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Abstract

Theories of auditory attention suggest that humans decompose complex auditory input into individual auditory objects, which then compete for attention to dominate auditory perception. Since emotional significance of external stimuli has been argued to provide cues for sensory prioritization and allocation of attention, emotionally salient auditory objects can receive attention to dominate auditory perception. Based on the function of audition as an alarm system that informs the organism about its immediate surroundings, and on empirical evidence that emotion can modulate auditory perception, we argue that auditory stimuli with greater emotional saliency would dominate perception in multi-source environments. In order to test our hypothesis we employed a change detection task where participants are asked to indicate if multi-source auditory-scenes were identical or different. Participants were better at detecting changes at the presence of an emotionally negative environment compared to neutral. Further, we found that participants were better at detecting changes of emotionally negative targets compared to neutral targets. Our results demonstrate that detecting changes in auditory-scenes is influenced by emotion. The findings are discussed in the light of the theories of auditory attention, emotional modulation of attention, and the adaptive function of emotion for perception.

Keywords: emotion, change deafness, auditory perception

Emotional Bias in Change Deafness in Multi-Source Auditory Environments

In daily life we are subjected to a constant stream of sounds that informs us about our environment. We are able to process this stream of auditory input, identify different sound sources and attend to a particular stream of information while pushing the others into the background (Bregman, 1990). Theories of auditory attention show that listeners, by help of a variety of acoustic dimensions, decompose complex auditory input into auditory objects and streams, which then compete for attention to dominate auditory perception (Fritz et al., 2007; Shinn-Cunningham, 2008).

In order to investigate which auditory objects receive attention and dominate auditory perception in a multi-source environment a so called change-detection paradigm is often used. In this measurement paradigm participants, after listening to two auditory-scenes composed of multiple sounds, simply are asked to indicate whether the auditory-scenes were identical or if there was a change. Changes take place in the forms of sound replacement, location change, or sound addition or deletion (Eramodugolla et al., 2005; Gregg & Samuel, 2008; Pavani & Turatto, 2008). Change-deafness, which refers to the failure to detect changes in an auditory-scene, has been argued to stem from failure to attend to the changing event. Previous research showed that change-deafness can be influenced by physical properties of changing sounds, directed attention, and semantic representation of auditory events (Eramodugolla et al., 2005; Gregg & Samuel, 2008; 2009). One neglected aspect of the perception in auditory environments is the emotional salience of auditory stimuli. Here we investigate the role of emotion in change-deafness.

The emotional significance of objects in our surrounding environment is an important cue for prioritization and allocation of attention and mental resources due to a possible survival-related function. Detecting and reacting to possible threats through emotion that in turn enhances sensory processing and modulates attention is paramount to survival in hostile environments (Öhman, Flykt & Esteves, 2001; Mineka & Öhman, 2002; Vuilleumier, 2005; Vuilleumier & Driver, 2007). However, much of the existing scientific evidence on the emotion-perception link to date is focused on visual perception.

In the visual domain, behavioral evidence suggests that emotional stimuli more easily attract attention than neutral stimuli (Vuilleumier, 2005). In attentional-blink paradigm, where a second visual target (T2) is often missed when it is presented shortly after a first target (T1), the failure to detect T2 is lower when it is emotionally arousing (Anderson, 2005). It has also been shown that the accuracy of detecting T2 was worse when it is presented soon after an emotionally arousing T1 compared to a neutral T1 (Most et al. 2005; 2007). However, the role of emotion in change-blindness (equivalent paradigm to change-deafness) has not been studied as much. A behavioral study (McGlynn et al, 2008) showed that it was easier to detect changes when highly emotion inducing stimuli (a snake) was present in the visual scene. These and other findings suggest that visual perception is informed by emotion, and that predictions made by the brain during visual perception contains emotional value as a necessary part of conscious visual experience (Barrett & Bar, 2009: see also Becker, 2009; Phelps, Ling & Carrasco, 2006; Bocanegra & Zeelenberg, 2009).

The role of emotion in auditory perception, on the other hand, is much less studied. Some recent neurophysiological studies however indicate that emotion can influence auditory processing: negative emotion can affect auditory event-related-potentials (ERP) as early as 20 ms (Wang, Nicol, Skoe, Sams & Kraus, 2008); learned emotional meaning can modulate early auditory processing and engage attention networks (Bröckelmann et al., 2011); and in an oddball sequence angry voice deviants produced larger mismatch-negativity (MMN, a neural correlate of pre-attentive change detection) compared to neutral voice deviants (Schirmer, Striano, Friederici, 2005). Further, recent behavioral evidence suggests that negative emotion can influence auditory perception. Induced negative emotion caused participants to perceive the same auditory stimuli as being louder compared to the ratings of a control group (Siegel & Stefanucci, 2011). Another recent study showed that loudness perception (a basic low-level perceptual process) can be influenced by emotional significance of the auditory stimuli itself and that this can occur through low-level affective learning (Asutay & Västfjäll, 2012).

Based on work suggesting that auditory system is an alarm system evolved to inform the individual about its immediate surroundings (Juslin & Västfjäll, 2008), and on neurophysiological (Wang et al., 2008; Bröckelmann et al., 2011) and behavioral (Siegel & Stefanucci, 2011; Asutay & Västfjäll, 2012) evidence that emotion can modulate auditory perception, we argue that auditory perception in multi-source environments is guided by the emotional significance. We predict that auditory stimuli with greater emotional saliency would inform and affect perception of complex auditory environments. In order to test this hypothesis we employed an auditory change-detection task and introduced a novel feature: we varied the emotional significance of the sounds in the auditory-scenes. The goal of the experiment was to determine the role of emotion in change deafness.

Method

Participants

18 normal hearing individuals (7 females; mean age: 25.3±0.97) participated in the study. They gave their informed consent prior to the inclusion in the experiment and were compensated after the study. The experiment was conducted in accordance with the ethical standards in the

1964 Declaration of Helsinki. The experiment was carried out in a dark, sound attenuated room, where participants completed all materials individually. Prior to the task participants completed an instruction trial in order to get familiar to the procedure.

Materials and Procedure

In the experiment, 24 environmental sounds were used (Table 1). All the auditory stimuli were 3-second long, and sampled at 44.1 kHz. In order to equalize loudness of the auditory stimuli we set their 5th percentile Zwicker loudness value (N5) to 6.5 sone. N5 is suggested as an index of loudness for time-varying auditory stimuli (Fastl & Zwicker, 2007). In two separate pilot sessions, emotional responses to the auditory stimuli were collected using the standard 9-point scales of valence (positive/negative content) and arousal (high/low arousal level) (Lang, 1980). Auditory stimuli were divided into two categories (i.e. negative and neutral) according to their mean valence ratings (Table 1). Within each valence category 4 of the stimuli were designated as target stimuli and the rest were scene stimuli.

Auditory scenes in the experiment consisted of 5 scene stimuli and one target stimulus, which are presented simultaneously. All 5 scene stimuli in a scene were either emotionally neutral or negative (scene valence); and the target stimulus, independent of the scene valence, was either negative or neutral. In each trial, participants first listened to an auditory-scene. Then, they heard a second auditory-scene, which was either the same scene or in which the target stimulus in the first scene (T1) was replaced with a different target stimulus (T2). Participants' task was to indicate if the two scenes were same or different by pressing a button. 750 ms of white noise which was preceded and followed by 750 ms of silence periods was presented in between the two auditory-scenes. In one-third of the trials no change occurred, while in the rest of the trials T2 was either negative or neutral.

Three of the sounds in each scene were presented from a loudspeaker pair located in front of the participant, while the rest were presented using a pair of loudspeakers located behind. All the loudspeakers (Genelec 8030A) were placed at 1.2 m height and at 1 m distance from the participant. The angle between both the front and the rear loudspeaker pairs was 45 degrees from the participants' point of view. Each target stimulus was presented in front of and behind the participants at equal times, while the presentation location of non-target stimuli was selected randomly. In the trials where a change occurred T1 and T2 were presented at the same location.

Design

A Factorial design of the conditions resulted in 96 unique trials: 2 (scene-valence; negative or neutral) X 2 (T1-valence; negative or neutral) X 2 (target location; front or back) X 3 (change conditions; negative T2, neutral T2, and no-change) X 4 (stimuli). Stimuli factor indicates that all conditions were realized four times with different target stimuli in different scenes. All the target stimuli appeared the same number of times as T1 and as T2.

We expected lower change-deafness for negative compared to neutral targets (both for T1 and T2), since emotional stimuli would attract more attention compared to neutral stimuli (Vuilleumier, 2005). Further, we expected that the presence of emotionally arousing stimuli to increase overall attention (Phelps & LeDoux, 2005), which would lead to higher change detection accuracy for negative scenes compared to neutral scenes. The location factor (back-front) was added to examine if perceptual sensitivity is modulated by the perceptual field. Change-deafness was expected to be lower when the change occurs outside one's visual field. Previous results show that people tend to locate sound sources behind them when no visual cues are available (Begault, 1994; Tajadura-Jiménez et al., 2007); and due to this we expected that participants could detect changes that occur behind easier compared to in front.

Forming Auditory-Scenes

Based on the use of eight scene stimuli 56 possible combinations of five could be formed. 48 of those, for each valence category (i.e. a total of 96), were selected randomly for use in the experiment. Then, the target stimuli were added to form the auditory-scenes.

Previous research indicated that the physical dissimilarity of the stimuli that replace each other in auditory change detection tasks influences detection performance (Gregg & Samuel, 2008). In order to control for this, mean pitch and harmonicity of the target stimuli were calculated (Table 1). For the trials where a change occurred, differences in mean pitch and harmonicity were computed between the target stimuli that replaced each other. Even though the correlation between the percentage of detected changes (PDC) and the difference in mean pitch ($r=.23$, $p=.07$, $N=64$)[1] was better compared to the correlation between PDC and the difference in mean harmonicity ($r=-.06$, $p=.63$, $N=64$), none of them reached statistical significance.

Results

Consistent with previous auditory change detection studies (e.g. Gregg & Samuel, 2008); we found that percentage of correct responses was higher for no-change trials (85±2.5 %) compared to change trials (68±2.3 %).

In order to test our hypothesis, we used hit-rate as dependent variable. Hit-rate was submitted to a repeated-measures analysis of variance (ANOVA) with four within-subject

[1] Since this correlation was marginally significant, we conducted additional post-hoc analyses to check the contribution of the mean pitch difference to the reported effects (see the results section). Hit-rate was used as dependent variable and mean pitch difference as a time-dependent covariate. We entered factors that produced significant main effects and interactions from the repeated-measures ANOVA (for detail; see the results section) into a linear mixed model. As results indicated, mean pitch difference did not yield a statistically significant effect ($F(1,257)=.007$, *ns*) or produce any significant interactions with other factors.

factors: scene valence (negative vs. neutral), T1 valence (negative vs. neutral), T2 valence (negative vs. neutral), and change location (front vs. back). Results of the ANOVA (see Table 2 for means across all conditions) showed, consistent with our prediction, that hit-rate was significantly higher for negative auditory-scenes compared to neutral ones ($F(1,17)=23.03$, $p<.001$, $\eta^2=.58$). Mean hit-rate for negative scenes was .76 (±.02; SE of the mean), while it was .62 (±.03) for neutral scenes. Further, significant main effects were found for both T1 ($F(1,17)=14.9$, $p<.01$, $\eta^2=.47$) and T2 ($F(1,17)=42.5$, $p<.001$, $\eta^2=.71$). These effects showed that hit-rate was higher for negative targets (mean hit-rate for negative T1 and T2 were .72±.02, and .77±.02, respectively) compared to neutral targets (mean hit-rate for neutral T1 and T2 were .65±.03, and .60±.03, respectively)[2].

A statistically significant interaction of T2-valence and change location ($F(1,17)=5.33$, $p<.05$, $\eta^2=.24$) indicated that an influence of change location on hit-rate was stronger when T2 was neutral. In other words, for the trials where T1 was replaced with a neutral T2, subjects were better at detecting changes when they occurred behind compared to in the front. However, change location did not affect change detection as much when T2 was negative (Figure 1B). Moreover, a significant interaction of scene valence and T2 valence was found ($F(1,17)=20.3$, $p<.001$, $\eta^2=.54$). Difference in change detection due to T2 valence was larger at the presence of a neutral scene compared to a negative scene (Figure 1A).

[2] The reason we decided to report hit-rate instead of sensitivity (d'; Macmillan & Creelman, 1991) is that in the current design it cannot be determined whether the effects of T2-valence and change location are due to d' or changes in the criterion. However, for the effects of scene-valence and T1-valence one can compute the false alarms in a proper way. Hence, as a result of separate analysis, we found that the scene valence effect was due to perceptual sensitivity ($F(1,17)=15.56$, $p<.01$, $\eta^2=.48$). Average false alarms rate for the two conditions (scene-valence and T1-valence) can be seen in Table 2.

Discussion

The present study aimed to investigate the role of emotion in auditory perception in multi-source environments using an auditory change detection task. The results clearly show an emotional bias in change-deafness. Detection of change increased systematically when the auditory events in a complex scene were emotionally significant. This is a novel finding, since previous research on change-deafness has only found that change detection performance is modulated by physical properties of auditory stimuli, semantic representations of auditory events, and directed attention (Eramodugolla et al., 2005; Gregg & Samuel, 2008; Gregg & Samuel, 2009). Here, we show that the ability to detect a change in an auditory environment is guided by the emotional significance of events within that environment.

Most importantly, we found that emotional salience of changing stimuli (T1 and T2) had highly significant effects on change detection. It was easier to detect changes when they involved an emotionally negative stimulus. Change-deafness has been argued to stem from failure to attend to the changing event. Hence, this finding suggests that emotionally salient auditory stimuli can receive attention to guide perception.

Changes that occurred in negative auditory-scenes were easier to detect compared to neutral scenes. This finding seems to be in contradiction with the perspective of competing auditory stimuli for attentional resources, since the targets are in direct competition with the negative scene stimuli. We argue that the presence of an emotionally negative and arousing (see Table 1 for arousal ratings of individual stimuli) environment caused the overall auditory perceptual threshold to decrease. Phelps and LeDoux (2005) have argued that increased arousal leads to an increase in attention and vigilance. Following this line of reasoning, we argue that change in attention induced by emotion is responsible for the decrease in change deafness at the presence of an emotionally negative and arousing environment. Other research, using an auditory oddball paradigm that was combined with aversive conditioning, has shown that aversive conditioning broadened the focus of spatial selective attention (Pauli & Röder, 2008). However, the Pauli and Röder study showed that only early processing stages that were indexed by event-related-potentials (ERPs) were influenced by emotional salience, while the later selection indices as well as behavioral performance were unaffected. Our study provides behavioral evidence that the presence of emotionally negative stimuli increased the overall alertness, thus causing the perceptual threshold to decrease. This explanation can also account for the significant scene-valence*T2-valence interaction effect: the hit rate was lower only for neutral T2 in neutral auditory-scenes compared to the rest (Figure 1A).

Moreover, when a neutral stimulus replaced the target change detection accuracy was modulated by the perceptual field, i.e. it was easier to detect the changes that occurred behind compared to in the front. We argue that the emotionally salient changes could be detected regardless of the perceptual field. However, the changes, which do not inflict an immediate threat, receive priority when they occur outside one's visual field. Previous research has speculated that the auditory system is an alarm system informing the organism about its immediate surroundings (Juslin & Västfjäll, 2008). It is in charge of detecting possible threats and alarming the individual to shift attention. Hence, this novel finding might suggest a bias in auditory attention for the perceptual field outside the reach of vision (Tajadura-Jiménez et al., 2010), so that the attention could be quickly shifted when necessary. This finding also points to possible cross-modal interactions in emotional processing. Future research could use attentional paradigms in audio-visual environments to examine this more systematically.

There is ample evidence that emotionally salient visual stimuli can affect attention and perception (for reviews see Phelps & LeDoux, 2005; Vuilleumier, 2005; Vuilleumier & Driver, 2007); even though the influence of emotion in change-blindness (visual equivalent of change-deafness) has not been exhaustively studied. However, the evidence on the link between emotion and attention in auditory domain is sparse. Previous research has found that emotionally conditioned auditory stimuli engage attention networks at early auditory processing due to their greater emotional salience (Bröckelmann et al., 2011) and that emotional salience broaden the focus of spatial auditory attention (Pauli & Röder, 2008). The present study, using a change detection paradigm, is the first to provide behavioral, psychophysical evidence that emotional salience of auditory events influence auditory attention and perception in complex multi-source auditory environments. Our results indicate that emotionally negative and arousing stimuli receive priority and cause the attention to increase and perceptual threshold to decrease. These findings are in line with current theories of the role of arousal in perception, memory and judgments: Mather and Sutherland (2011) argue that arousal during an event increases the bias of competition for attention in favor of high-priority stimuli (arousal-biased competition). Further, another novel finding in our experiment show that perceptual field also has an impact on auditory attention. Neutral changes were prioritized when they appear behind participants.

Based on the results of our experiment, we suggest that emotional significance of auditory stimuli plays a crucial role on allocation of attention. Our findings are also in line with the research on the adaptive function of emotion for survival (Mineka & Öhman, 2002; Vuilleumier, 2005) and suggest that emotion is integral to low-level auditory processing in humans.

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Table 1. Stimuli information. Valence and arousal ratings were collected in two separate pilot sessions with 18 and 13 participants, respectively. Ratings that were collected in the first pilot session (N=18) are marked with asterisk. Mean pitch and harmonicity of the stimuli were computed using Praat software.

Sound	**Mean valence ratings (±SE)**	**Mean arousal ratings (±SE)**	**Mean pitch [Hz]**	**Mean harmonicity [dB]**
Neutral Target Stimuli				
Horse hooves*	6.67 (±.42)	3.78 (±.5)	1006	3.1
Toilet flush	4.77 (±.44)	4.38 (±.35)	557	-0.2
Crushing a tin can*	4.72 (±.37)	5.29 (±.5)	1216	-2.9
Female yawn	4.38 (±.5)	3.15 (±.48)	293	15.6
Negative Target Stimuli				
Growling dog	2.75 (±.44)	7.33 (±.28)	291	5.4
Fire alarm	2.69 (±.35)	7.15 (±.25)	431	7.4
Dentist's drill	2.23 (±.32)	7.31 (±.35)	1235	5.2
Female scream	1.77 (±.2)	7.92 (±.35)	1373	6.1
Neutral Scene Stimuli				
Typewriter*	5.89 (±.29)	4.56 (±.46)	3578	-0.9
Hen	5.85 (±.46)	5.38 (±.26)	948	8.1
Helicopter	4.92 (±.29)	6.31 (±.33)	2636	0.1
Cuckoo clock	4.77 (±.58)	6.15 (±.49)	251	3.9
Boiling water	4.77 (±.36)	5.46 (±.29)	3446	2.4
Microwave	4.54 (±.55)	4.85 (±.56)	381	0.9
Cracking door	4.23 (±.28)	5.85 (±.34)	340	4.8
Compressed air*	4.06 (±.29)	5.11 (±.4)	3690	-0.3
Negative Scene Stimuli				
Hissing cougar	3.85 (±.39)	6.67 (±.36)	380	4.9
Roaring tiger	3.69 (±.31)	7.54 (±.29)	212	3.4
Wasps	3.54 (±.61)	6.85 (±.34)	217	4.4

Jackhammer	2.92 (±.36)	6.92 (±.33)	2069	-2.8
Fingernails on blackboard	2.54 (±.39)	7.31 (±.36)	1396	-1.6
Buzzer	2.46 (±.35)	7.92 (±.33)	306	2.1
Crying baby	2.31 (±.41)	7.38 (±.33)	881	12.5
Scratching a Styrofoam	2.31 (±.33)	7.23 (±.28)	1547	-2.8

Table 2. Mean hit-rates across all the conditions in ANOVA. Table also shows average false alarms rates for scene-valence and T1-valence conditions. False alarms rates cannot be determined properly for T2-valence and change location factors due to the design of the experiment.

			Mean hit-rate (± 95CIs)		**Average False Alarms Rate**	
T1 Valence	**T2 Valence**	**Location**	**Negative Scene**	**Neutral Scene**	**Negative Scene**	**Neutral Scene**
Negative	Negative	Front	0.81 (±.091)	0.75 (±.105)		
		Back	0.79 (±.115)	0.79 (±.077)		
	Neutral	Front	0.76 (±.117)	0.44 (±.138)		
		Back	0.76 (±.067)	0.67 (±.095)		
Neutral	Negative	Front	0.79 (±.088)	0.78 (±.119)		
		Back	0.79 (±.098)	0.68 (±.093)		
	Neutral	Front	0.64 (±.106)	0.42 (±.148)		
		Back	0.69 (±.109)	0.40 (±.129)		
Negative					0.19 (±.036)	0.14 (±.029)
Neutral					0.10 (±.021)	0.20 (±.037)

Figure legend

Figure 1. Statistically significant interaction effects on Hit Rate (95CIs are indicated). (A) Interaction of scene valence (Negative scene vs. Neutral scene) and T2 valence (negative vs. neutral). (B) Interaction of change location (Front vs. Back) and T2 valence (negative vs. neutral).

Figure 1