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Biased towards food: Electrophysiological evidence for biased attention to food stimuli

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ABSTRACT

We investigated the neural mechanisms involved in bias for food stimuli in our visual environment using event related lateralized (ERL) responses. The participants were presented with a cue (food or non-food item) to either identify or 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 performance was strongly affected by food cues, especially when food was held in WM compared to when the cues were merely identified. The temporal dynamics of electrophysiological measures of attention (the N1pc and N2pc) showed that the orienting of attention towards food stimuli was associated with two different mechanisms; an early stage of attentional suppression followed by a later stage of attentional orienting towards food stimuli. In contrast, non-food cues were associated only with the guidance of attention to or away from cued stimuli on valid and invalid trials. The results demonstrate that food items, perhaps due to their motivational significance modulate the early orienting of attention, including an initial suppressive response to food items.

1. Introduction

Food stimuli appear to have special attentional significance, and this can have practical consequences for eating behaviour. For example, using a dot-probe task, they have shown that hunger states bias attentional deployment to food related stimuli (Mogg, Bradley, Hyare, & Lee, 1998), with attention being attracted more strongly when participants are hungry. Furthermore, a recent study by Calitri, Pothos, Tapper, Brunstrom, and Rogers (2010) found that heightened attention to food cues predicted weight gain over one year in a student population. Biased attention to food may occur in obese individuals due to preoccupation with consumption of food (Braet & Crombez, 2003). Food stimuli have been found to attract attention in an automatic fashion perhaps reflecting the perception food as a salient reward related cue (Nijs, Muris, Euser, & Franken, 2010).

In a recent study, Higgs, Rutters, Thomas, Naish, and Humphreys (2012) examined effects on attentional guidance from the earlier presentation of food items. Participants had either to hold an initial cue in working memory (WM) (for later matching, at the end of a trial) or to merely identify it (without holding the cue in memory). Participants then searched for a different target which appeared along with a distractor. These search items were flanked by stimuli which could be the cue or a different item. On valid trials the cue reappeared flanking the target. On invalid trials it re-appeared flanking the distractor. On neutral trials the cue did not re-appear and new stimuli appeared instead. Reaction times (RTs) and response accuracy were affected by cue validity (see also Downing, 2000; Soto, Heinke, Humphreys, & Blanco, 2005). Relative to when neutral cues were present, performance benefited when cues were valid and it was disrupted when cues were invalid. This effect of cue validity was stronger when cues were held in WM relative to when they were merely identified, and the effects were larger when the cues were food items compared with when they were other stimuli (e.g., items of stationery). The data suggest that food cues may be particularly influential in modulating visual attention.

Models of visual attention propose that stimulus selection is guided by automatic exogenous factors, which bias attention towards salient stimuli, and volitional endogenous factors, which direct attention towards task relevant objects and locations (Hickey, Chelazzi, & Theeuwes, 2010) and also away from

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irrelevant distractors (Watson & Humphreys, 1997). Attentional biases can also be observed when the internal template of an object matches with an external stimulus, when the matching object receives an increased 'processing weight' (Beck & Kastner, 2009). Event related potentials (ERPs) have been used to examine automatic and voluntary aspects of attention. For example, electrophysiological evidence indicates that early stimulus driven automatic allocation of attention is observed in the N1 time range (Fu, Fan, Chen, & Zhuo, 2001; Hillyard, Luck, & Mangun, 1994; Shedden & Nordgaard, 2001; Wascher & Beste, 2010; Wascher, Hoffmann, Sanger, & Beste, 2009). In an ERP study Fu et al. (2001) found a smaller contralateral N1 potential for valid trials than invalid trials after a peripheral cue modulated involuntary exogenous attention. However, the contralateral N2 was enhanced for valid relative to invalid trials (Hillyard et al., 1994). Enhancement of N1 component reflects the orientation and engagement of attention to relevant stimulus locations (Mangun & Hillyard, 1991). An opposite pattern of N1 activity is observed in slow voluntary attention tasks where enhanced contralateral N1 activity is observed for valid trials relative to invalid trials (Eimer, 1993; Mangun & Hillyard, 1991).

A second lateralized ERP component related to visual attention is the N2pc. The N2pc is linked to the processes involved in attentional selection (Kiss, Van Velzen, & Eimer, 2008) and the suppression of distractor information (Hickey, Di Lollo, & McDonald, 2009), with target-related lateralized activity occurring earlier than activity related to distractor suppression (Hickey et al., 2009). The magnitude of the N2pc varies according to the difficulty of target selection (Luck & Hillyard, 1994). The N2pc is also modulated by semantic relatedness between the target and distractors and indexes attentional selection (Hickey, van Zoest, & Theeuwes, 2010; Kumar, Soto, & Humphreys, 2009; Telling, Kumar, Meyer, & Humphreys, 2010). Linked to the study reported here, previous studies have shown that items held in WM modulate attentional deployment to target stimuli and affect the N2pc (Kumar et al., 2009). In Kumar et al. (2009) participants were asked to hold an item in WM and search for a different target. Notably, the N2pc was enhanced when the target and cued item were in the same visual field compared to when the cued item and the target were in different visual fields (invalid trials) or the cue and target did not match (neutral condition) during a WM task. In contrast, the N2pc did not differ across different validity conditions in a priming task where participants had to identify the cue but not to hold it in memory (Kumar et al., 2009).

Recent studies have investigated the neural basis of enhanced attention to food using ERPs. When normal-weight, hungry participants are presented with food pictures, both early stage ERPs (170–300 ms) (Stockburger, Hamm, Weike, & Schupp, 2008) and the later P300 are enhanced (Nijs, Franken, & Muris, 2009), and the peak P300 latency occurs earlier, suggesting enhanced allocation of attention to food pictures. Several studies have examined attentional bias towards food stimuli by modulating the hunger and satiety of both normal healthy individuals (Lavy & van den Hout, 1993; Mogg et al., 1998; Stockburger et al., 2008; Stockburger, Schmalzle, Flaisch, Bublatzky, & Schupp, 2009) and obese/overweight individuals (Nijs, Franken, & Muris, 2008; Nijs et al., 2010). Stingl et al. (2010) used a one-back WM task and magnetoenchalographic recording and showed early differences in low-level visual areas (~120 ms), and later increased inactivity in the temporal cortex (~350 ms) for food versus non-food stimuli. Their results showed that a food stimulus held in the WM increases neural responses to a proceeding food stimulus.

In the present study we analysed event related lateralized (ERL) activity to index different stages of the deployment of attention to food items which appeared as cues that initially had to be identified or held in WM. The ERLs are computed by subtracting the ipsilateral activity from the contralateral activity related to the stimulus of interest. We examined the N1pc and the N2pc in order to examine the time course of attentional deployment based on these components. We hypothesized that food cues would induce category-specific activity and early modulation of attention, relative to non-food stimuli. Whether these effects arise from bottom-up activation from the food cue, or top-down from a memory for food, was examined by contrasting the effects of food (vs. other) cues when they are held in WM and when they are merely identified.

2. Materials and methods

2.1. Participants

Fifteen students (8 females and 7 males) from the School of Psychology of the University of Birmingham, who were all unaware of the purpose of the experiment, took part for either course credits or cash. Their mean age was 23 years (range 19–38 years), and their mean body mass index (BMI) was 24.8 kg/m^2 (range 18–35 kg/m^2) with 50% of the participants being overweight, including only one of the participants being obese. All participants had normal to corrected-to-normal-vision. Participants provided written consent to participation. The study was approved by the Ethics Committee of the University of Birmingham, and conformed to the Declaration of Helsinki.

2.2. Procedure

Participants consumed their regular breakfast before the start of the study. Feelings of hunger and fullness were scored by Visual Analogue scales (VAS) before and after performing both tasks. Participants then completed the priming and working memory (WM) tasks, with an option of a 5 min break between tasks. Before leaving, participants completed the Three Factor Eating Questionnaire (TFEQ) (Stunkard & Messick, 1985), and had their height (cm) and weight (kg) measured.

2.3. Tasks

The priming and WM tasks were completed in a counterbalanced order. The priming task consisted of 1945 trials, taking about 120 min, and the WM task consisted of 1500 trials, and took 106 min to complete. The trials were divided into smaller blocks of about 150 trials, after which the subject had a few minutes rest. The priming and WM tasks were similar; however, the instructions to the subjects differed. In the WM task participants were asked to hold the initial cue in memory for later matching with a probe item. In the priming condition participants were asked to attend the cue but not to hold it in memory (see Fig. 1a). A trial started with a central fixation cross for 600 ms, followed by a cue for 500 ms. The cue was either a picture of a food item or non-food item (a car, or a stationery item). Ten different pictures for each of the stimulus types; food, car, and stationary; were used. All pictures were presented in black and white, sized 480 × 480 pixels, and appeared in the middle of the screen with a black background. The cue was followed by a 200–1000 ms blank interval with a fixation cross. After the interval, a target (circle) and a distractor (square) were presented randomly to the left or right of fixation. Participants had to press 'c' if the circle appeared on the left and 'm' if it appeared on the right, with the maximum response time set at 800 ms. The target and the distractor were each flanked by a picture of a food item, a car or a stationery object. The intertrial interval was 400 ms. In the priming task the cue was replaced with a different picture after 250 ms on 20% of trials (catch trials).

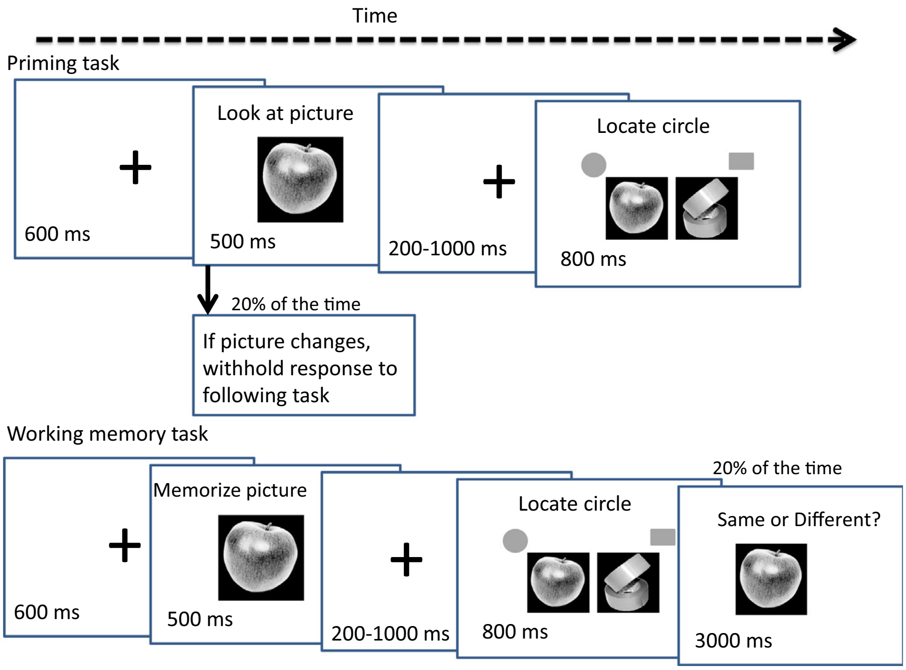

Fig. 1a. Illustration of the Priming and Working Memory tasks; subjects were presented with a cue (food or non-food item) for 500 ms to either attend to or hold in WM. Subsequently, they had to search for a target (for 800 ms), while the target and distractor were each flanked by a picture of a food or non-food item. On a small proportion of priming trials (20%), the priming cue disappeared and was replaced by a different image. On these priming probe trials participants were instructed not to carry out the search task that normally followed the initial cue. This ensured that participants attended to the cue. In the WM task participants were asked to hold the cue in memory across the trial, for a subsequent memory test on a minority of occasions (again 20% of the trials).

On these trials, participants withheld their response. On the other trials, when the pictures were the same, participants went on to carry out the search task. On WM trials only, a memory probe followed the search display on 20% of the trials; this was an item from the same category as the cue and it appeared for 3000 ms. The participants indicated whether the item was the same or different to the cue.

There were three conditions: (1) on valid trials, the target was flanked by an image that was the same as the cue and the distractor in the search display was flanked by an image from one of the other stimulus types, (2) on invalid trials, the distractor was flanked by an image that was the same as the cue and the target was flanked by an image from one of the other stimulus types, and (3) on neutral trials both the target and distractor were flanked by images from a stimulus type different to the cue (see Fig. 1b for an example of the WM task, representing a food valid, food neutral, and food invalid trials). The conditions occurred randomly with equal probability.

2.4. Apparatus

Stimuli were presented using E-Prime (Version 1.2 – Psychology Software Tools) on a Pentium IV computer with an ATI RAGE PRO 128-MB graphics card, displayed on a SyncMaster 753s colour monitor (SAMSUNG, Seoul, Korea). The monitor resolution was 1024 × 768 pixels and the frame rate was fixed at 85 Hz.

2.5. Electroencephalogram data processing

Electroencephalogram (EEG) recordings for each participant were taken continuously with Ag/AgCl electrodes from 128 scalp electrode locations. The electrodes were placed according to the 10–5 electrode system (Oostenveld & Praamstra, 2001) using a nylon electrode cap. Vertical eye movement was monitored by a unipolar electrode placed at the infra-orbital area of the left eye and horizontal eye movement was monitored by a bipolar electrode placed at the outer canthus of the left and right eyes. CMS and DRL were used for references and ground. EEG and electrooculogram signals were amplified (BioSemi ActiveTwo, Amsterdam, the Netherlands) and sampled at 512 Hz. The continuous EEG recordings were off-line referenced to the average of the left and right mastoids and band pass filtered between 0.5 and 30 Hz. Continuous EEG signals were segmented into epochs from 200 ms before trial onset to 1000 ms after trial onset for each of the conditions for each subject. Epochs were rejected if the voltage in the horizontal eye electrode exceeded ±60 and ±100 μV in any other electrodes. On average, percentage of trials rejected due to voltage in horizontal eye electrode exceeding ±60 μV ranged between 8.1% and 11.8% across validity conditions and tasks. The number of rejected trials across different validity conditions and tasks was not significantly different from each other (all $ps > .07$). Catch trials and error trials were not included in the analysis. Overall, the average percentage of trials rejected after applying all the rejection criteria ranged between 13.2% and 27.2% across validity conditions and tasks. The 200 ms prior to the onset of the WM and priming stimulus was used as a baseline for WM and Priming task related ERP data respectively, and the EEG signals reported have been calculated relative to this baseline activity. We were interested in evaluating the modulation of two early lateralized attentional components, N1pc and N2pc. The N1pc and N2pc components were analysed at the pooled five posterior and lateral occipital electrodes (PPO5h/PPO6h, P05h/PO6h, PO3h/PO4h, O1/O2 and PO7/PO8) based on the ERL activity CSD maps in the N1pc and N2pc time window, where the source of the N1pc and N2pc activity was observed across the conditions. The N1pc and N2pc components were quantified as the mean amplitude in 130–230 ms and 230–330 ms time windows respectively.

2.6. Analysis

The data were analysed using SPSS Statistics 19 (IBM). Differences in reaction times and electrophysiological measures

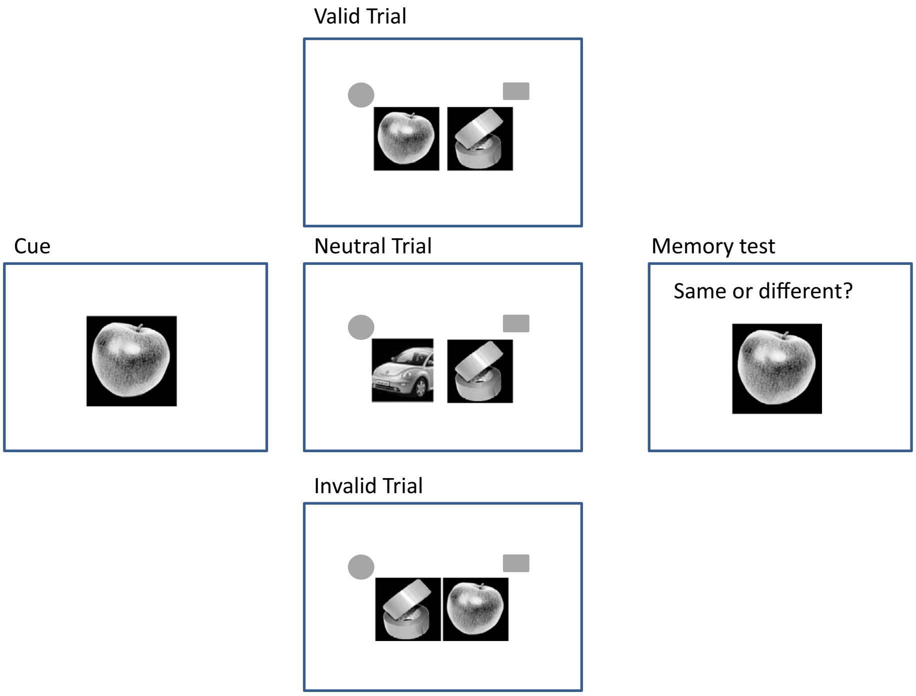

Fig. 1b. Illustration of trials in the Working Memory task, representing a food valid, food neutral, and food invalid trial. On valid trials, the target in the search display was flanked by an image that was the same as the cue and the distractor was flanked by an image from one of the other cue categories, while on invalid trials, the distractor was flanked by an image that was the same as the cue and the target was flanked by an image from one of the other cue categories, and finally on neutral trials both the target and distractor were flanked by images from categories different from the cue.

between the tasks (WM, priming), trials (valid, neutral, invalid), and cues (food vs. non-food items) were analysed using repeated-measures ANOVAs. Additionally, paired *t*-tests were performed. All tests were two-tailed and differences were considered significant at $p < 0.05$. Values are expressed as means. Greenhouse-Geisser corrections for degrees of freedom were used whenever the assumption of sphericity was violated.

3. Results

3.1. Participant characteristics

The participants (8f/7m) were young, had a normal weight, and had low dietary restraint, disinhibition, and hunger scores. The mean age, BMI, TFEQ cognitive restraint, disinhibition, and hunger scores were 23.2 ± 4.8 y; 24.8 ± 4.5 kg/m^2; 7.1 ± 5.0; 5.8 ± 2.8; and 4.9 ± 2.6. The mean hunger and fullness scores (VAS) at the start of the experiment were 15.3 ± 13 and 59.4 ± 26 mm, which suggests that subjects were sated.

3.2. Reaction times

Incorrect responses to the search task, catch trials on priming task, and incorrect responses to memory trials on WM task, as well as reaction times (RTs) that were ±3 standard deviations from the mean were removed. In both the priming and WM tasks, the accuracy for the search task was high; an average of 93% correct. In the priming condition, responses on catch trials were withheld as instructed; an average of 92% correct, and in the WM condition, responses to the memory task were correct on 87% of all trials. There was no evidence of a speed–accuracy trade-off.

Mean reaction times (in milliseconds) to food and non-food cues for Valid, Invalid, and Neutral trials, for both the Priming and the WM tasks, are presented in Fig. 2. First, we carried out a $2 \times 3 \times 2$ repeated-measures ANOVA with the factors being task (priming vs. WM task), validity (valid, invalid, neutral trials), and cue (food vs. non-food items). We observed a significant two-way interaction between task and validity ($F(2,28) = 21.5$, $p < 0.001$, $\eta^2_p = 0.605$); RTs were faster for valid trials compared to invalid trials ($p < 0.001$), and compared to the neutral trials ($p < 0.001$) in the WM task. We observed a similar pattern in the priming task; however, the effect was smaller, and only the difference between valid and neutral trials was reliable ($p < 0.05$). Additionally, we observed a significant two-way interaction between validity and cue ($F(2,28) = 47.8$, $p < 0.001$, $\eta^2_p = 0.773$); RTs were faster following food cues compared to non-food cues in the valid trials ($p < 0.001$), but not in the invalid condition ($p = 0.7$) or neutral trials ($p = 0.9$). Along with these interaction effects we observed several significant main effects: RTs were slower in the WM task than in the priming task ($F(1,14) = 10.44$, $p < 0.006$, $\eta^2_p = 0.427$), consistent with the greater cognitive load during the WM task (Soto et al., 2005). There was a main effect of validity ($F(2,28) = 60.9$, $p < 0.001$, $\eta^2_p = 0.813$), whereby RTs were faster for the valid trials than the neutral and invalid trials, and RTs for the neutral trials were faster than the invalid trials (all $p < 0.05$). There was also a main effect of cue ($F(1,14) = 5.6$, $p < 0.03$, $\eta^2_p = 0.287$); RTs following the food cues were faster than RTs following the non-food cues. The three-way interaction between task, validity, and cue ($F(2,28) = 1.96$, $p = 0.16$, $\eta^2_p = 0.123$), and the two-way interaction between task and cue were not significant ($F(1,14) = 1.3$, $p = 0.27$, $\eta^2_p = 0.087$).

3.3. Error rate analysis

Error rates were arcsine transformed and we carried out a $2 \times 3 \times 2$ repeated-measures ANOVA with the factors being task (priming vs. WM task), validity (valid, invalid, neutral trials), and cue (food vs. non-food items) on arcsine transformed error rates. We observed a significant two-way interaction between task and validity ($F(1.37,19.25) = 15.4$, $p < 0.001$, $\eta^2_p = 0.523$); error rates

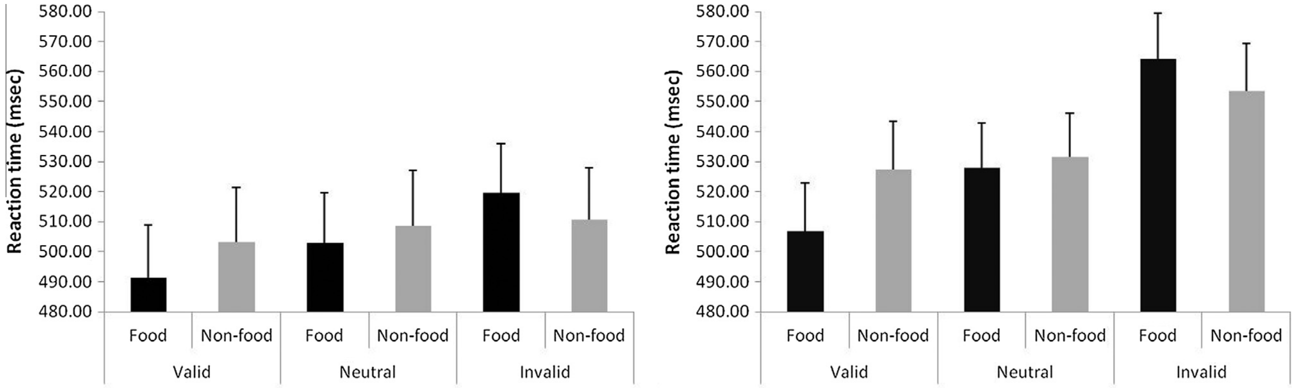

Fig. 2. Mean reaction times (in milliseconds) to food, and non-food cues for Valid, Invalid, and Neutral trials, for the Priming and Working Memory task. Values are means ± SEM.

were significantly lower for the valid trials (0.033) compared to invalid trials (0.105) ($p < 0.001$), and compared to the neutral trials (0.048) ($p = 0.003$); error rates for the neutral trials were also significantly lower compared to the invalid trials ($p = .001$) in the WM task. We observed a similar pattern in the priming task; however, the effect was smaller, error rates were significantly lower for valid trials (0.079) compared to invalid trials (0.118) ($p = 0.012$), and compared to the neutral trials (0.093) ($p < 0.009$); error rates for the neutral trials were also significantly lower compared to the invalid trials ($p = 0.044$) in the priming task. Overall, the differences in error rates for the valid and neutral trials compared to the neutral trials were larger in the WM task. Additionally, we observed a significant two-way interaction between validity and cue ($F(2,28) = 5.40$, $p < 0.01$, $\eta_p^2 = 0.278$); error rates were significantly lower for the valid trials (0.049) compared to invalid trials (0.098) ($p = 0.001$), and compared to the neutral trials (0.067) ($p = 0.007$); error rates for the neutral trials were also significantly lower compared to the invalid trials ($p = 0.005$) for the food cues. We observed a different pattern for the non-food cues, and the error rates were significantly higher for the valid trials (0.132) compared to invalid trials (0.097) ($p = 0.019$), and compared to the neutral trials (0.085) ($p < 0.013$). However, the error rates for the neutral trials were not significantly different compared to the invalid trials ($p = 0.112$) for the non-food cues. Along with these interaction effects we observed several significant main effects: Error rates were larger for the non-food cues compared to the food cues ($F(1,14) = 21.2$, $p < 0.001$, $\eta_p^2 = 0.602$). There was a significant main effect for validity ($F(2,28) = 20.1$, $p < .001$, $\eta_p^2 = 0.589$); whereby errors were larger for the invalid trials than the valid and neutral trials, and errors for the neutral trials were larger than the valid trials (all $p < 0.05$). The three-way interaction between task, validity, and cue ($F(2,28) = 0.056$, $p = 0.945$, $\eta_p^2 = 0.004$), the two-way interaction between task and cue ($F(1,14) = 0.049$, $p = 0.827$, $\eta_p^2 = 0.004$) and the main effect of task type ($F(1,14) = 1.90$, $p = 0.190$, $\eta_p^2 = 0.119$) were not significant.

3.4. Event related lateralized activity analysis

Visual inspection of the contralateral–ipsilateral grand averaged waveforms showed an early contralateral positivity for the food valid and non-food invalid conditions in the N1pc time window. An opposite pattern was observed for the food invalid and the non-food valid conditions, where contralateral negativity was observed on food invalid and non-food valid trials. The contralateral positivity in the N1pc time window for the food valid condition became contralateral negativity in the N2pc time window. However, the earlier contralateral positivity remained for the non-food invalid condition in the N2pc time window too. Similar changes were observed for the food and non-food invalid conditions. The early contralateral negativity remained for the non-food valid conditions, while it became contralaterally positive for the food invalid condition in the N2pc time window. The pattern of the waveforms suggests that, across the two time windows of the N1pc and N2pc, the waveform morphology changed only for food stimuli. See Figs. 3a and 3b for topography maps and waveform morphology associated with the N1pc and N2pc components. Fig. 4 shows changes in the N1pc and N2pc amplitude for food and non-food cues collapsed across the two tasks.

Statistical analysis of the ERL components (N1pc and N2pc) was carried out similar to the RT analysis with $2 \times 3 \times 2$ repeated-measures ANOVA with the factors being task (priming vs. WM task), validity (valid, invalid, neutral trials), and cue (food vs. non-food items). Greenhouse-Geisser corrections for degrees of freedom were used whenever the assumption of sphericity was violated. In the 130–230 ms time period (N1pc) there was a significant interaction between cue type and validity ($F(1.71,16.39) = 25.9$, $p = .001$, $\eta_p^2 = .650$); the N1pc amplitude was largest for the invalid condition followed by the neutral and valid conditions for food stimuli. In fact, the neutral and valid trials of food had opposite polarity for the N1pc component, i.e., they showed positive potentials in the N1pc time window. Pairwise comparisons showed that, for food cues, the invalid condition differed significantly from both the valid and neutral conditions (invalid > valid, $p = .005$, invalid > neutral, $p = .012$) but no significant difference was observed between valid and neutral condition ($p = .131$). In contrast for the non-food stimuli, the valid condition had the largest N1pc potential followed by the neutral and invalid conditions. An opposite polarity (positive polarity) was observed for the invalid condition with non-food stimuli. Pairwise comparisons for non-food stimuli showed that all three validity conditions differed significantly from each other (valid > invalid, $p = .001$, valid > neutral, $p = .001$, neutral > invalid, $p = .001$). In addition we also observed a marginal significant main effect of validity ($F(2,28) = 3.31$, $p = .051$, $\eta_p^2 = .191$). The three way interaction between task, validity and cue ($F(2,28) = 1.58$, $p = .223$, $\eta_p^2 = .102$), the two way interactions between task and validity ($F(2,28) = 0.268$, $p = .767$, $\eta_p^2 = .019$) and the two way interaction between task and cue ($F(1,14) = 2.81$, $p = .116$, $\eta_p^2 = .167$) were not significant.

We were interested in understanding how attention to food related stimuli be related to the participant's BMI. As our prediction was that attention to food stimuli would be different when participants keep food information in WM as compared to when they merely attend to food stimuli. Therefore, we carried out correlation analyses between the body mass index (BMI) of the participant and N1pc amplitude with food valid condition only in priming and WM task conditions. The Pearson product moment

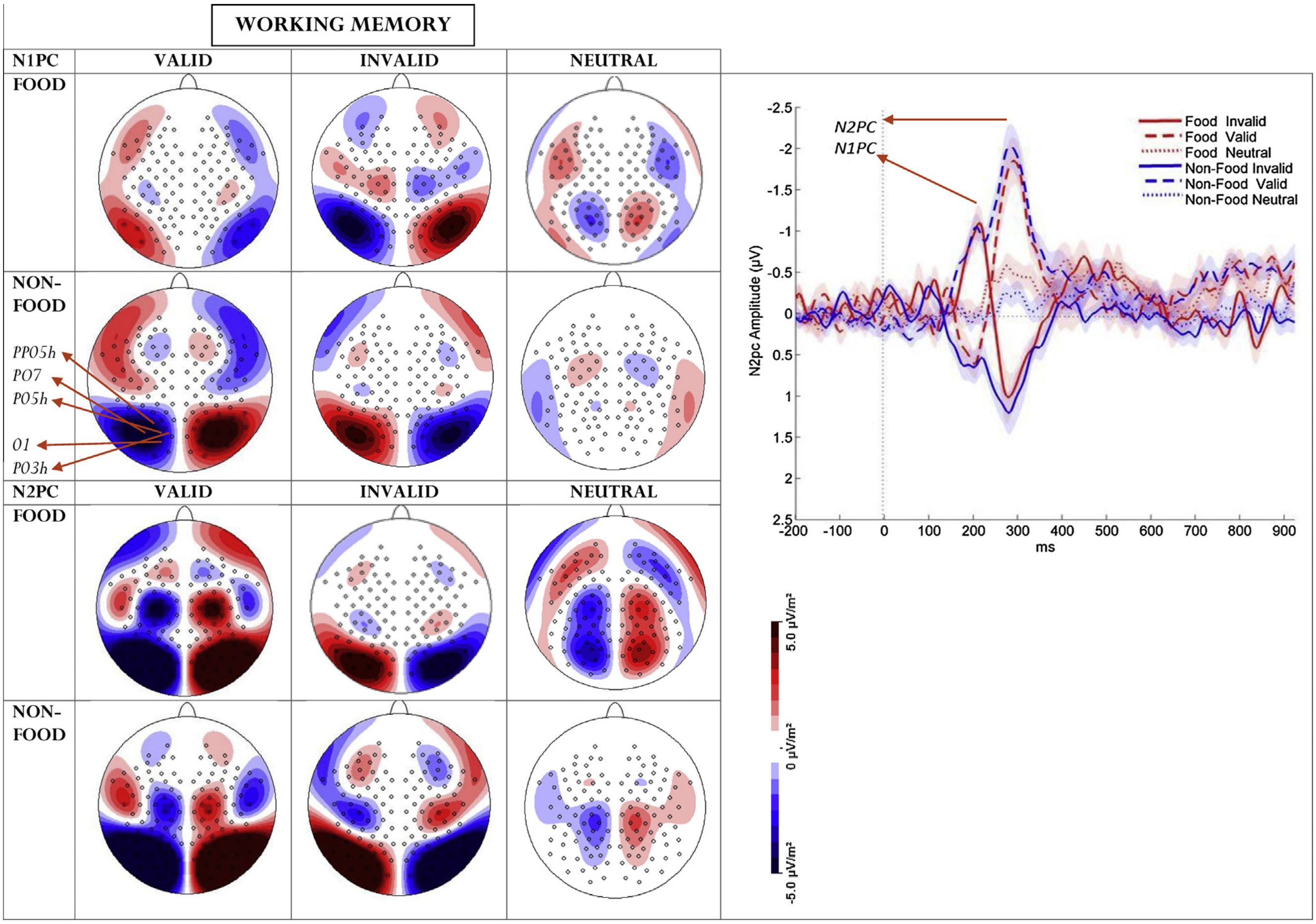

Fig. 3a. Current source density topography maps (computed from the grand average of contralateral–ipsilateral activity) for the N1pc and N2pc period and grand averaged waveforms of contralateral–ipsilateral processing related to the target from pooled electrodes over parieto-occipital scalp region for ERL activity during the WM task. The shaded area around the grand averaged waveforms shows 1 standard error of mean. Electrodes chosen for the ERL analysis are shown in the non-food valid N1pc condition topography map.

correlations between N1pc amplitude and the body mass index (BMI) of the participant showed that the N1pc amplitude for the food valid conditions in the priming and WM task was positively correlated with the BMI of the participant ($r = .655$, $p = .008$ and $r = .622$, $p = .013$ respectively).

Analysis of the mean amplitude for N2pc component (230–330 ms) showed significant 2 way interactions between task and cue type ($F(1,14) = 5.425$, $p = .035$, $\eta_p^2 = .279$); the N2pc amplitude for food stimuli did not differ between the priming and WM tasks ($t = 1.46$, $p = .167$). However, the N2pc amplitude for non-food stimuli in the priming task was significantly larger than in the WM task ($t = 3.66$, $p = .003$). We also found a reliable interaction between task and validity ($F(1.07,14.99) = 11.470$, $p = .004$, $\eta_p^2 = .450$); the N2pc amplitude for valid trials did not differ significantly between the priming and WM tasks ($t = 2.08$, $p = .056$). However, invalid and neutral trials had significantly larger N2pc amplitudes in priming task than in the WM task ($t = 3.84$, $p = .002$ and $t = 2.98$, $p = .01$ respectively). There was a further two way interaction between cue type and validity ($F(2,28) = 10.9$, $p = .001$, $\eta_p^2 = .438$); that food valid trials had a significantly smaller N2pc amplitude than non-food valid trials ($t = 2.39$, $p = .031$). In contrast, food invalid trials had a significantly larger N2pc amplitude than non-food invalid trials ($t = 4.05$, $p = .001$). However, no difference was found between food and non-food neutral trials (when a food cue did not appear in the search display) ($t = 1.16$, $p = .265$). The main effects of task type ($F(1,14) = 7.95$, $p = .014$, $\eta_p^2 = .362$) showed that the N2pc amplitude for priming was larger than for the WM task. In addition, we also observed a significant main effect for validity ($F(1.15,16.14) = 41.1$, $p = .001$, $\eta_p^2 = .746$); the N2pc amplitude for valid trials was significantly larger than for invalid and neutral trials (all $p = .001$). The neutral trials also had significantly larger N2pc amplitudes than invalid trials ($p = .001$). The three way interaction between task, validity and cue ($F(2,28) = 1.60$, $p = .214$, $\eta_p^2 = .104$) was not significant. Fig. 5 shows N2pc amplitude for food and non-food cues across 3 validity and 2 tasks types.

The significant results are summarized in Table 1. Pearson product moment correlations between the N2pc amplitude and the BMI of the participants showed that the N2pc amplitude for the food valid conditions in the WM task was positively correlated with the BMI of the participant ($r = .631$, $p = .012$).

4. Discussion

The current study examined the electrophysiological correlates of food-related attention selection. The behavioural data replicated earlier reported findings (Higgs et al., 2012); a food cue presented before a search display modulated the deployment of visual attention to a search target more than non-food cues, even though it was irrelevant for target selection. In particular, RTs were facilitated to food items on valid trials but not on neutral and invalid trials; this last result held across the WM and priming conditions. The evidence for fast RTs following valid food cues irrespective of

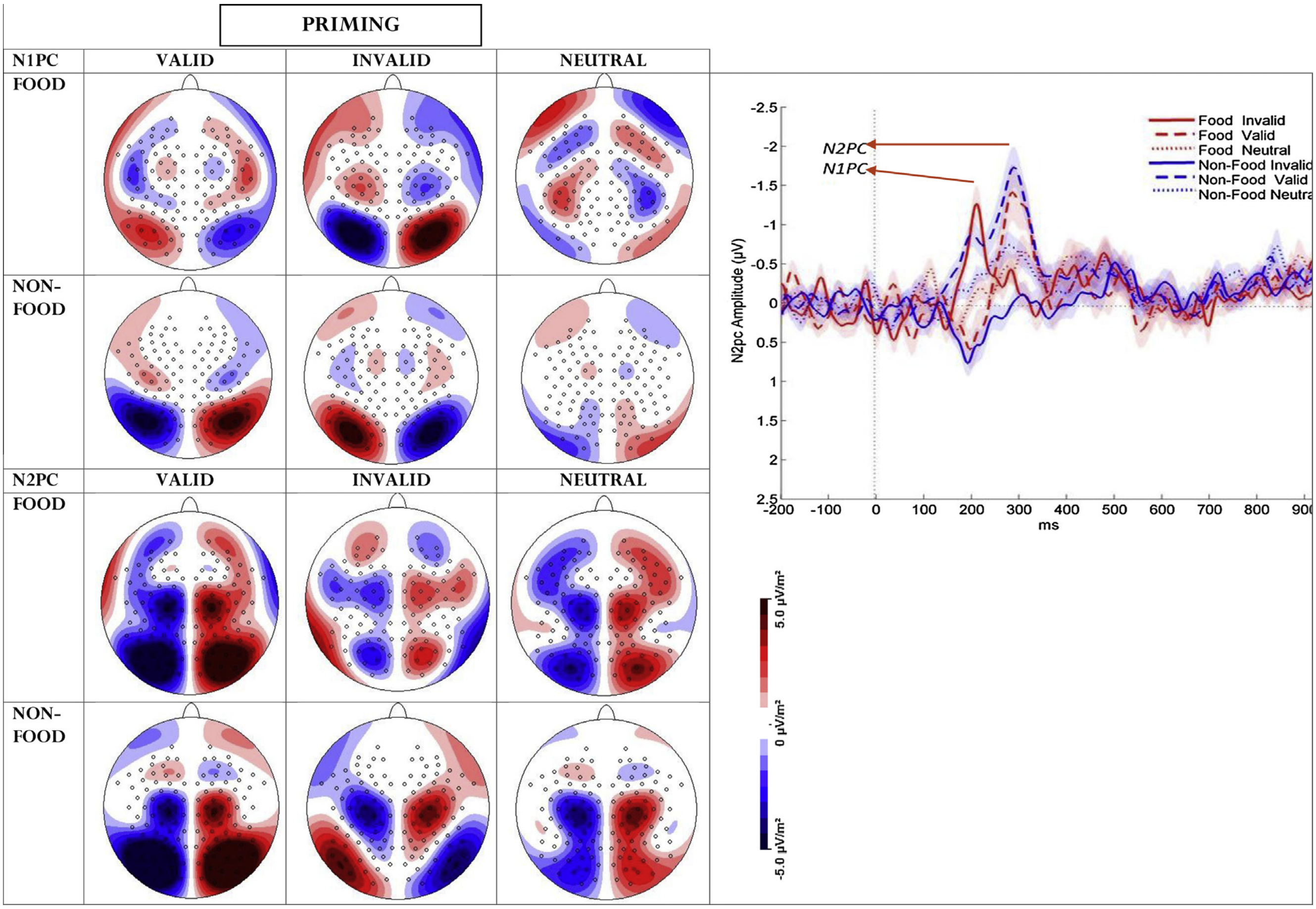

Fig. 3b. Current source density topography maps (computed from the grand average of contralateral–ipsilateral activity) for the N1pc and N2pc period and grand averaged waveforms of contralateral–ipsilateral processing related to target from pooled electrodes over parieto-occipital scalp region for ERL activity during the WM task. The shaded area around the grand averaged waveforms shows 1 standard error of mean.

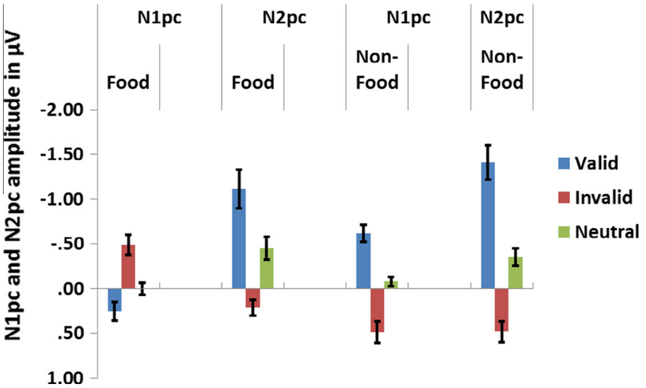

Fig. 4. Mean event related lateralized activity in the N1pc and N2pc time window collapsed for WM and priming task for food and non-food stimuli across three trials type.

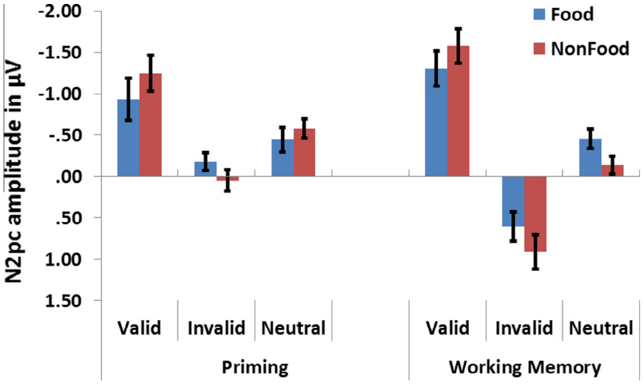

Fig. 5. Mean event related lateralized activity in the N1pc and N2pc time window for the WM and priming task for food and non-food stimuli across three trials type.

whether the cue was held in WM suggests one of two possibilities: there may be some bottom up component to cueing attention to food (present in priming and WM conditions) or it may be difficult to prevent food items from entering WM and therefore cueing attention from WM and therefore cueing attention in both the WM and priming conditions. Similar effects of food cues were observed on the error rates, and fewer errors were made to food items on valid trials in WM task. However, when food cues were only attended to, more errors were made to food items in valid trials indicating attentional deployment was facilitated by holding food information in WM.

In the present study we found a striking difference in the ERL components to food and non-food cues in the two time bins of interest (N1pc and N2pc). For non-food cues, activity in N1pc and N2pc time bins followed a similar pattern. The N1pc and N2pc components (reflected in the negative amplitudes) were greater on valid trials than on neutral trials, consistent with attentional cueing to validly cued target. On invalid trials the N1pc and N2pc components showed the opposite polarity (now there was a

Table 1
Summary table showing significant effects for N1pc and N2pc components.

Significant effects	
N1pc	
Cue type × validity	Food: Invalid > Valid & Neutral (valid & neutral trials had opposite positive polarity to invalid trials) Non-food: Valid > Neutral > Invalid (invalid trial had opposite and positive polarity to valid & neutral trials)
N2pc	
Task	Priming > WM
Validity	Valid > Neutral > Invalid (invalid trial had opposite and positive polarity to valid & neutral trials)
Cue type × validity	Food invalid > Non-food invalid
Cue type × task	Non-food priming > Non-food WM
Task × validity	Invalid priming > Invalid WM Neutral priming > Neutral WM

positive amplitude). This result suggests that attention was directed away from the target but towards the invalidly cued distractor. The pattern of results matches that previously reported from cueing effects with simple geometric shapes (Kumar et al., 2009). In contrast to this, the N1pc and N2pc components showed opposite effects of cueing for food items. In this case, the N1pc had a negative going deflection for trials where the food cue was invalid while there was a positive going deflection when the food cue was valid. This result suggests that there was early suppression of orienting to the food cue and orienting of attention to the opposite location (generating a larger negative amplitude on invalid trials). The result is similar to distractor suppression previously linked to the Pd component (Mazza, Turatto, & Caramazza, 2009; Sawaki & Luck, 2010). However, at the later time bin, the N2pc component showed a pattern of results consistent with strong orienting towards food cues. Now there was a negative deflection (a normal N2pc) on valid trials and a positive deflection on invalid trials with the results suggesting orienting of attention towards food cues. The electrophysiological results on attentional orienting to food cues also did not vary as a function of the task (in the priming and WM conditions). Again it may be that food stimuli cue attention in a bottom up manner in both the priming and WM conditions, and so there is no modulation by task type. These effects of food on the N1pc and N2pc are also supported by the correlations we conducted. The N1pc amplitude on trials with valid food cues correlated with the BMI of the participants, and this held for the priming and WM conditions alike. The N2pc amplitude also correlated with BMI values, though this held only for the WM condition. These correlation analyses suggest that the effects of the food cue operate in a bottom-up manner to affect early ERL components (for the priming and WM conditions alike) while there are differential effects on the later components (N2pc) from food cues in WM. Both of these effects are stronger in individuals with a high BMI.

The evidence for an initial bias against food items was unexpected. One account, however, is that food items tend to enter WM in both the priming and WM conditions. To prevent attentional biasing merely due to entering WM, participants may attempt to suppress inappropriate responding to food items just because they enter WM. This idea is explained further below.

The contrasting directions of the N1pc and N2pc for food and non-food cues provide strong evidence for food having a differential impact on attentional orienting. Non-food items here behaved similar to neutral, geometric shapes in the study of Kumar et al. (2009); valid cues directed attention to the target (generating larger negative N1pc and N2pc), while invalid cues directed attention to the distractor (generating reverse positive N1pc and N2pc relative to the target). The opposite results for food items at the N1pc time window suggest instead that there was initial suppression of these items, so that attention was biased to targets on invalid trials (producing a negative N1pc for invalid trials and a positive N1pc for valid trials). This suppression disappeared at the later time window, where stronger orienting to the target was found on valid trials while, on invalid trials, there was orienting to distractor (generating negative and positive N2pcs respectively). The apparent early suppression of the food cue may occur if this item is a stronger competitor for the search task. Studies particularly of WM effects on attentional selection indicate that there can be competition between the representation of a cue in WM and the search target. For example, effects of the WM item on search are stronger when the search item is constant relative to when it varies across trials (see Olivers, 2009). This pattern of result fits with the idea that the WM cue and the 'template' for the search target compete for representation. When the search target is refreshed on each trial (due to it changing on a trial by trial basis), then the search template is dominant and effects of attentional guidance from the irrelevant item in WM decrease. However, when the search target is constant, the WM item can hold a more dominant position and influences search. In addition, there is evidence that participants can attempt to control selection from irrelevant item in WM, so that search can be biased away from repeated WM items-facilitating search on invalid trials (when the target falls on the side of space opposite to the WM cue) and limiting it on valid trials (e.g., Han & Kim, 2009; Woodman & Luck, 2007). This result is found particularly when the WM cue is always invalid and there is time to inhibit the WM item (Han & Kim, 2009). The data with food cues here indicate that there was early suppression of the cue in WM which we suggest is due to the food item competing for representation with the search target. This early suppression, however, could not be maintained, and the food cue then exerted a strong effect on attentional guidance at the N2pc time window. According to this argument, food cues are inhibited as potent distractors but also overcome this inhibition over time to then guide attention.

The correlations we report with BMI values indicate that there are links between eating behaviour and attentional engagement. This fits with data from prior research. Hollitt, Kemps, Tiggemann, Smeets, and Mills (2010) found that restrained eaters show a heightened vigilance for food cues. Similarly Nijs et al. (2008) showed that the P300 ERP component was positively associated with self-reported increase of hunger indicating eating behaviour influences attention to food cues. The strong triggering of attention to food cues may make it difficult for individuals to restrain from eating, biasing them towards a high BMI.

Alongside the effects of food on the N1pc and N2pc indices of attentional orienting we found that the priming condition led to larger N2pc amplitude than the equivalent WM conditions (particularly on invalid and neutral trials); in contrast there was no variation in the N1pc amplitude between the priming and WM conditions. The larger N2pc amplitude on invalid and neutral trials may be due to the task being more difficult on the invalid and neutral trials in the WM condition due to the effects of memory load in the WM condition (Hyun, Woodman, & Luck, 2009; Tsvetanov, Arvanitis, & Humphreys, 2012). Notably, this affected the later N2pc rather than the N1pc here.

Taking the present results together, we suggest that food cues can have a differential effect on the guidance of attention. In the present data there was an early suppressive bias against food items followed by a positive bias that was stronger than the effects for non-food items. This later bias was modulated by WM while the initial bias was affected by the mere presentation of food as an initial cue (in the priming and WM conditions alike). We conclude that food cues modulate both bottom-up and top-down guidance of attention.

Conflict of interest

None disclosed.

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