

## ERP evidence for spatial attention being directed away from disgusting locations

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### Abstract

When we change sidewalks because we see vomit or dog feces, we are avoiding disgusting stimuli. However, it is unclear how we shift spatial attention itself away from disgusting stimuli. In the present study, we used a multisensory spatial-cueing paradigm as a tool to test if a disgusting sound is avoided by redirecting visual attention to the opposite side. Our results show that behavioral responses as well as the P3 component indicated an inverse validity effect when cued by disgust. Validity differences on the P3 were increased ipsilaterally instead of contralaterally over visual electrode sites. In contrast, the N1 component, time-locked to sound cues, indicated the typical contralateral attentional arousal effect. Thus, disgusting sound cues first attract attention toward their location and later, after the processing of their emotional content, direct spatial attention away from the location of their origin to the opposite location.

**Descriptors:** Spatial attention, Disgust avoidance, Emotion, Spatial cueing, EEG, ERP

When we walk through the streets after a city festival, we try to avoid stepping into vomit, dog feces, or rotten remnants of food. When we act like this, we spatially avoid the disgusting stimuli. Although scientific literature often defines disgust avoidance by the avoidance of rotten food, dirty places, or sick people (Armstrong, McClenahan, Kittle, & Olatunji, 2014; Chapman & Anderson, 2012; Davey, 2011; Matchett & Davey, 1991; Oaten, Stevenson, & Case, 2009), it is rarely questioned if disgust stimuli already divert spatial attention. To the extent of our knowledge, there are only two behavioral studies that have delivered evidence that disgusting stimuli (like pictures and taboo sounds) direct spatial attention away from their location (Bertels, Kolinsky, Coucke, & Morais, 2013; Cisler & Olatunji, 2010). Both studies have used spatial cueing paradigms with the disgusting stimulus (sound or picture) as a lateralized presented cue, followed by a neutral target (either a ‘/’ and ‘X’ or a neutral sound beep) on the same (valid) or opposite side (invalid). In both studies (Bertels et al., 2013; Cisler & Olatunji, 2010; see healthy control group), reaction times to neutral targets invalidly cued by disgust were shorter than those after valid cues. This indicates that a disgust stimulus directs spatial attention away from the location of its origin. It is unclear, however, how spatial disgust avoidance proceeds over time. In the pres-

ent study, we use the high temporal resolution of EEG to investigate how and when the attention shifts away from the location of the disgusting stimulus.

So far, the neuronal basis of spatial avoidance has been studied only once and very recently using a purely unisensory visual design (Liu, Zhang, & Luo, 2015). In this experiment, facial disgust cues preceded a neutral target (a triangle) on the same (valid) or opposite side (invalid). When the target matched the side of the facial disgust cue, target-related P1 activity was increased for the invalid compared to the valid condition, whereas the P3 activity revealed the opposite pattern. With facial anger cues, this pattern was reversed. The inverse cueing results for facial disgust stimuli selectively indicated disgust avoidance. However, it is unclear whether spatial attention is shifted away from the location of the disgusting stimulus to the opposite side. Due to their paradigm, Liu and colleagues (2015) could not investigate possible lateralization effects of the P1 and P3 (greater amplitudes over one hemisphere compared to the other). It is also unclear whether disgust avoidance is found across sensory modalities. The latter is highly likely; for example, bad food may be avoided due to its bad smell or its bad looks (cf. Armstrong et al., 2014; Chapman & Anderson, 2012; Davey, 2011; Matchett & Davey, 1991; Oaten et al., 2009). In crossmodal spatial cueing with disgust, a disgusting sound should decrease the behavioral and neuronal response to a visual neutral target that is located on the same side of the sound, while enhancing the response at the opposite side. In our previous neuroimaging studies (Zimmer, Ithipanyanan, Grent-‘t-Jong, & Woldorff, 2010; Zimmer, Koschutnig, Ebner, & Ischebeck, 2014; Zimmer, Roberts, Harshbarger, & Woldorff, 2010), we could show that neutral and emotional sound stimuli can crossmodally influence the detection

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of a visual target. Other researchers investigating emotion-specific differences presented stimuli always at a central position (e.g., Krusemark & Li, 2011, 2013; Leutgeb, Schäfer, & Schienle, 2011; Paulmann, Ott, & Kotz, 2011; Sauter & Eimer, 2010; Scharmüller, Leutgeb, Schäfer, Köchel, & Schienle, 2011). In an EEG study, Krusemark and Li (2011) presented a visual search task (detecting a horizontal bar between vertical bars), which was overlaid on a disgusting, fearful, or neutral picture. Already early at 100 ms and 250 ms, smaller P1 and P250 amplitudes were observed for disgust compared to fearful pictures (Krusemark & Li, 2011). However, while such central paradigms are perfect to reveal general differences in the processing of emotions (disgust vs. fear, happy, etc.), they cannot catch differential effects of spatial attention guided by emotion. To investigate if and how a disgusting stimulus will shift attention away from its location (spatial avoidance), a spatial cueing paradigm is a suitable tool (cf. Bertels et al., 2013; Cisler & Olatunji, 2010).

In contrast to research on disgust, the directing of spatial attention has been tested in various studies on fear. Behaviorally, fearful cues typically enhance spatial attention at their location, as evidenced by faster responses to validly versus invalidly cued neutral targets (e.g., Fichtenholtz, Hopfinger, Graham, Detwiler, & LaBar, 2007; Pourtois, Thut, Grave de Peralta, Michel, & Vuilleumier, 2005; Pourtois & Vuilleumier, 2006). With regard to evoked potentials, an increased amplitude of the contralateral P1 was observed for spatially validly cued targets compared to invalidly cued targets. (Brown, El-Dereby, & Blanchette, 2010; Pourtois et al., 2005; Pourtois & Vuilleumier, 2006; but see without contralaterality: Brosch, Sander, Pourtois, & Scherer, 2008; Brosch, Grandjean, Sander, & Scherer, 2009). With emotional gaze cues, Fichtenholtz and colleagues (2007) found an increased P3 amplitude for invalidly compared to validly cued targets. These results indicate that fearful stimuli direct spatial attention to their location. For the present study, we will investigate whether spatial cueing with a disgust stimulus can also modulate P1/P3 components during target processing. If disgust cues shift attention to the opposite location, we should observe inverse P1/P3 validity effects (e.g., for P3 validly cued more positive than invalidly cued) compared to the ones found for fear (e.g., Brosch et al., 2009; Fichtenholtz et al., 2007). Second, validity effects should be visible for ipsilateral rather than contralateral electrode locations.

In the present study, we used a modified spatial cueing paradigm while recording the electrophysiological activity of our participants. In a pretest, the disgusting sound cue (vomiting) and the neutral sound cue (biting into an apple) were rated for their emotional valence by an independent group of subjects. In the main EEG experiment, each of these two sounds were presented to the right or left ear. Each sound cue was followed by a bilateral visual presentation, which consisted of a left and a right apple picture. On one of the two apple pictures, a slug was present that served as target stimulus. Participants had to respond to the location of the slug by pressing the left or right button, while ignoring the sound. Valid trials were defined as trials where the sound cue was presented on the same side as the visual target (slug on the apple); in invalid trials, the sound cue and the slug target were on opposite sides. We hypothesized that, in the case of spatial disgust avoidance, disgust sounds should direct attention away to the opposite side of space (i.e., a disgusting sound cue presented to the left should direct spatial attention to the right side and vice versa). Thus, in contrast to usual spatial cueing paradigms, the invalidly cued targets should be detected faster than the validly cued targets. With regard to the ERP results, we expected the P1 or P3 components to show validity

effects when time-locked to the target. We expected that disgust sounds should show validity effects opposite to known emotional cueing effects (P1: Brosch, Sander, Pourtois, & Scherer, 2008; Brosch et al., 2009; Liu et al., 2015; P3: Fichtenholtz et al., 2007; Liu et al., 2015), resulting in a greater P1 and a smaller P3 amplitude for invalidly cued targets compared to validly cued targets. Second, these validity effects should be located ipsilaterally instead of contralaterally to the side of target presentation.

## Method

### Participants

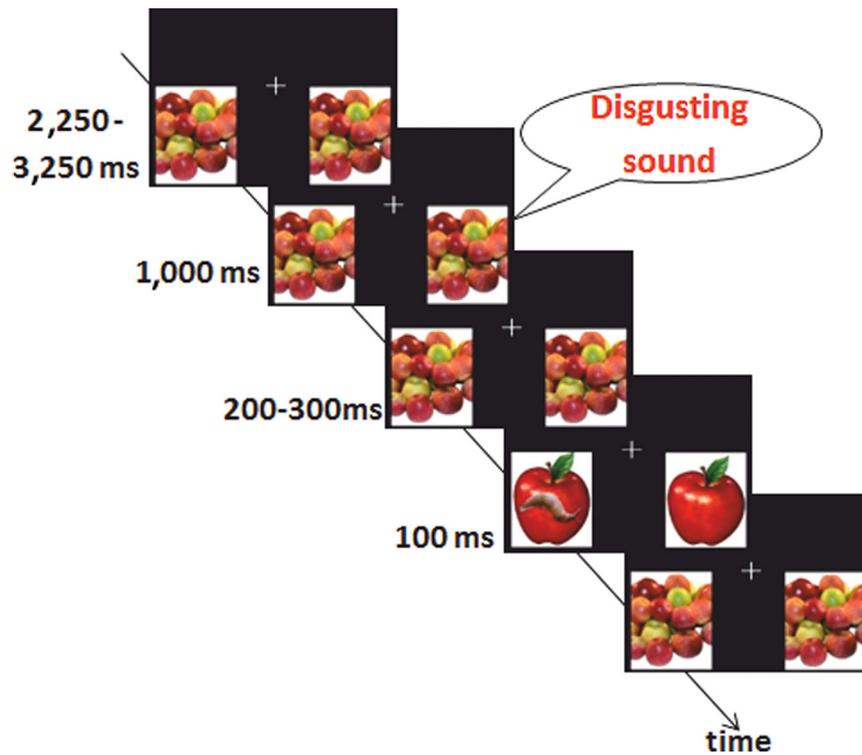
Twenty-seven participants (15 men,  $M_{\text{age}} = 26.6$  years,  $SD = 6.3$ ) took part in the ERP experiment. All were right-handed, had normal or corrected-to-normal vision, and had no history of psychiatric or neurological disease. Six of these participants were excluded from the final data analysis due to poor quality of the EEG signal (excessive movement or drifts). Participants were paid 10€ for their participation. All subjects gave written informed consent. The study was approved by the Ethics Committee of the University of Graz.

### Material and Procedure

We used a crossmodal spatial cueing paradigm to investigate if disgusting sounds would redirect spatial attention to the location opposite of their origin. If true, reaction times to visual targets should be faster for invalid targets compared to valid targets, the opposite of the effects typically observed in a spatial cueing paradigm. This behavioral difference should be mirrored in increases of the ERP positivity components (P1/P3) during valid versus invalid presentation. To test this hypothesis, participants had to detect on which apple (left/right) a slug was presented. Two thirds of the slug targets were preceded either by an emotional or a neutral sound (disgust/neutral) on the same (valid) or opposite (invalid) side of space.

To investigate the emotional quality of the stimulus materials for this EEG experiment, 25 participants were first asked in a pretest to name the emotion elicited by the separately presented sounds and pictures including the possibility of “no emotion at all.” Secondly, apple images (with/without slug) as well as sound stimuli had to be rated on a scale of 1 (*strongly positive*) over 3 (*neutral*) to 5 (*strongly negative*) according to their valence. Whereas the disgusting sound (vomiting) was judged by the pretest participants as emotionally negative, the neutral sound (someone biting into an apple) was rated as neutral (more results below). The sounds and the apple pictures (with/without slug) were then used in the main EEG experiment. Participants in the pretest did not take part in the EEG experiment.

In the EEG experiment, the participants were seated approximately 60 cm in front of the computer monitor. During the whole experiment, a fixation cross was presented at the center of the screen. To the left and right of the fixation cross ( $\pm 9.5^\circ$  horizontally), slightly below central fixation ( $4^\circ$ ), two rectangular boxes ( $3.5 \times 3.8 \text{ cm}^2$  corresponding to  $3.3^\circ \times 3.6^\circ$ ) were positioned that each held a picture of an apple, one with a slug and one without a slug. The side of presentation of the apple with the slug was randomized on a trial-by-trial basis. The pictures of the apple were shown for 100 ms and forward and backward masked by a picture showing a crowd of apples (see Figure 1). The emotional cueing sounds consisted of two different types of sound stimuli, which



**Figure 1.** Task paradigm. An example of a stimulus sequence is shown (invalidly cued by disgust). The task of the participants was to fixate on the central cross and to detect the side of presentation of a slug on an apple (50% probability each side). In two thirds of all trials, the slug target was preceded by a sound cue (disgust/neutral). Sounds were preceding either on the side of the target (valid, 50%) or opposite to it (invalid, 50%). Participants were instructed to ignore the auditory sound cue and to focus on the detection of the slug.

could be presented either to the right or the left side. The first stimulus was a vomiting sound (disgusting sound) and was rated as significantly emotionally negative in the pretest. The second stimulus was the sound of someone biting into an apple (neutral sound), which was rated emotionally neutral in the pretest. Both sounds had a duration of 1,000 ms. The sound duration was chosen to ensure that the emotional content of the sound was fully processed by the participants before the occurrence of the target. Paulmann and Pell (2010) had shown for a priming paradigm that the emotional content of auditory primes was only effective when sounds were presented for 400 ms, but not 200 ms. The overall sound level was aligned to 66 dB for both emotional sounds. To conserve the emotional character of the sounds, the time-frequency structures of the original disgusting as well as the original neutral sound were not changed (cf. for happy/sad emotional sounds: Banse & Scherer, 1996; Juslin & Laukka, 2001, 2003). For lateralized presentation, the originally stereo-recorded sounds (someone vomiting and biting into an apple, respectively) were converted into mono-channel sounds by using Au Adobe Audition (<http://www.adobe.com>). During EEG measurement, these mono-channel sounds were then delivered using the software Presentation (Neurobehavioral Systems; <http://www.neurobs.com>) to either the left or the right loudspeaker (AppleDesign Powered Speakers M6082; 90-dB sound pressure level at 0.5 m at 90 Hz) located on the left and right side of the screen. We did not use headphones because they would have to be mounted on the cap, leading to artifacts due to slipping or head movements. To exclude any resulting activity due to the specific physical time-frequency patterns of the two sounds, we only compared valid

and invalid targets for the same emotional type. In this comparison, any effects due to physical differences between the two sounds are removed, leaving only activity related to validity differences. When validity differences for disgust-cued targets are then compared to validity differences for neutrally cued targets, the results are due to the emotional content of the cue rather than their physical differences.

One third of all target trials were visual-only trials (target pictures presented without a sound), one third of the trials were multisensory target trials with the disgusting sound cue, and one third of the trials were multisensory target trials with the neutral sound cue. All trials were presented in randomized order with an equal proportion of validly cued and invalidly cued trials (50%). In a validly cued trial, the target appeared on the side of the sound (disgusting/neutral); in an invalidly cued trial, it appeared on the opposite side of the sound (see Figure 1 for an example of an invalidly cued disgust trial).

Every trial started with a random interstimulus interval (ISI) of 2,250, 2,500, 2,750, 3,000 or 3,250 ms. Following this interval, on two thirds of the trials, the presentation of the apple pictures (target pictures) was preceded by a disgusting or neutral sound stimulus, which was presented either to the right or left side. The duration of the sound was 1,000 ms. After an ISI of 200, 250, or 300 ms, the masking pictures were replaced by the target pictures. The pictures were presented for 100 ms with the target—a slug, either on the right or left apple. Participants were instructed to press the left/right arrow key of the response keyboard for the side where the target (slug) was presented while focusing on the fixation cross and ignoring the sound stimuli. All participants completed 15 runs. Each run consisted of

60 trials and lasted about 3 min, leading to a total experimental run time of about 45 min.

### EEG Recording

The EEG was recorded with the BrainVision Recorder (Brain Products, Germany <http://www.brainproducts.com/>) and 36 of 64 channels mounted on an elastic electrode cap of the EEG system Easy Cap (Brain Products, Germany). The 36 electrodes were positioned according to the extended 10-20 EEG system and covered the frontal (FPz, AF7, AF3, AF4, AF8, F7, F3, FZ, F4, F8, FC5, FC1, FCZ, FC2, FC6), central-temporal (T7, C5, C3, CZ, C4, C6, T8, CP5, CP1, CP2, CP6), and parieto-occipital area (P7, P3, PZ, P4, P8, PO7, PO3, POZ, PO4, PO8). Horizontal eye movements were detected by two extra bipolar electrodes placed at the outer canthi of the eyes, whereas vertical eye movements or blinks were detected by another electrode, placed at the glabella. Further, two additional electrodes were placed on the right and left mastoids. All scalp electrodes were referenced to the algebraic mean of both mastoids. The ground electrode was placed on the collar bone. Electrode impedances were kept below 5 k $\Omega$  for all electrodes. Recording was done in a dimly lit, sound-attenuated, and electrically shielded chamber.

### Behavioral Data Analysis

**Pretest.** Sounds and pictures were presented separately. Stimulus durations during the pretest were the same as in the ERP study (pictures: 100 ms; sounds: 1,000 ms). After each stimulus presentation, each of the 25 participants was first asked to name the emotion evoked by the presented stimulus including the possibility of “no emotion at all.” Then, they rated the valence of the stimuli on a scale from 1 to 5 (1 = *very positive*; 2 = *positive*; 3 = *neutral*; 4 = *negative*; 5 = *very negative*). We counted how many of our participants named disgust-related, neutral or positive emotions for the four presented stimulus types. Next, ratings of valence were averaged across participants for each stimulus type (sound: disgust/neutral; picture: apple with/without slug). *T* tests were calculated for the estimated emotional valence of the sounds and pictures. Further, one-sample *t* tests determined if the averaged estimated emotional valence values were significantly different from the test value 3, indicating that the stimulus was rated emotionally neutral.

**Behavioral data during ERP recording.** Our main interest was to find evidence for spatial disgust avoidance. To ensure that validity differences were due to the emotional character alone, rather than to the presence or absence of a cue, only target responses following sound cues were analyzed and compared with each other. Pure visual trials were only included in the paradigm as an independent dataset to create time windows for the ERP components (P1/P3). Only trials with behavioral responses between 200 ms and 1,000 ms after the presentation of the auditorily cued target pictures were considered for further behavioral analysis (98% of trials in total). Reaction times (RTs) and accuracy rates for correctly detected slug locations were computed separately for the valid and invalid cue conditions. Repeated measures analyses of variance (ANOVAs) were performed with the within-subject factors condition (valid, invalid) and emotion (disgust, neutral). Significance was inferred for *p* values < .05. Scheffé post hoc *t* tests tested for a significant difference between specific emotional conditions.

### ERP Data Analysis

The aim of our study was to investigate crossmodal effects of spatial disgust avoidance. More specifically, we wanted to investigate if and how behavioral effects of spatial disgust avoidance due to sound stimuli would be mirrored in brain activity to emotionally neutral visual targets. Therefore, we first time-locked to the onset of the target pictures. For the main analysis, we compared the ERPs for invalidly with validly cued target pictures that followed either the disgusting or the neutral sound cue. We expected that validity effects (the difference between valid vs. invalid trials) of targets cued with disgust would be reflected in a decrease of the P1 component and/or an enhancement of the P3 component compared to targets cued with neutral sounds. In the case of significant validity effects, we then tested in a follow-up analysis for lateralization, such as increased parieto-occipital validity effects for ipsi- versus contralaterally cued targets (cf. Donohue, Todisco, & Woldorff, 2013). In a separate control analysis, we time-locked to the sound cues to test whether spatial cueing was successful. We specifically tested for lateralized activity changes (auditory N1 peak) due to sound location. That is, the right auditory cortex should show increased activity for contralateral left sounds compared to right sounds (McDonald, Störmer, Martinez, Feng, & Hillyard, 2013). This finding would show that the lateralized sounds were at first indeed shifting attention to the left or right side of space independent of their emotional character. In conclusion, general cueing effects should appear at early time points (cueing phase), whereas spatial disgust avoidance effects would appear during later (target phase) processing.

After recording, all ERP data were processed with the custom ERPSS software (Event-Related Potential Software System, UCSD, San Diego, CA), an add-on to the open source EEGLAB software (an open source environment for electrophysiological signal processing, UCSD, San Diego, CA). For each participant, the raw data of the 15 runs were transformed into ERPSS format and then combined into one large data file for further analysis. Data were referenced to the algebraic mean of the two mastoid electrodes.

We then conducted two ERP analyses differing with regard to time-locking to the event type (the visual targets or the sounds) while keeping all other analysis parameters and follow-up steps identical. Thus, the continuous EEG data were divided into 800-ms epochs, either time-locked to the onsets of the visual targets or to the sounds, plus a prestimulus baseline of 200 ms. Artifact rejection was performed by rejecting any voltage amplitudes under  $-100$   $\mu$ V and over  $+100$   $\mu$ V, therefore discarding epochs contaminated by eye movements, eye blinks, excessive muscle activity, drifts, or amplifier blocking. Artifact-free EEG epochs were then averaged together, separately for the various trial types in each of the two types of analyses (i.e., invalid vs. valid trial types for the disgusting, the neutral, or the no-sound condition when time-locked to the visual target; disgust vs. neutral when time-locked to the sound). These averages were then subsequently digitally low-pass filtered (IIR-Butterworth) with a running average filter of 30 Hz.

**Time-locking to visual targets.** Our main interest was to find neural evidence for spatial disgust avoidance. Focusing on visual ERP components, we expected a greater P1 and a smaller P3 amplitude for visual targets invalidly cued by disgust compared to validly cued visual targets. These effects are opposite to those observed in typical spatial cueing Posner paradigms (P1: Brosch et al., 2008, 2009; Pourtois & Vuilleumier, 2006; P3: Fichtenholtz et al., 2007). Our analysis made sure that validity effects were

specifically due to the emotional character of the cue rather than the presence of the cue or physical differences between the two cue sounds.

Selection of electrode sites and time windows was done as follows. Keil and colleagues (2014) suggested selecting time windows and electrode sites on the basis of prior research. In the present study, electrode sites were chosen based on previous literature, which had indicated that spatial cuing effects on visual targets are usually found over parieto-occipital electrode sites (for emotional cues: Pourtois & Vuilleumier, 2006; Liu et al., 2015; for neutral cues: McDonald et al., 2013). Thus, electrode positions located symmetrically over left and right visual cortex areas (left: CP1/P3/P03; right CP2/P4/PO4) were combined to a left and right region of interest (ROI). To select the P1/P3 windows, we followed a data-driven approach by using the data from the pure visual condition. Note that the pure visual condition was not analyzed with regard to validity effects and could therefore be used as an independent prior data set. First, in each subject, averaged over both ROIs defined above, the latency of the P1 peak (P3 peak) was defined as the onset of the maximum positive peak in a time window between 50–150 ms (300–500 ms). The means and standard deviations of these two data sets were then used to compute a time window for the P1 and a time window for the P3 (temporal mean of the maximum peak of the P1/P3  $\pm 1$  SD). This procedure yielded the time windows 112 ms  $\pm$  18 (i.e., 94–130 ms) for the P1 and 429 ms  $\pm$  21 ms (i.e., 408–450 ms) for the P3. These time windows were then used for all subsequent analyses.

For our main analysis, we first investigated if P1/P3 activity time-locked to targets differed between invalidly cued trials and validly cued trials depending on the auditory cue (disgust vs. neutral). Statistical analysis of the ERP data employed repeated measures ANOVAs on mean P1 and P3 amplitude values separately around each peak (Donohue et al., 2013). Thus, each  $2 \times 2$  ANOVA consisted of the factor emotion (disgust/neutral sound) and validity (validly vs. invalidly cued trial). Amplitude values were averaged over the ROIs of the left and right hemisphere.

In a second step, we tested for the laterality of spatial disgust avoidance on target detection: validity effects should be strongest in the ROI ipsilateral to the visual target presentation. We entered the mean amplitude values of the P1 and P3 derived from the validity difference waves (valid minus invalid), into an additional  $2 \times 2$  ANOVA with ROI side (left/right) as one factor and target side (left/right) as the other factor (see Donohue et al., 2013).

**Time-locking to the cueing sounds.** To investigate whether the cueing sounds successfully directed attention to the cued side, we tested for differences in peak amplitudes of the auditory N1 component between right and left sound presentations. If our sounds cued correctly, we should find larger N1 amplitudes for the attended ear in the contralateral auditory cortex when time-locking to the cueing sound (Hillyard, Hink, Schwent, & Picton, 1973; McDonald et al., 2013). Methodically, such lateralized differences can be best revealed when comparing auditory activity of two laterally and oppositely located electrodes such as T7/T8 (see also Bonath et al., 2007; McDonald et al., 2013, for a similar  $2 \times 1$  electrode approach). It should be noted that another component related to spatial cueing is the N2ac/N2pc. However, we did not observe this component in the present experiment. This is most likely due to our paradigm. An N2ac/N2pc is observed when cue and target are in close proximity. It is absent when stimuli are presented one at a time as in the present study (Gamble & Luck, 2011; Luck, 2012, for a review).

Importantly, as our sounds varied by their physical properties, they might also vary in the temporal onset of the N1 (Näätänen & Picton, 1987). We therefore first used a *t* test to specify any differences in N1 latencies between the disgusting and the neutral sound averaged over presentation side. More specifically, we compared all disgust sounds (left/right) versus all neutral sounds (left/right) averaged over T7/T8 locations for differences in N1-peak latency in the time window from 100 ms to 200 ms. This analysis could show that N1 peaks are different; this justified the use of different time windows for the N1 elicited by the two sounds.

To investigate spatial cueing effects, the resulting N1-peak amplitudes of each sound type (averaged in a time window from 100 ms to 200 ms) were then entered into a  $2 \times 2$  ANOVA (factor Side of Sound (left/right)  $\times$  Side of ROI (left/right)) separately for each sound type to reveal any attentional lateralization effects.

## Results

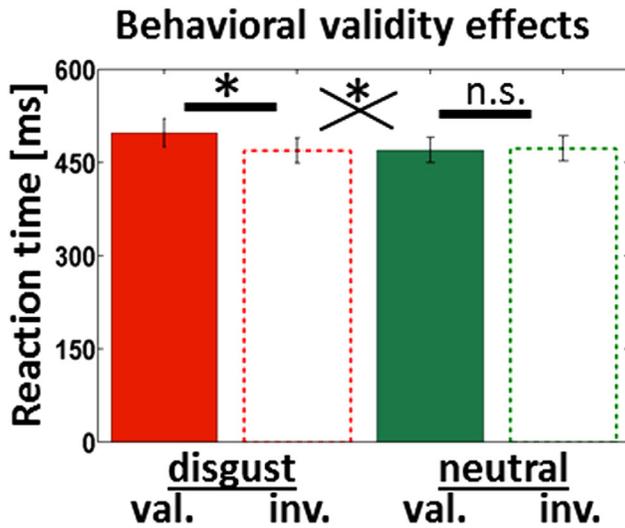
### Results of the Pretest

The analysis of the emotional sound types indicated that the disgusting sound (vomiting) was described with disgust-related words (“disgust,” “nausea,” “vomit”) by 96% of the pretest participants (24 out of 25). In the case of the neutral sound (someone biting into an apple), participants complained about the impossibility to assign any emotion, resulting in predominantly answers of “no emotion” and “curiosity” by 96% of participants (24 out of 25). The valence of the stimuli was rated on a 1 to 5 scale (1 = *very positive*; 2 = *positive*; 3 = *neutral*; 4 = *negative*; 5 = *very negative*). The analysis for the disgusting sound revealed an average value of 4.4 (*SD* 0.63), whereas the neutral sound was averaged to the neutral value of 3.0 (*SD* 0.34). Follow-up *t* tests revealed that these ratings were significantly different from each other,  $t(24) = 8.78$ ,  $p < .001$ . One-sample *t* tests also confirmed that the disgusting sound was significantly different from the neutral rating 3,  $t(24) = 10.84$ ,  $p < .001$ , whereas the neutral sound was not,  $t(24) = 0.57$ ,  $p = .57$ .

Despite the short presentation duration (100 ms), the apple pictures elicited different emotions dependent on the absence or presence of the slug. Note that this duration was kept identical to the EEG experiment for comparable conditions. The apple picture with a slug was mostly named with disgust-related nouns (“disgust,” “aversion”) by 72% of the pretest participants (18 out of 25); the remaining 28% of the participants used descriptions like “I don’t know.” In contrast, the clean apple without a slug was mostly named with positive adjectives (“appetizing,” “delicious”) by 84% of the pretest participants (21 out of 25); the remaining participants used “I don’t know” answers. Corresponding to the naming, the valence of the apple picture with slug was estimated negative (mean = 3.8, *SD* 0.62), whereas the one without slug was rated positive (mean = 2.0, *SD* 0.53). Follow-up *t* tests confirmed that these averages differed between each other,  $t(24) = 9.4$ ,  $p < .001$ . In addition, both averages also significantly deviated from the neutral rating 3 (with slug:  $t(24) = 6.72$ ,  $p < .001$ ; without slug:  $t(24) = 8.91$ ,  $p < .001$ ).

### Behavioral Results During EEG

Our EEG participants were instructed to visually attend to the apple pictures and to detect the presentation side (left/right) of the slug with a corresponding button press (left/right). The percentage of excluded trials due to RTs larger than 1,000 ms was 2% over all participants. Our main research interest was the possible presence of



**Figure 2.** Behavioral results. Reaction times to targets cued by the disgusting or the neutral sound for valid and invalid cue-target presentations. Validity effects were only present for disgust-cued targets and indicate longer search times for validly compared to invalidly cued targets. The interaction of Emotion  $\times$  Validity was significant (see cross). val. = validly cued; inv. = invalidly cued.

spatial disgust avoidance. The group mean RTs were 497 ms ( $SD$  98 ms) for targets validly cued with disgust, 468 ms ( $SD$  86.7 ms) for targets invalidly cued with disgust, 470 ms ( $SD$  87.9 ms) for valid neutral, and 472 ms ( $SD$  89.1 ms) for invalid neutral targets (Figure 2). The participants' reaction times were entered into a repeated measures ANOVA with the factors emotion (disgusting sound vs. neutral sound) and validity (validly vs. invalidly cued targets). A significant interaction of Emotion  $\times$  Validity was observed,  $F(18) = 24.371, p < .001$ ; see Figure 2. Subsequent paired  $t$  tests for the disgusting emotional sound revealed that reaction times were significantly faster in the invalid case (slug opposite to the disgusting sound)  $t(18) = 5.327, p < .001$ ; see Figure 2. In contrast, there was no validity effect for the neutral sound,  $t(18) = 0.926, p = .367$ .

Accuracy rates were defined as behavioral responses for indicating correctly the absence or presence of the slug. Accuracy rates for each of the conditions were as follows: target preceded by the disgusting sound: valid 91.86% ( $SD$  7.67%); invalid 91.89% ( $SD$  7.22%); by the neutral sound: valid 91.40% ( $SD$  7.85%); invalid 91.51% ( $SD$  8.81%). For follow-up statistics, accuracy rates were analyzed by using a repeated measures ANOVA with the factor emotion (disgusting sound vs. neutral sound) and validity (validly vs. invalidly cued). However, neither the interaction of these factors nor the main effects were significant.

## ERP Results

**Time-locking to visual targets.** As spatial cuing effects on visual targets are usually found over parieto-occipital electrode sites (for emotional cues: Pourtois & Vuilleumier, 2006; for neutral cues: McDonald et al., 2013), we used similar electrode positions over visual cortex areas to define our ROIs (left: CP1/P3/P03; right CP2/P4/PO4). Time windows for the P1 as well as the P3 were selected by using the pure visual condition as a prior data set (Keil et al., 2014). Thus, using the pure visual condition of target processing, the latency for the P1 peak was found at  $112 \text{ ms} \pm 18 \text{ ms}$ ; that is, the P1 time window was set from 94 ms to 130 ms. The

latency of the P3 peak was at  $429 \text{ ms} \pm 21 \text{ ms}$ , corresponding to a time window from 408 to 450 ms. The P1 and P3 time windows used were fixed and unchanged for all participants and ROIs. The mean amplitude values in these fixed time windows were then used for statistical analysis of the cued target conditions.

In the first part of our analysis, we aimed to reveal general differences of sound cueing on visual targets. Thus, we compared activity due to validly and invalidly cued targets averaging over both visual ROIs. For the P1 and P3 time window each, a  $2 \times 2$  ANOVA was calculated with Sound Type (disgusting vs. neutral)  $\times$  Validity (valid vs. invalid). For the P1 time window ( $112 \text{ ms} \pm 18 \text{ ms}$ ), this ANOVA did not reveal any significance for the interaction Sound Type  $\times$  Validity,  $F(18) = 0.011, p = .913$ ; mean amplitudes (see Table 1): disgust-valid:  $0.08 \mu\text{V}$  ( $SD$  0.27); disgust-invalid:  $-0.37 \mu\text{V}$  ( $SD$  0.32); neutral-valid:  $0.25 \mu\text{V}$  ( $SD$  0.26); neutral-invalid:  $0.19 \mu\text{V}$  ( $SD$  0.25). In contrast, for the P3 time window ( $429 \text{ ms} \pm 21 \text{ ms}$ ), this interaction of Sound Type  $\times$  Validity was significant (Table 1;  $F(18) = 4.58, p = .038$ ; mean amplitudes: disgust-valid:  $9.02 \mu\text{V}$  ( $SD$  0.87); disgust-invalid:  $8.04 \mu\text{V}$  ( $SD$  0.83); neutral-valid:  $8.91 \mu\text{V}$  ( $SD$  0.86); neutral-invalid:  $9.0 \mu\text{V}$  ( $SD$  0.89)). Scheffé post hoc tests for the P3 indicated that validity differences were only present when a visual target followed a disgusting sound cue ( $p = .019$ ), but not after a neutral sound cue ( $p = .66$ ). Importantly, this result indicated that, in the disgust condition, P3 amplitudes were increased for the validly cued compared to the invalidly cued targets. Neutral sounds did not reveal any validity effects (see Figure 3A) and were therefore not investigated further.

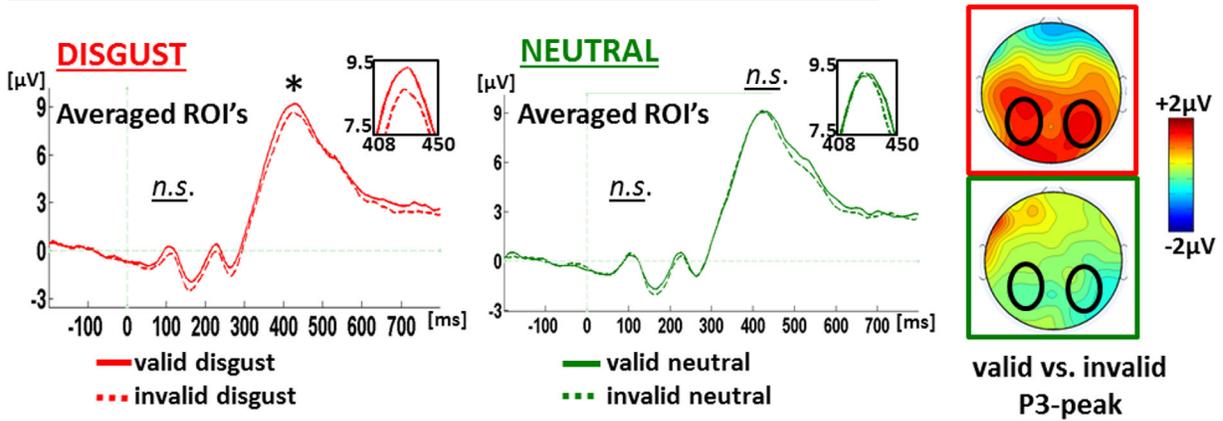
Next, we investigated whether the processing of visual targets showed any lateralized visual activity when cued by disgusting sounds. Importantly, we tested for laterality only after finding a validity effect. For this laterality ANOVA, activity differences of validity effects (valid minus invalid) in the P3 time window were compared for the factors target side (left/right) and ROI side (left/right) exclusively for targets cued by disgusting sounds. We found a significant interaction between both factors,  $F(18) = 4.934, p = .024$  (see Table 2). Scheffé post hoc tests revealed that, for right-sided targets, validity effects were stronger in the left than in the right ROI ( $p = .026$ ; mean amplitudes of validity differences for right-sided targets: left ROI:  $0.12 \mu\text{V}$  ( $SD$  0.25); right ROI:  $0.65 \mu\text{V}$  ( $SD$  0.25); Figure 3B, upper row; Table 2). Similarly, left-sided targets showed stronger validity effects in the ipsilateral left hemisphere than the contralateral right hemisphere (Scheffé post hoc test:  $p = .031$ ; mean amplitudes of validity differences for left-sided targets: left ROI:  $0.95 \mu\text{V}$  ( $SD$  0.22); right ROI:  $0.50 \mu\text{V}$  ( $SD$  0.24); Figure 3B, lower row; Table 2). Further, Scheffé post hoc tests indicated that validity effects were greater in the right ROI for right- versus left-sided targets ( $p = .042$ ) and vice versa for the left ROI ( $p = .036$ ). Thus, larger P3 validity differences (valid vs. invalid) were always found on the ipsilateral side of the disgust-cued target.

**Table 1.** Mean Amplitudes ( $SD$ ) of Emotional Validity

	Disgust		Neutral	
	Valid	Invalid	Valid	Invalid
P1	$0.08 \mu\text{V}$ (0.27)	$-0.37 \mu\text{V}$ (0.32)	$0.25 \mu\text{V}$ (0.26)	$0.19 \mu\text{V}$ (0.25)
P3	$9.02 \mu\text{V}$ (0.87)	$8.04 \mu\text{V}$ (0.83)	$8.91 \mu\text{V}$ (0.86)	$9.0 \mu\text{V}$ (0.89)

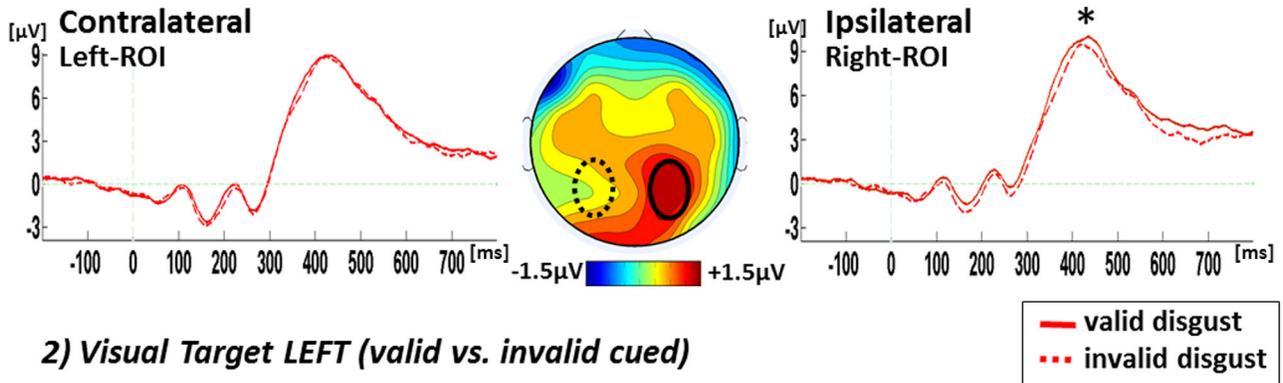
Note. P1: 94–130 ms; P3: 408–450 ms (time windows received from ROI analysis).

**A) Atypical validity effect in targets cued by disgust**

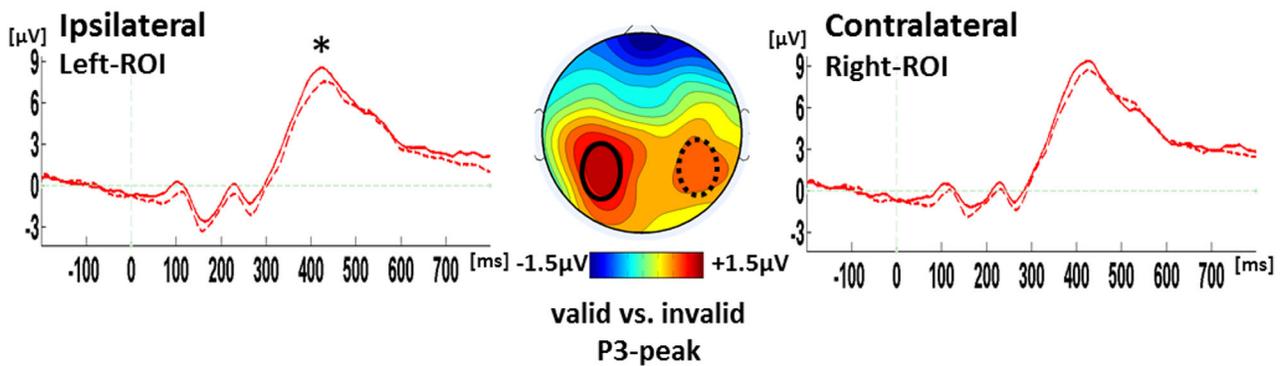


**B) Lateralization effects of validity differences for targets cued by disgust**

**1) Visual Target RIGHT (valid vs. invalid)**



**2) Visual Target LEFT (valid vs. invalid cued)**



**Figure 3.** ERPs time-locked to visual target presentation. A: Comparison of validity activity revealed by the disgusting sound or the neutral sound averaged over the side of presentation (ERP activity in traces averaged over both ROIs). Validity effects were observed only for targets cued by disgust and only for the P3 component, but not for the P1 component. Topographies on the right indicate validity differences around the P3 peak (408–450 ms). Black circles on the topographies show the ROIs used for statistical analysis. B: Lateralization effects of validity differences for targets cued by disgust. (1) Right-sided targets showed an ipsilateral increased P3 amplitude difference for validly versus invalidly cued targets. (2) Left-sided targets also revealed an ipsilateral enhanced validity effect on the P3 component. Black lined circles on the topographies indicate the ipsilateral ROI; black dotted circles indicate the ROI contralateral to the side of visual target.

**Time-locking to cueing sounds.** To test whether the sounds cued successfully, we investigated lateralization effects of the auditory N1 component. Note that the N2ac (the auditory equivalent of the N2pc) was not evident in the data. The most likely reason for this is that the N2ac or N2pc are only observed when a distractor is placed in close proximity but largely absent when stimuli are pre-

sented one at a time, as in the present study paradigm (Gamble & Luck, 2011; Luck, 2012, for a review). As both sounds were physically different from each other, they might also differ in N1 latencies. Thus, we first defined N1 components via peak amplitude and peak latency in a 100-ms to 200-ms time window averaged over T7/T8 electrodes. Results indicated that the N1 for disgust was

**Table 2.** Mean Amplitudes (SD) of Lateralized Validity Effects (valid versus invalid) in Disgust

		Valid vs. invalid			
		Right-sided targets		Left-sided targets	
P3		Left ROI	Right ROI	Left ROI	Right ROI
		0.12 $\mu$ V (0.25)	0.65 $\mu$ V (0.25)	0.95 $\mu$ V (0.22)	0.50 $\mu$ V (0.24)

Note. P3: 408–450 ms (time window received from ROI analysis).

peaking significantly earlier than the N1 for the neutral sound. More specifically, for disgust, the peak latency was 147 ms (SD 18.5), in contrast to 165 ms (SD 23.8) for the neutral sound (Figure 3A). A *t* test indicated that both peak latencies differed significantly,  $t(18) = 4.21, p = .001$ ; Figure 3A, therefore justifying our use of different N1 time windows for the two sounds in the following analyses of lateralization effects.

Lateralization effects on the N1 amplitude for disgust were investigated with a  $2 \times 2$  ANOVA, which indicated a significant interaction of the factors Side of ROI (left/right)  $\times$  Side of Sound (left/right),  $F(18) = 7.001, p = .016$ ; Figure 4B, upper panel and Figure 4C, left topographies). Scheffé post hoc tests indicated that, for the left ROI, the N1 amplitude was increased for right versus left sounds,  $p = .007$ ; mean amplitude: right sound:  $-1.41 \mu$ V (SD 0.45); left sound:  $-0.81 \mu$ V (SD 0.42), whereas for the right

ROI the opposite pattern was significant,  $p = .028$ ; mean amplitude: left sound:  $-1.19 \mu$ V (SD 0.39); right sound:  $-0.93 \mu$ V (SD 0.44). Similarly, when comparing the activity for each sound between both ROIs, disgust sounds revealed significantly more activity in the contralateral than the ipsilateral ROI (left disgust sound:  $p = .009$ ); right disgust sound:  $p = .042$ ); Figure 4B, upper panel). Thus, disgusting sounds evoked increased N1 peaks in the hemisphere contralateral to their spatial location (Figure 4B,C).

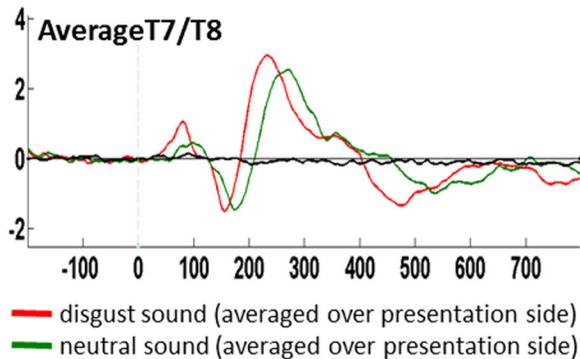
Lateralization effects on the N1 amplitude for the neutral sound were analyzed correspondingly. A significant interaction of the factors Side of ROI (left vs. right)  $\times$  Side of Sound was found (left vs. right),  $F(18) = 3.345, p = .045$ ; Figure 4B, lower panel). Scheffé post hoc tests for each ROI indicated that laterality effects (contra vs. ipsilateral stimulation) were only found for the left ROI ( $p = .032$ ; mean amplitudes: right sound:  $-1.04 \mu$ V (SD 0.35); left sound:  $-0.62 \mu$ V (SD 0.28)), but not the right ROI,  $p = .744$ ; mean amplitudes: left sound:  $-1.26 \mu$ V (SD 0.34); right sound:  $-1.20 \mu$ V (SD 0.37). Scheffé post hoc tests of sound location indicated that only the neutral sound presented to the right cued laterally ( $p = .014$ ), whereas a neutral sound presented to the left did not ( $p = .241$ ; Figure 4C, right topographies). Thus, laterality effects were weaker in the neutral sound condition compared to the disgusting sound condition.

**Discussion**

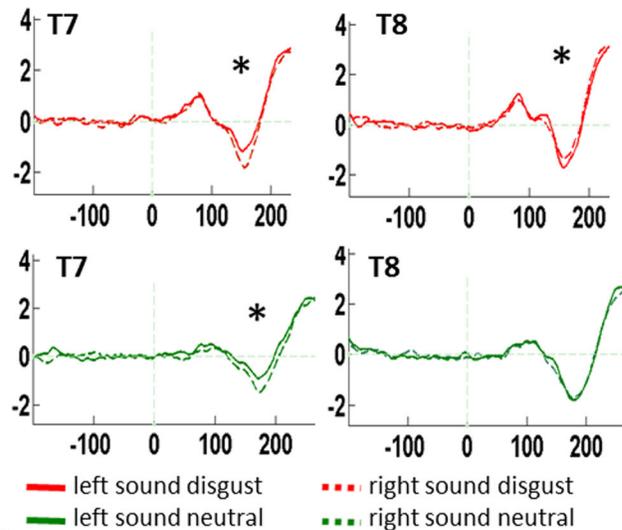
We used a crossmodal spatial cueing paradigm as a tool to investigate whether disgust avoidance would lead to a direction of spatial

**ERP-activity to sound cues**

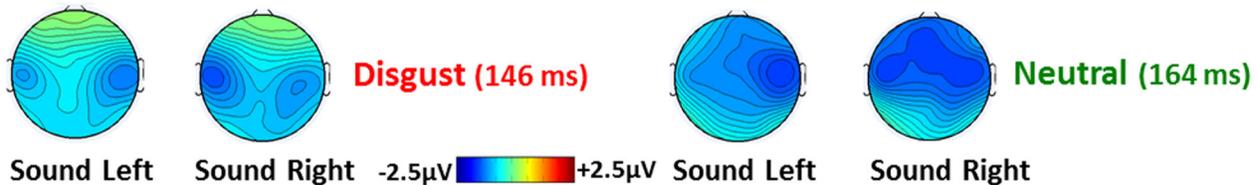
**A) Averaged over side of presentation**



**B) Separate for side of presentation**



**C) Topos: separate for side of presentation**



**Figure 4.** ERPs time-locked to the sound cue. A: Comparison of activation by the disgusting sound compared to the neutral sound averaged over the side of presentation. N1 and P2 effects peak earlier during the processing of the disgusting sound than the neutral sound. B: N1 lateralization effects due to side of sound presentation. For the disgusting sound as well as the neutral sound, N1 effects are stronger in the hemisphere contralateral to the side of sound presentation. C: Topographical views visualizing the N1 lateralization effects due to side of sound presentation. Note that contralateral N1 effects are enhanced in all sound presentations.

attention away from the location of a disgusting sound to the opposite side. A sound cue, of either disgusting or neutral character, was presented to the left or right ear and preceded the bilateral presentation of two apple pictures with and without a slug. Participants were instructed to locate the slug on one of the two pictures and to ignore the sound cue. Spatial avoidance of disgust was evident in an inverse cueing effect: behavioral results indicated that participants were faster in responding to invalidly cued than validly cued targets when these were preceded by a disgusting sound cue, whereas no validity effect was observed for targets preceded by a neutral sound cue. Similarly, time-locking to visual targets revealed neural validity differences for the P3, when targets were cued by the disgusting sound, but not by the neutral sound. Importantly, the disgust validity differences were increased for validly minus invalidly cued targets over the ipsilateral, but not contralateral occipital cortex. The ipsilateral validity effects of the P3 component indicate that targets presented opposite to the disgusting sound cues received enhanced processing compared to same-side targets, thus mirroring the behavioral results. We conclude that disgusting sounds can shift attention away from their spatial position to the opposite side of space, which provides evidence for a spatial avoidance of the location of the disgusting sound.

### Behavioral Evidence for Disgust Avoidance

In the present study, we found evidence for spatial disgust avoidance in behavioral and neural data. When visual targets followed disgusting sound cues, reaction times were faster for invalidly compared to validly cued targets. While this result seems to be in alignment with results of two behavioral studies that have used disgusting cues (Bertels et al., 2013; Cisler & Olatunji, 2010, see healthy control group), it is opposite to usual cueing effects. Other negative emotional cues such as fear or anger (presented as sounds or as faces) elicit typical cueing effects. For example, when using fearful gaze cues, Fichtenholtz and colleagues (2007) found faster reaction times to validly versus invalidly cued pictorial targets. Similarly, cued by short fearful sound buzzes, participants reacted faster to a validly cued versus an invalidly cued artificial visual object (Brosch et al., 2009). Thus, fearful cues seem to result in a typical cueing pattern, different from disgust cues. Although disgust may be seen as an emotion related or contributing to anger (Krusemark & Li, 2011), avoidance seems to be a key feature typical for disgust, but not anger (Davey, 2011, for a review; Krusemark & Li, 2011; Susskind et al., 2008). Our behavioral results indicate that disgusting sounds are avoided by directing spatial attention away from them to the opposite side of space. This avoidance of disgust was strong enough that targets were detected faster when presented on the invalidly cued side of space compared to the valid side.

### Neural Evidence: Inverted and Ipsilateral P3 Effects

Typically, in non-emotional spatial cuing paradigms (e.g., target letters cued by an arrow or sounds cueing visual targets), a P3 is observed that is more positive for invalid targets than valid targets (Eimer, 1993, 1994; Flores, Gómez, & Meneres, 2010; Hughdahl & Nordby, 1994). However, in the ERP results (time-locked to visual targets) observed here, the P3 component showed atypical validity differences (valid more positive than invalid) when visual targets were preceded by disgusting sounds, but not neutral sounds. These results seem to be specific for disgust as typical cueing effects were observed for other negative emotions, such as fearful

gaze cues (Fichtenholtz et al., 2007) or angry facial cues (Liu et al., 2015). When fearful gaze cues were used for spatial cuing, Fichtenholtz and colleagues (2007) found validity effects similar to the emotionally neutral stimuli, that is, an increased amplitude of the P3 component for the invalid targets. However, as in the present data, this P3 pattern was inverted when facial disgust cues were presented in a purely visual study design (Liu et al., 2015). Thus, the present disgust-evoked validity effects can be seen as neural markers of disgust avoidance that are also present across sensory modalities.

Importantly, the present data show for the first time that the disgust-related validity effects of the P3 component are located over occipital areas ipsilateral to the side of target presentation. Typically, validity effects are observed contralaterally. This indicates that the visual stimulus located opposite to target position received enhanced processing instead of the target itself. Typically, when attention is directed to a laterally presented visual stimulus (uncued or cued), increased activity in the visual cortex contralateral to its location is observed (Talsma & Woldorff, 2005; fMRI: e.g., Kastner, Pinsk, De Weerd, Desimone, & Ungerleider, 1999). Again, the ipsilateral cueing effects observed here seem to be specific for disgust: in fearful emotional cueing, faster detection of neutral targets (e.g., vertical bars) preceded by valid fearful facial cues was accompanied by increased contralateral visual activity time-locked to the target (Brown et al., 2010; Pourtois et al., 2005; Pourtois & Vuilleumier, 2006; but see Brosch et al., 2008, 2009, for findings without contralaterality).

It should be noted that cueing effects often also occur earlier (N1, P1 effects) than the presently observed P3 effects. Our finding of a late rather than early modulation of ERP components due to disgust might indicate that the directing of attention due to disgust avoidance caused by auditory stimuli is a comparatively slow process. Importantly, the ipsilateral location of the observed validity effects indicates that the visual location opposite to the target received enhanced visual processing. Thus, the present ipsilateral P3 validity effect serves as a further neural indicator for the spatial avoidance of disgust.

### Temporal Occurrence of Spatial Disgust Avoidance

The question arises whether the spatial avoidance effects are already present during the phase of cueing with the disgust sound. To answer this question, we investigated the lateralization of the auditory N1 component time-locked to the cue. When time-locking to the sound cues (disgust/neutral), ERP patterns of every sound type (disgust/neutral) revealed typical cueing effects, that is, stronger N1 components over the contralateral auditory cortex. Similar increases in the N1 contralateral to the sound location have been found for nonemotional sounds in other studies (McDonald et al., 2013; Woldorff et al., 1999) even when sound locations were illusorily evoked (Bonath et al., 2007, with a somewhat later laterality effect). Increased auditory N1 activity is often seen as evidence for an attentional focus on the side of the sound cue (Hillyard et al., 1973; Woldorff, Hansen, & Hillyard, 1987). This indicates that, in our experiment, there was no evidence for any spatial avoidance of disgusting sounds compared to neutral sounds at this early time point. It is possible that these early laterality effects indicate a general arousal effect which, at this time point, is independent of the emotional or nonemotional character of the sound.

Taken together, spatial avoidance effects were found relatively late (350–400 ms) during target processing, but not during immediate sound processing. By default, we seem to be initially attracted

to the location of a spatial visual or auditory cue independent of the cue's emotional content. Then, the analysis of the emotional content of the sound determines whether the cued location needs to be avoided or not. This is supported by Paulmann and Pell (2010) who observed in an EEG study on emotional priming that the evaluation of auditory emotional content needs some time. They varied the duration of prosodic voice primes (200 ms or 400 ms) that directly preceded a target face and observed priming effects only for prosodic primes with a duration of 400 ms, but not 200 ms. This indicates that it takes longer to recognize auditory stimuli when they carry emotional information. It is also possible that the duration of the emotional stimulus determines the time it takes to process its content. Whereas a cueing fear sound for 500 ms or a facial cue for 100 ms elicited P1 validity differences around 100 ms after target onset (sound: Brosch et al., 2009; face: Pourtois et al., 2005), presenting faces with included gaze cues for a total duration of 1,200 ms resulted exclusively in validity effects on the later P3 component, but not on the earlier P1 component (Fichtenholtz et al., 2007). To conclude, disgusting sound cues first seem to trigger attentional processes to their location and later, after the processing of their emotional content, lead to spatial avoidance and redirection of attention to the location opposite to their spatial position.

### Spatial Avoidance, But Not Inhibition of Return

One might argue that the present effects are due to inhibition of return (IOR) rather than spatial avoidance of disgust. In IOR, faster reaction times to the invalidly compared to the validly cued target are observed (McDonald, Ward, & Kiehl, 1999; Yang, Yao, Ding,

Qi, & Lei, 2012). Further, the IOR is understood to be a general mechanism of attention and therefore should not be modulated by emotion. However, in the present data set, there was no inverse validity effect for the neutral sound condition. In addition, other studies with visual stimulation using emotional cues also show the emotional specificity of the validity effects. Importantly, even when using short cueing windows of 100–300 ms, these studies found an inverse validity effect exclusively for targets cued by disgust but not by neutral or anger cues (compared to neutral: Cisler & Olatunji, 2010; compared to anger: Liu et al., 2015). This suggests that spatial cuing effects due to disgust are not caused by IOR, but rather by spatial disgust avoidance.

### Conclusions

We used a spatial cueing paradigm to search for behavioral and neural evidence indicating spatial avoidance of disgust. We found an atypical cueing effect with faster reaction times for invalidly compared to validly cued targets when preceded by a disgust cue. Second, we found greater P3 activity for targets validly cued by disgust compared to invalidly cued targets ipsilateral to the side of target presentation. Third, at an earlier time point, however, directly after the presentation of the auditory sound cue, N1 amplitudes time-locked to the sound cue showed a typical arousal effect of increased attention at the sound location. We conclude that spatial disgust avoidance occurs in a two-step process: a disgusting sound first directs spatial attention toward and then redirects it away from its spatial location.

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