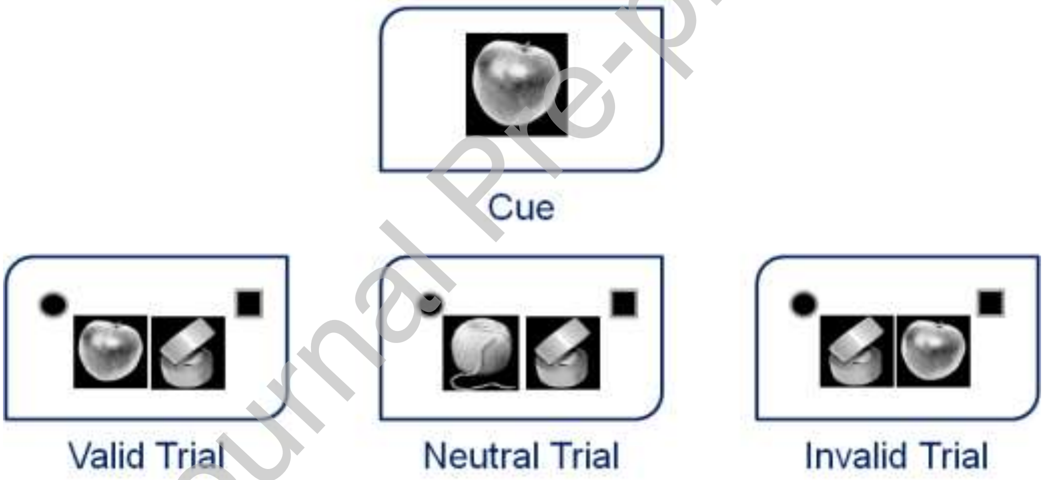
Figure 1

a





b

Figure 1

Figure 1a: Illustration of the Working Memory tasks

Figure 1b: Illustration of trials in the Working Memory task, representing a food valid, food neutral, and food invalid trial

Figure 2. Mean reaction times (in milliseconds) to food stimuli and non-food stimuli for valid, invalid and neutral trials in 32 women. Values are means ± SEM. * The significant interaction effect; participants reacted faster in the food valid trials compared to the non-food valid trails.

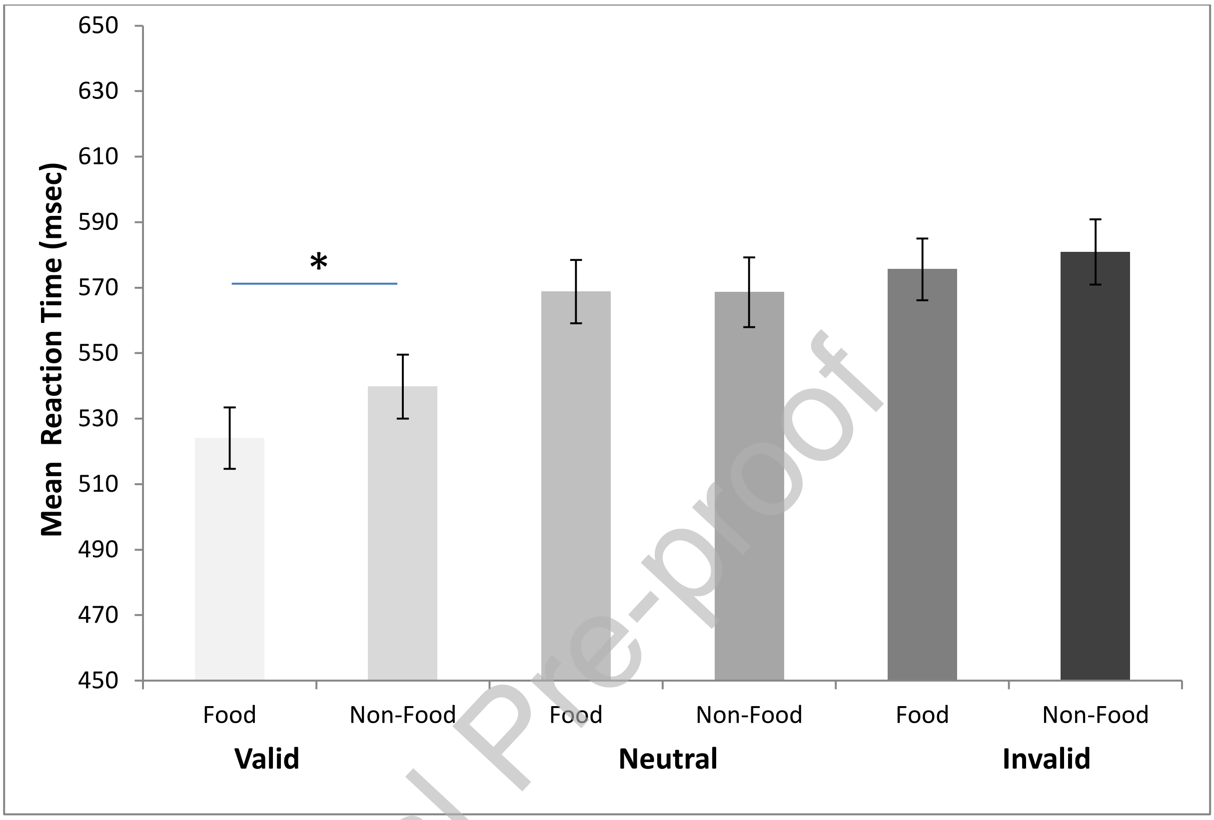


Figure 3. Brain regions associated with the main effects of stimulus type or search in working memory in 30 women. Figure 3A: Comparing holding a non-food versus food stimulus was associated with increased activity in middle superior frontal gyrus and posterior occipital cortex, extending to ventral (inferior occipital gyrus and fusiform gyrus) and dorsal (inferior parietal cortex) associative cortex. Figure 3B: Comparing invalid versus valid search trial was associated with an increased response in bilateral inferior parietal sulci extending to bilateral superior parietal sulcus; bilateral inferior occipital extending to the fusiform gyrus.

Figure 3: fMRI Results I: Main effects

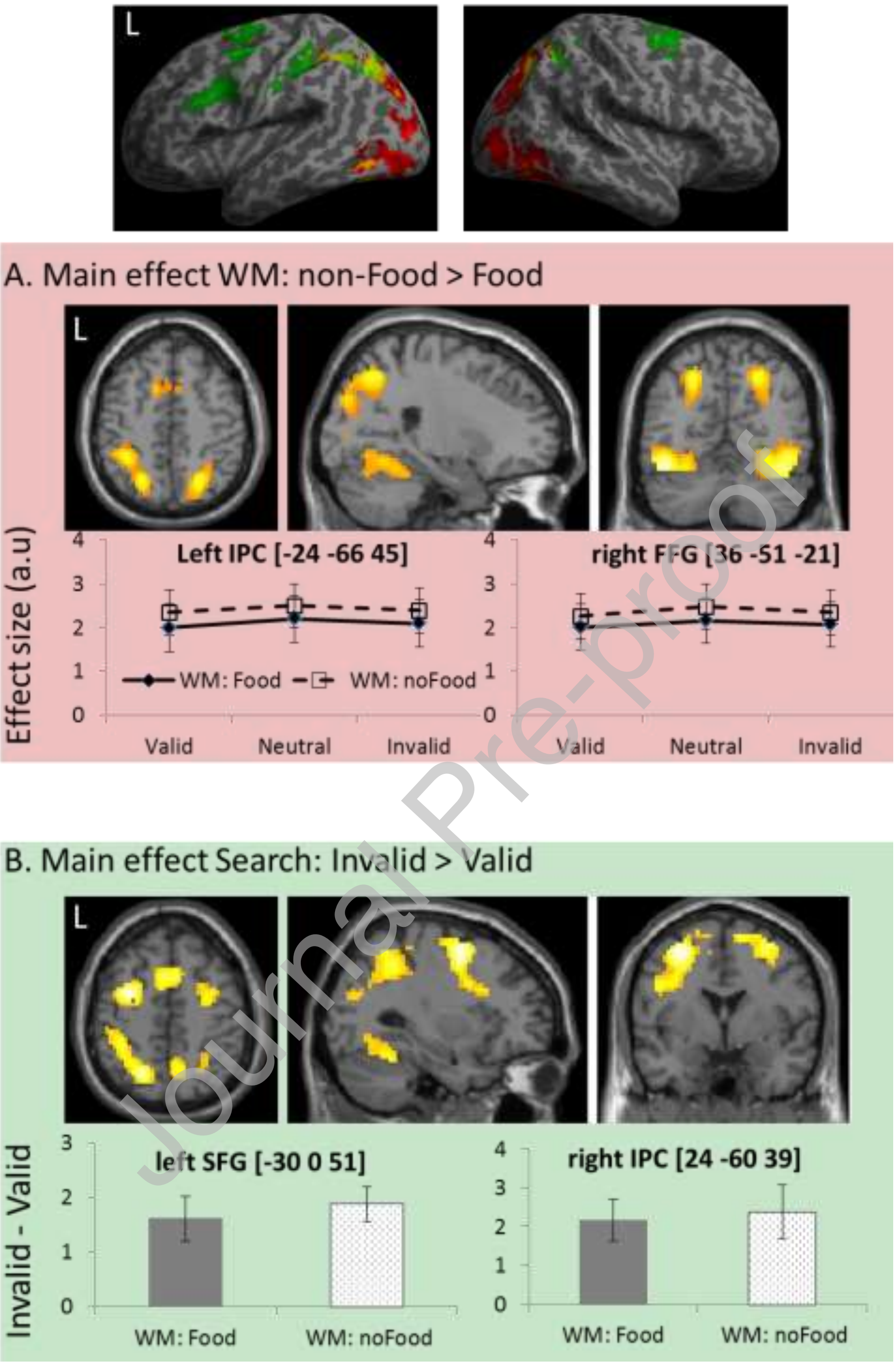


Figure 4. Brain regions associated with the interaction between memory and selective attention in 30 women.