When a bang makes you run away: Spatial avoidance of threatening environmental sounds

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HIGHLIGHTS

- Attentional biases to emotional sounds were studied through the beep probe task.
- Left-presented negative and taboo nonverbal sounds elicited attentional avoidance.
- Left-presented taboo nonverbal sounds also initiated an IOR phenomenon.
- Taboo sounds elicited a freezing reaction, whatever their location.

ABSTRACT

Environmental sounds can be powerful alarm signals. Hence, attentional orienting towards their location might occur extremely rapidly. Here, we used the beep probe task to investigate attentional biases to negative, positive and taboo sounds. While both left-presented negative and taboo sounds elicited attentional avoidance, taboo but not negative sounds triggered Inhibition of Return. Moreover, taboo sounds slowed participants’ responses, whatever the sound and beep locations. Positive sounds had no effect. Interestingly, although spatial effects specific to taboo sounds were related to their disgusting nature, their non-spatial effects were linked to their shocking/surprising trait. This is the first evidence of emotional sounds’ influence on spatial attentional orienting and of the involved emotional dimensions.

Consider an ordinary day and focus on its auditory qualities. Silence is rare: background noise is almost constant and, as Bradley and Lang [7] point out, you cannot “shut your ears” as you can close your eyes. Hopefully, you will not react to each sound you hear. Rather, only those relevant to your goals or personal concerns will attract your attention. However, despite concentrated on the paper you are writing, you will probably notice the screaming ambulance rushing down the street. Given their speed of transmission and relative insensitivity to intervening stimuli, environmental sounds are very powerful alarm signals [21].

Emotional sounds have been found to capture attentional resources [e.g., 16,27]. Nevertheless, no study specifically investigated whether these sounds influence spatial orienting of attention, namely to what extent attentional resources are oriented to their location. Yet, identification of an auditory object relevant for survival or ecological adaptation might orient attention towards its location, putting the listener in a better position to process subsequent information from the same source. Consistently, we [4,5] reported preferential attentional orienting to the location of negative and taboo (i.e., shocking) spoken words. Also, cross-modal modulation of visual spatial attention by anger prosody has been reported [9].

It is thus established that the emotional content of auditory linguistic stimuli modulates spatial attentional orienting. The present study aimed at investigating whether this phenomenon also occurs for non-linguistic stimuli, namely emotional nonverbal environmental sounds. Since the conceptual processing of environmental sounds is comparable to that of words [24], similar attentional biases may occur for both types of stimuli.

Yet there are differences in the processing of words and environmental sounds. First, contrary to the arbitrary relationship that the sound pattern of words has to real-world objects or events, for many environmental sounds the mapping with meaning results from the physical properties of the object or event in question [28], which may lead to stronger attentional biases towards the emotional content of sounds. Second, several studies reported partially dissociated brain regions in the higher-order processing of verbal
and nonverbal stimuli, including a greater involvement of the left and right hemisphere, respectively [e.g., 15,26]. Third, the spatial distribution of attention for verbal and nonverbal sounds could not follow the same rules. Kinoshine [17] argued that the presentation of verbal (vs. nonverbal) material activate the left (vs. right) hemisphere preponderantly, leading to involuntary orientational biases to the right (vs. left) side of space. Furthermore, although there is a frontal position advantage in localizing both verbal and nonverbal stimuli due to sound attenuation by the pinna [29], only linguistic stimuli induce a frontal position advantage in identification (i.e., better recognition of inputs from the front than from the rear) due at least partly to the habit of looking at our interlocutors (e.g., [6]). Hence, laterality effects and the distribution of attention might modulate differently the spatial attentional biases associated with the emotional meaning of verbal and nonverbal sounds.

In this study, we used an auditory variant of the dot-probe task, the beep probe task [4,5], as it is well-suited to investigate the spatial attentional biases triggered by emotional sounds. Indeed, in the emotional pairs of this task, the simultaneous presentation of one neutral and one emotional sound, each one to one side, is followed by a monaural peripherally-presented beep. Reaction time to this probe as a function of its position and of the position of the emotional sound inform us about the allocation of attention when an emotional sound is presented.

Taboo, negative and positive emotional valences were contrasted to assess the impact of the negative (i.e., threatening) vs. positive valence of sounds, and of their shock value. Following results obtained with emotional spoken words [4,5], we predict (1) that threatening and shocking sounds influence one’s attention to their location, with shorter RTs to probes presented at the same than at the opposite location as the threatening or shocking sound of the pair, and (2) a general, non-spatial slowing effect, delaying the processing of probes after shocking sounds, whatever their location. Here we predict that the spatial bias would occur only for left-, not right-presented emotional nonverbal sounds, reversing the laterality pattern observed with verbal stimuli [4,5]. In previous studies, we indeed observed attentional biases to negative and taboo spoken words only when these were right-presented. We argued that the use of verbal material would have activated the left hemisphere preponderantly [17], favoring the occurrence of spatial attentional biases when emotional words are presented in the contralateral (i.e., right) side of space. In the present study the use of nonverbal sounds would activate the right hemisphere preponderantly, inducing involuntary orientational biases to the left. Given the right hemisphere superiority for processing emotional material [e.g.,12], the emotional nature of the stimuli would even increase this laterality effect.

1. Method

1.1. Participants

Forty-six right-handed students of Université Libre de Bruxelles (35 women, mean age: 21.1, SD: 2.4) participated for course credits.

1.2. Material and apparatus

Stimuli consisted of 48 emotional pairs, in which one of the sounds was emotionally charged and the other was neutral, and 16 neutral pairs, consisting of two emotionally neutral sounds (e.g., scissors/tennis, see Supplementary material). The emotional pairs included 16 positive (e.g., laughter/sneeze), 16 negative (e.g., growling dog/farm animals) and 16 taboo pairs (e.g., diarrhea/grade crossing), defined as such because the emotional sound in the pair was positive, negative or taboo, according to our selection studies. In a first selection study, 80 participants rated 390 sounds (from the IADS-2 [8] or found on http://www.universal-soundbank.com) for familiarity on a five-points scale, ranging from (1) unfamiliar to (5) very familiar, as well as on one of four emotional scales (20 participants each): emotional valence, arousal, threat and shock values. Valence and arousal were assessed on seven-points scales, from (1) very negative/very quiet to (7) very positive/very exciting. Participants were asked to respond “4” when the sound was not emotional or not particularly arousing. Threat and shock values were rather estimated on five-points scales, from (1) not threatening/not shocking to (5) very threatening/very shocking, since the endpoints of these scales were not polarized.

In a second study, 40 participants had to press a keyboard spacebar once they recognized the sound, and to key in its meaning. Sounds were then selected so that emotional sounds of each category were matched on familiarity, arousal, percentage of correct recognition and recognition times to the neutral sounds associated with them in a pair (F < 1; F[1,126] = 3.26, p = .07; F[1,126] = 1.14, p = .10; F < 1). Also, to strengthen differences on the desired emotional characteristics between the sounds of a pair and to ensure that positive, negative and taboo pairs truly differ on the dimensions of interest, we applied a priori criteria considering the length of the scales (5 or 7 points). The two sounds of emotional pairs had to present at least a one-point scale emotional valence difference. Regarding shock value, they had to differ by more than 1.5 point in taboo pairs and less than 1.5 in positive and negative pairs. The threat difference in positive pairs had to be smaller than 1.5. A smaller maximal criterion (one point) was set for neutral pairs, whatever the scale, in order to minimize any difference between the neutral sounds constituting these pairs.

This resulted in taboo, negative and positive sounds differing in terms of emotional valence, shock and threat values, F(2,47) = 872.093, 351.496 and 31.804, all p < .001. Bonferroni adjusted post hoc comparisons (α = .0166) revealed that taboo sounds were more shocking and negative than negative sounds, p < .001 and p = .01, with no threat value difference, p > .10. Both taboo and negative sounds were more shocking, negative and threatening than positive sounds, all p < .001.

In a post-selection study, 20 participants rated the selected sounds on six seven-points scales (1: not at all; 7: absolutely) depicting basic emotions: joy, surprise, fear, anger, disgust and sadness [10]. Taboo, negative and positive sounds differed in terms of how much they evoked these emotions, F(2,47) = 365.774, 5.589, 14.549, 24.426, 42.215, 14.159, all p < .01. In particular, Bonferroni adjusted post hoc comparisons (α = .0166) revealed that taboo sounds were more disgusting and surprising than negative sounds, p < .001 and p = .011. Both negative and taboo sounds elicited increasing levels of anger, fear, sadness and disgust, but decreasing levels of joy, than positive sounds, all p < .10. Taboo but not negative sounds were more surprising than positive ones, p < .03 and p > .50.

Sounds were cleaned and normalized with the Protos Digidesign 6.2.2. software. Within each pair they were synchronized for onset and offset through short excisions. Mean duration was 1499 ms (SD: 115 ms). Each pair was presented through headphones, one sound in each ear, simultaneously, and followed by a 100-ms beep. Admittedly, processing sounds in this situation is different from processing sounds occurring in the real world. Some experiments were run in realistic conditions [13,25], but this was impossible here given the large diversity of the sounds we used. Using loudspeakers provides a rough approach to realistic conditions. Yet, in a previous study [3] we did not report any difference of headphones vs. loudspeakers presentation on the attentional effects of emotional spoken words. Hence headphones were preferred because (1) the distance between ears and the sound source.
remains constant even when the participant is moving slightly, and (2) we wanted to avoid any effect of emotional (in particular taboo) sounds due to joint listening by the participant and the experimenter.

1.3. Procedure

Participants were tested individually. Stimulus presentation and data collection were controlled using E-Prime response box and 1.1.4.1. software [23].

Participants were told that during each trial they would hear two different sounds simultaneously, one in each ear, immediately followed by a beep on the left or on the right. They should localize this beep as quickly and accurately as possible by pressing the left or right key of a response box.

Each trial started with a centrally-presented 750-ms fixation cross. A pair of sounds was then presented. A 100-ms target beep was presented immediately after their offset so that the SOA varied on each trial, depending on the sounds’ duration (1499 ms on average). The participant had a maximum of 3000 ms to answer. This time limit was set in case participants did not respond before or participant’s answer was not recorded. However, both are very improbable. The interval between the response and the next trial was 1000 ms.

Trials were pseudo-randomly presented within each block: more than three repetitions in the same ear of a beep or of a sound of the same emotional category were prevented.

The experiment included 16-trial practice block, followed by four 64-trial experimental blocks. Practice sounds were not used in experimental blocks. All sounds were presented once in each block, in a different order. Each participant was thus presented with each pair of sounds four times, once in each of the four different conditions defined by the locations of the emotional sound and of the beep.

2. Results

Incorrect localizations (0.9% on average) were excluded from further analyses. Fig. 1a displays the mean correct response latencies (RTs) for each type of emotional pair, location of the emotional sound and location of the probe. Henceforth, left- and right-presented emotional sounds (or probes) are referred to as left and right emotional sounds (or probes). By extension, left and right trials refer to trials in which the emotional sound was left- or right-presented, respectively.

A 3 (type of emotional pair: negative/positive/taboo) × 2 (probe location: left/right) × 2 (emotional sound location: left/right) repeated measures ANOVA design was applied on RTs.1

The main significant effects were type of emotional pair, F(2,90) = 6.807, p < .005, partial η2 = .131, and probe location, F(1,45) = 17.165, p < .001, partial η2 = .276. Taboo pairs led to longer RTs than negative pairs (262 vs. 255 ms), p < .001, and participants localized faster right than left beeps (255 vs. 263 ms). Emotional sound location interacted with type of emotional pair, F(2,90) = 4.228, p < .025, partial η2 = .086, and probe location, F(1,45) = 5.635, p < .025, partial η2 = .111. The three-way interaction was significant, F(2,90) = 3.866, p = .025, partial η2 = .079.

Considering separately each type of emotional pair, probe location and emotional sound location interacted for taboo and negative pairs, F(1, 45) = 8.972, p < .005, partial η2 = .166 and F(1,45) = 16.121, p < .001, partial η2 = .264, not for positive pairs, F < 1. Pairwise comparisons adjusted for multiple comparisons using a Bonferroni correction (α = .0125) revealed that participants localized faster right than left beeps with left taboo or negative sounds, T(45) = 5.090 and 3.974, both p < .001, not with right ones, T(45) = 1.629, p > .10 and t < 1.

Attentional biases to taboo and negative sounds were thus negative (−16 and −13 ms) since, with left sounds, RTs on congruent trials (i.e., with a left beep) were longer than RTs on incongruent trials (i.e., with a right beep).

Nevertheless, as illustrated in Fig. 1b, the biases do not reflect exactly the same phenomenon for taboo and negative sounds. Given that no significant bias had been observed with right emotional sounds, we took these conditions (average RTs on left and right beeps following right emotional sounds) as baseline, separately for taboo and negative pairs (see [4,5]). For negative sounds, RTs were shorter on left incongruent trials (i.e., with left sound and right beep) compared to baseline, T(45) = 5.781, p < .001, whereas RTs on left congruent trials (i.e., with left sound and beep) were not, t < 1; for taboo sounds, RTs were shorter on left incongruent trials but longer on left congruent trials, T(45) = 2.863 and 3.251, p = .025 and p < .01 (all ps Bonferroni corrected, α = .0125).

Given that taboo sounds were judged more shocking, negative, disgusting and surprising than negative sounds, one might wonder which trait(s) was/were responsible for the specific effects of taboo sounds. Correlational analyses on negative and taboo sounds revealed that both more shocking and more surprising sounds were associated with larger overall RTs, r(30) = .373, p = .035 and .371, p < .04, respectively. No correlation was observed for emotional valence and disgusting trait, r(30) = −.124, and .233, respectively, both ps > .10. Since shock and surprise values were inter-correlated, r(30) = .559, p = .001, these correlations were not significant once controlling for the other value, both ps > .10, suggesting that shock and surprise are different facets of a same trait.

Regarding the spatial attentional effect, more negative and more disgusting sounds were linked to a larger RT difference between left congruent and right trials, r(30) = −.421, p < .02 and r(30) = .505, p < .01. No such correlation was observed with the shock or surprise value, r(30) = .205 and .02, both ps > .25. Nevertheless, disgust, not emotional valence, would be crucial: once controlling for disgust, the correlation between valence and the RT difference was no longer significant, r(30) = −.230, p > .10, whereas once controlling for valence, the correlation between disgust and the RT difference remained significant, r(30) = .377, p < .05.

3. Discussion

The present experiment investigated spatial attentional biases towards emotional environmental nonverbal sounds, using the beep probe task. Consistent with our hypothesis, results revealed modulation of spatial attentional orienting by left- but not right-presented negative and taboo sounds, with no effect of positive sounds. Nevertheless, results were not exactly as expected: with a left-presented negative or taboo sound, participants localized slower a beep presented to the same than to the opposite ear. Moreover, despite the apparent similarities between attentional biases to negative and taboo sounds, a closer look at the results suggests they reflect quite different phenomena.

We will first discuss commonalities between attentional biases to negative and taboo sounds, and then focus on specific (spatial and non-spatial) effects of taboo sounds.

3.1. Laterality effects

As predicted, attentional biases occurred only when the negative or taboo sound was left-presented, reversing the laterality

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1 Since no interaction involving gender was significant (all p > .35), we did not consider this factor in the analyses.
pattern observed with spoken words in the same task. In that case, attentional biases occurred only when emotional stimuli were right-presented [4,5]. We then argued that the use of verbal material activated the left hemisphere preponderantly [17], favoring the occurrence of spatial attentional biases towards emotional words presented at the contralateral side. Similarly, here the use of nonverbal stimuli may have activated the right hemisphere preponderantly. There is indeed evidence from dichotic listening studies that non-linguistic stimuli are processed more efficiently in the right hemisphere (e.g., [2,19]). Moreover, recent studies suggested right hemisphere predominance in the acoustic and semantic analysis of environmental sounds (e.g., [15,26]). The greater activation of the right hemisphere would thus have favored the occurrence of attentional biases linked to left-presented emotional sounds.

Another possibility is that these laterality effects depend on the emotional content of sounds. According to the “right hemisphere hypothesis” (e.g., [12]), the right hemisphere would play a critical role in processing emotions. The presentation of emotional sounds would thus have activated this hemisphere preponderantly, which would have led to more attention devoted to the left. However, the fact that in the same task attentional biases were only observed for right emotional words [4,5] prevents any interpretation of the laterality effects of emotional sounds as resulting exclusively from their emotional nature. Rather, their emotional nature might have potentiated the laterality effects due to their nonverbal nature.

3.2. Attentional avoidance of negative and taboo sounds

The pattern of results shows that, after presentation of a left negative or taboo sound, attention is oriented towards the right side of the auditory space. This most probably results from an attentional avoidance reaction to these left-presented sounds. Indeed, with negative and taboo sounds, participants localized the probe faster in left incongruent trials (i.e., with right beeps) compared not only to congruent trials (i.e., with left beeps) but also to right (congruent and incongruent) trials. This facilitation in localizing a right beep following a left negative or taboo sound compared to the other conditions clearly indicates that attention had been shifted towards the opposite side of space in reaction to the left presentation of a negative or taboo sound.

Hence, the (left) presentation of a negatively charged, threatening sound, shocking or not, would trigger an avoidance reaction, resulting in shifting attentional resources towards the opposite side. Negative emotional valence and its threatening correlate would thus be crucial aspects of emotional sounds eliciting attentional avoidance.

The fact that threatening sounds, signaling danger, elicit avoidance (rather than vigilance) might seem counterintuitive. Although the present results are not isolated and might reflect avoidance of the stress inductor agent [20], a possibility is that the length of our stimuli favored the observation of secondary (although fast and probably involuntary) effects, and that vigilance was in fact the first reaction to threatening sounds. Using shorter SOAs would allow
3.3. Taboo sounds elicit IOR and general non-spatial effects

The results linked to negative and taboo pairs were not identical, supporting that differences between their emotional content impact the occurrence of spatial and non-spatial effects.

Regarding spatial attentional biases, whereas for negative sounds left congruent trials led to similar RTs as right trials, for taboo sounds they led to longer RTs. This suggests the occurrence of Inhibition of Return (IOR [22]) for left taboo but not for negative trials. IOR is believed to be an involuntary effect that reflects a mechanism biasing attentional scanning towards novel rather than previously inspected items: after some time, attention directed to the stimulus location is drawn back to the central location and inhibited from returning to the initial location [18,22]. This would result in increased RTs on congruent relative to other types of trials, since, solely in this situation, attention had to come back to the inhibited location. Indeed, if attention had not been inhibited from returning there, one would have expected similar RTs for congruent and right trials, as observed for negative sounds.

Emotional modulation of the IOR is well documented (e.g., [3,11]). Here, the avoidance attentional shift following initial orienting of attention towards the (left) spatial location of the taboo or negative sound of the pair provides the condition for the application of inhibitory processes in this previously explored location. However, this would only hold true for taboo, not for negative stimuli, an idea we already demonstrated using the cuing task with spoken words [3].

Interestingly, this specific spatial effect of taboo sounds would stem from their disgusting nature, not from their negative valence or their shock/surprising trait. Hence, although both left negative and taboo sounds would provoke an avoidance reaction shifting attention towards the opposite side of space, this reaction would only elicit inhibitory processes when the sound is particularly disgusting, which might reflect stronger avoidance of these sounds. Further studies should explore this suggestion further.

As predicted, taboo sounds elicited general, non-spatial effects: similar to our observations with spoken words [4,5], participants localized probes more slowly when they followed taboo than negative pairs, whatever the emotional sound and beep locations. Hence, both verbal and nonverbal taboo stimuli most probably elicited a freezing reaction [1], namely an inhibition of motor responses, creating a generic slowdown. This would be mainly due to their shock/surprise value, not to their disgusting trait or negative valence. Consistently, Harris and Pashler [14] showed that the surprise reaction elicited by the perception of high-priority, emotional stimuli interrupts ongoing processing, slowing participants’ responses.

Hence, although negative, threatening sounds (in contrast to positive, non-threatening ones) would elicit attentional avoidance (whatever their degree of negative emotionality, shock or threat values), a high degree of disgust would cause IOR, while the shock/surprise dimension would elicit general, non-spatial effects.

4. Conclusions

The present results revealed that both negative and taboo environmental sounds influence the spatial orienting of attention. Hence, similar to what has been observed with emotional spoken words, the presentation of negative threatening sounds, whatever their shocking nature, affects attentional engagement to their location.

However, although nonverbal sounds provoke an avoidance reaction, verbal stimuli instead elicit vigilance to this location once attention has been drawn there [4,5]. As suggested above, these opposite effects of withdrawal vs. approach might result from the occurrence of secondary vs. primary effects of sounds vs. spoken words, respectively, due to the length of the former. This should be checked in further studies examining the time course of the attentional responses to such stimuli.

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Appendix A. Supplementary data

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References