Distraction by emotional sounds: Disentangling arousal benefits and orienting costs

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Abstract

Unexpectedly occurring task-irrelevant stimuli have been shown to impair performance. They capture attention away from the main task leaving fewer resources for target processing. However, the actual distraction effect depends on various variables; for example, only target-informative distractors have been shown to cause costs of attentional orienting. Further, recent studies have shown that high arousing emotional distractors, as compared to low arousing neutral distractors, can improve performance by increasing alertness. We aimed to separate costs of attentional orienting and benefits of arousal by presenting negative and neutral environmental sounds (novels) as oddballs in an auditory-visual distraction paradigm. Participants categorized pictures while task-irrelevant sounds preceded visual targets in two conditions: 1) informative sounds reliably signaled onset and occurrence of visual targets, and 2) non-informative sounds occurred unrelated to visual targets. Results confirmed that only informative novels yield distraction. Importantly, irrespective of sounds' informational value participants responded faster in trials with high arousing negative as compared with moderately arousing neutral novels. That is, costs related to attentional orienting are modulated by information whereas benefits related to emotional arousal are independent of a sound's informational value. This favors a non-specific facilitating cross-modal influence of emotional arousal on visual task performance and suggests that behavioral distraction by non-informative novels is controlled after their motivational significance has been determined.

Keywords

cross-modal distraction, novel environmental sounds, task-relevance, phasic alertness, attentional orienting

Introduction

Maintaining high performance even in the presence of distracting stimuli is fundamental for goal-directed behavior. Likewise, it is important to detect task-unrelated but relevant changes, such as cues signaling potential danger. Novel or unexpected stimuli have been shown to involuntarily attract attention, thereby disrupting task performance. This distraction effect can be modulated, for example, by the emotional or target-related informational content of distractors. These factors may affect different processes, namely alerting resulting in benefits in the main task and attentional orienting resulting in costs.

The role of emotion in distractor processing

Studies on the influence of emotion on behavior have mainly focused on the fact that autonomic and central measures, which index attentional orienting, are enhanced for emotional as compared with neutral stimuli (for a review on visual emotional stimuli see Bradley, Keil, & Lang, 2012). This has been related to their intrinsic motivational significance (e.g. Schupp, et al., 2004). For example, task-irrelevant emotional pictures preceding or accompanying visual targets have been shown to increase reaction times (Pereira, 2006, 2009) or reduce accuracy in an unrelated visual task (Hindi Attar, Andersen, & Müller, 2010; Most, Chun, Widders, & Zald, 2005; Most, Smith, Cooter, Levy, & Zald, 2007). Contrary, task-relevant emotional stimuli, that is stimuli that have to be processed in order to fulfill a task, have been found to improve performance in emotion unrelated tasks. Voice gender, for example, is discriminated faster for emotional as compared with neutral words in conflict trials (Kanske & Kotz, 2011c), suggesting that attended emotional stimuli speed up conflict resolution, even when emotion itself is not relevant for the task (Kanske & Kotz, 2010, 2011a, 2011b, 2011c). Kanske (2012) has suggested that task goals and emotional information coincide if targets are emotional, so that additional resources are devoted to the target, which speeds up processing. In contrast, task-irrelevant emotional stimuli capture attention away from the

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main task leaving fewer resources for target processing and thus, may impair performance in the main task (Kanske, 2012; Pessoa, 2009).

However, one may also argue that emotional stimuli, irrespective of their relevance for the current task, signal the general relevance of a situation. Imagine that while driving a car you suddenly hear the horn of an ambulance. In this situation it is important to keep attention highly focused on the visual scene in order to be able to react adequately to anything happening in front of you, e.g. an accident, or braking cars, and to not get distracted from driving by the emotional sound. In line with this idea, improved performance could also be shown for task-irrelevant emotional stimuli. For example, Phelps et al. (2006) reported enhanced contrast sensitivity when fearful relative to neutral faces preceded visual targets, suggesting that emotion enhances visual perception. Zeelenberg and Bocanegra (2010) reported evidence for beneficial cross-modal effects of emotional distracters. Spoken emotional, relative to neutral distracter words preceding visual targets, improved identification accuracy in a visual task. This suggests that emotional words enhance visual perception. Thus, task-irrelevant emotional stimuli may also facilitate sensory processing and behavioral performance in an unrelated task, since they may act as unspecific warning cues and enhance alertness (Okon-Singer, Lichtenstein-Vidne, & Cohen, 2012).

Disentangling benefits and costs of distractor processing

Another line of research also found evidence for a facilitating effect of distractors. Unexpectedly occurring environmental sounds (termed novels) attract attention involuntarily and thus, often disrupt performance in an unrelated task (Bendixen, et al., 2010; Escera, Yago, Corral, Corbera, & Nunez, 2003; Wetzel, Widmann, & Schröger, 2012). Mechanisms of distraction are often investigated with an auditory-auditory (e.g. Schröger & Wolff, 1998; Sussman, Winkler, & Schröger, 2003; Wetzel & Schröger, 2007; Wetzel, Widmann, Berti, & Schröger, 2006) or an auditory-visual distraction paradigm (e.g. Bendixen, et al., 2010; Escera, Alho, Winkler, & Näätänen, 1998; Parmentier, Elford, Escera, Andres, & San Miguel, 2008; Ruhnau, Wetzel, Widmann, & Schröger, 2010). In both paradigms a predictable auditory context is set up by the repetitive presentation of a sound (termed standard). In the cross-modal version, participants are engaged in a visual task, such as discriminating odd and even numbers or categorizing pictures. Even though not relevant for the task, rare and unexpected changes in the auditory context impair performance relative to trials with a standard sound. Increased reaction times or reduced hit rates in trials with novels relative to standards are termed the distraction effect. In the auditory-visual paradigm distraction can be explained by an attentional shift from the visual task to an irrelevant sound (Parmentier, et al., 2008).

However, recent studies suggest that novels (in contrast to non-unique deviants) may not only yield distraction, but also facilitation (Ruhnau, et al., 2010; SanMiguel, Linden, & Escera, 2010; SanMiguel, Morgan, Klein, Linden, & Escera, 2010; Wetzel, et al., 2012), that is, they may improve performance in novel relative to standard trials. A plausible explanation for this effect is that the orienting response towards salient sounds comprises not only attentional orienting, but also an alerting effect (Näätänen, 1992). Thus, what is reflected in behavior in trials with novels is the sum of both effects: costs of attentional orienting and benefits by the alerting component of novels (SanMiguel, Linden, et al., 2010). In a recent study by Wetzel and colleagues (2012), the alerting effect of novels has been related to novels' motivational significance. The authors compared the impact of unexpectedly occurring task-irrelevant novel sounds with meaningless bursts of white noise (deviants) and found shorter reaction times in trials with novels. Further, by modifying the informational value of sounds preceding visual targets, Wetzel et al. (2012) disentangled costs of attentional orienting and benefits in trials with novels. In a classical version of the auditory-visual distraction paradigm, task-relevant pictures are always preceded by task-irrelevant sounds with a fixed stimulus onset asynchrony. That is, sounds are informative since they signal appearance and onset of visual targets. However, when sounds do not predict targets the distracting effect diminishes (Ljungberg, Parmentier, Leiva, & Vega, 2012; Parmentier, Elsley, & Ljungberg, 2010; Wetzel, et al., 2012) while the bias towards facilitation for novels, but not for deviants, persists (Wetzel et al., 2012). The authors hypothesized that novels, due to their high motivational relevance relative to meaningless deviants, yield a non-specific increase in arousal for a short period of time (Aston-Jones & Cohen, 2005), that is they increase phasic alertness. Phasic alertness heightens response readiness (Sturm & Willmes, 2001) and may therefore improve performance in the visual task.

Aims and hypothesis of the current study

Here we focused on two questions. First, we aimed to test whether the unspecific bias towards facilitation by novels is due to increased alertness, as suggested by Wetzel et al. (2012). For this purpose, we directly compared behavioral performance in trials with high arousing negative novels and moderately arousing neutral novels, which we presented in an auditory-visual distraction paradigm. The participants' task was to categorize pictures and to ignore sounds. Novels were controlled for perceived valence and arousal on the basis of a pilot-study and a pre-test, in which participants evaluated sounds. Further, negative sounds, such as the drill of a dentist or the horn of an ambulance, have also been shown to elicit enhanced objective measures of arousal, such as enhanced heart rate deceleration and skin conductance responses (Bradley & Lang, 2000). Thus, we expected improved performance in trials with high arousing negative relative to lower arousing neutral novels. Contrarily, enhanced distraction in negative novel trials would support the hypothesis that mainly task-relevance, that is whether the emotional stimulus needs to be processed in order to perform the task, determines the direction of an emotional influence. The reasoning would be that negative relative to neutral novels are more effective in capturing attentional resources away from visual targets.

Second, we asked whether any effect of emotional arousal depends on the informational content of sounds, that is, whether sounds signal onset and occurrence of targets. Therefore we presented participants either with informative or non-informative sounds. If the motivational significance of sounds is determined only after target-related information has been processed, we expected an interaction of information and emotional arousal of novels. On the other hand, merely main effects of information and arousal would suggest that the motivational significance of sounds is determined irrespective of whether the cognitive system can take advantage of sounds. This would support the notion of a prioritized processing of motivational relevance in the sense that it is independent of target characteristics and thus, occurs *before* individuals shield against behavioral distraction by informative sounds.

Another factor that has been shown to influence distraction/facilitation is the timing of sound and target. For example, Schröger (1996) reported behavioral distraction in a visual task by task-irrelevant sounds only with short sound-target intervals. However, with respect to our stimuli, short sound-target intervals result in an overlapping presentation of sound and target, which may, in turn, modulate effects of emotional arousal. Zeelenberg and Bocanegra (2010) suggested that temporal competition between a distractor and a target decreases the effect of task-irrelevant emotion on behavioral performance. According to their hypothesis, effects of emotional arousal may be strongest when sound and target do not overlap and temporal competition is low. In order to control for these effects we presented stimuli in both versions: with a short, overlapping sound-target interval and a long, non-overlapping sound-target interval.

We further collected data about individual differences in depression, anxiety, and effortful control. Participants with high levels of subclinical anxiety and depression have been shown to be faster in detecting negative emotional stimuli and to show greater difficulties in reorienting to task-relevant neutral stimuli, especially when stimuli are negative (e.g. Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van, 2007). Thus, participants scoring high in depression and anxiety may be less efficient in evaluating negative emotional stimuli (e.g. Kanske & Kotz, 2013) and accordingly experience greatest costs from emotion. That is, they may show greater impairments or smaller improvements in trials with negative relative to neutral novels. Effortful control as measured with the Adult Temperament Questionnaire can be described as “capacity to control attention while experiencing emotion” (Evans & Rothbart, 2006, p. 883), so that we expected individuals scoring high in effortful control to be less sensitive to emotional distraction.

In sum, we measured reaction times and hit rates in a picture categorization task as a function of the preceding sound (high arousing negative novel, moderately arousing neutral novel, neutral standard) and sounds’ informational value (informative, non-informative). Moderately arousing neutral and high arousing negative novels were selected on the basis of a pilot study (see methods). If arousal facilitated performance we expected 1) improved performance in the visual task when negative relative to neutral novels precede pictures. We 2) expected an interaction of novel type and information if an effect of emotional arousal is contingent upon a novel’s usefulness for signaling the target, and 3) we expected an influence of sound-target interval if temporal competition modulates an effect of emotional arousal. Finally, we collected data on individual differences in order to exclude data of participants reporting moderate or severe depression symptoms and to test if an effect of novels’ emotional valence (negative, neutral) is modulated by anxiety, depression or effortful control.

Methods

Participants

Only females participated in this study because they have been shown to be more sensitive to distraction by auditory novelty in a negative emotional context (Garcia-Garcia, Dominguez-Borras, SanMiguel, & Escera, 2008). Data of one participant was excluded due to depression scores in the range of a moderate depression (Beck Depression Inventory = 26). Further 24 right handed females were randomly assigned to the informative condition (mean age 22 years and 5 month, standard deviation 4 years and 8 month) and 24 females to the uninformative condition (mean age 23 years and 1 month, standard deviation 4 years and 5 month). Handedness was measured with a shortened German version of the Oldfield Handedness Inventory (Oldfield, 1971). Participants received money (6 € per hour) or course credits for their participation. All gave written informed consent and reported normal or corrected-to-normal vision, normal hearing, and no history of neurological disorders.

Stimuli

Pictures. Target pictures were white line drawings on black background and comprised ten drawings of animals and ten drawings of clothing presented for 200 ms (Figure 1). We used the same pictures as in the study by Wetzel and colleagues (2012) chosen from the database of Snodgrass and Vanderwart (1980). Pictures were presented on a computer screen and replaced a white fixation cross on black background which was presented otherwise.

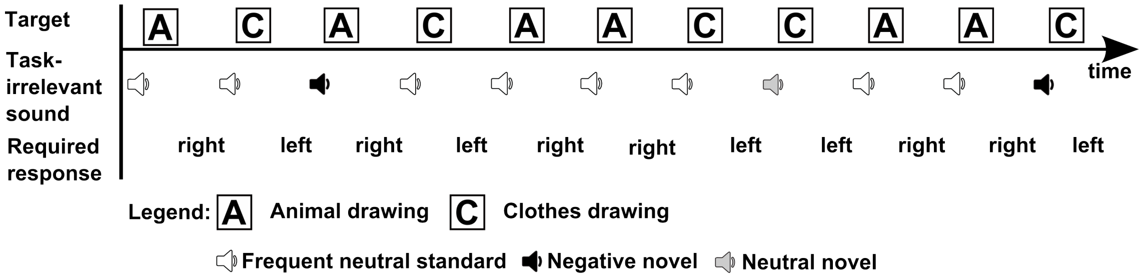

Figure 1. Sample sequence of the auditory-visual distraction paradigm with informative sounds. Participants' task was to categorize drawings (clothing versus animal).

Sounds. Task-irrelevant sounds were presented in an oddball paradigm (Figure 1), that is some sounds were presented infrequently in random order (p = .2, novels) and one sound frequently (standard). Novels were 32 high arousing negative sounds and 32 moderately arousing neutral sounds chosen on the basis of a pilot-study. For the pilot-study, 210 pleasant, unpleasant, and neutral environmental sounds were selected from the International Affective Digitized Sounds (Bradley and Lang, 2007), from a study by Hasting et al. (2010), and from www.thefreesoundproject.org. Sounds were up-sampled to 44100 Hz if required, and cut to 500 ms duration including a 5 ms rise- and a 5 ms fall- time (raised-cosine function). Loudness was equalized with root mean square normalization. Sounds were presented at approximately 65 dB (SPL) via headphones (Sennheiser HD 25-1). Ten additional participants rated each sound for valence (unpleasant – neutral – pleasant), and arousal (calm – arousing), identified the sounds, and rated their confidence in identification (very uncertain- rather uncertain-rather certain-very certain). Valence and arousal was rated on 9-point scales with the Self-Assessment Manikins (Hodes et al., 1984; Bradley & Lang, 1994). Confidence was rated on a 4-point scale. The assignment of start and end points of scales was counterbalanced across participants. The selected sounds for the main experiment comprised various non-speech sounds of different categories (Table 1, Appendix). A section of a gong of a bell was chosen as the frequently presented standard sound (Wetzel, et al., 2012) while all other sounds were repeated four times throughout the experiment.

Procedure

Participants sat in a sound attenuated cabin about 1 meter from a computer screen. The task was to discriminate drawings of animals and clothes by button presses with the right middle and index finger (two-alternative forced choice task). Button assignment was counterbalanced across participants. Participants practiced the task with all 20 drawings and no sounds.

Stimuli were presented in two blocks with different sound-target intervals: overlapping and non-overlapping. Half of participants started with the overlapping interval and the other half with the non-overlapping interval. In the non-overlapping block, task-irrelevant sounds and drawings (targets) were presented with a 600 ms mean stimulus onset asynchrony (SOA). Thus, sounds (500 ms duration) and target onset did not overlap. In the overlapping block, the mean SOA was 300 ms, that is the onset of visual targets fell within the presentation window of sounds. In order to keep the task equally difficult across both sound-target intervals, the mean target-onset to target-onset interval was kept identical (1600 ms, Figure 2). For this purpose the interval between target onset and the onset of the forthcoming sound (if there was one) was fixed to 1300 ms in the overlapping version and to 1000 ms in the non-overlapping version. Half of participants completed both versions with informative sounds and the other half with uninformative sounds. Informative and uninformative sounds differed in their relevance to detecting the target. Informative sounds reliably predicted occurrence and onset of visual targets. Each sound was followed by a drawing (100% probability) with a fixed SOA (overlapping sound-target interval: 300 ms, non-overlapping sound-target interval: 600 ms). Contrary, target appearance and onset were not predictable by uninformative sounds. A drawing followed only 50% of sounds and sound-target SOA randomly jittered around the mean SOA in 50 ms steps (overlapping sound-target interval: 200, 250, 300, 350, and 400 ms; non-overlapping sound-target interval: 500, 550, 600, 650, and 700 ms; equally distributed). Please note that even though informative sounds signaled target occurrence, they had no implications for the categorization task.

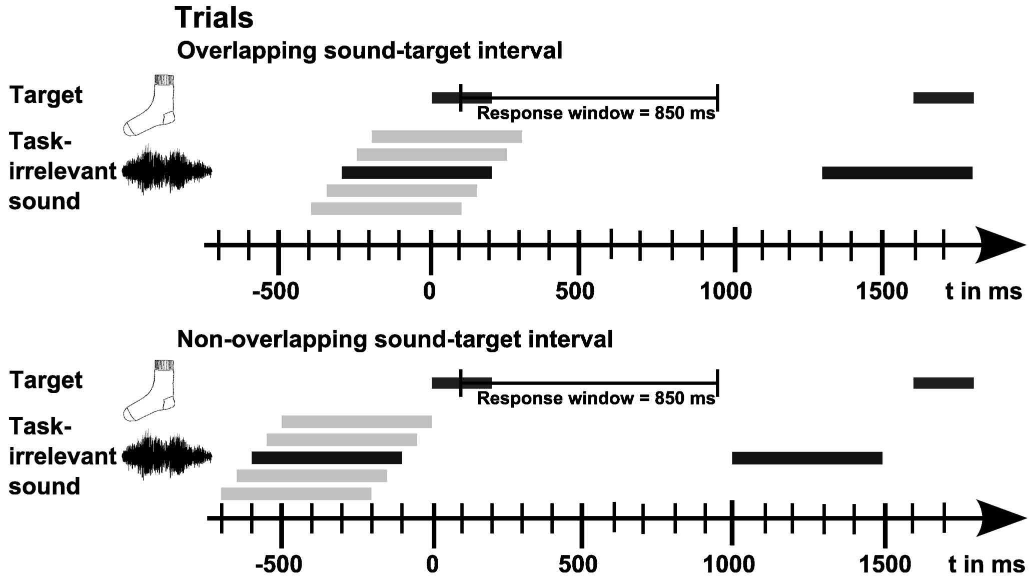

Figure 2. Trial structure. Trials with overlapping and non-overlapping sound-target intervals were presented with either informative (long black bar) or non-informative sounds (grey bars). Informative sounds always preceded targets with a fixed sound-target interval (overlapping version: 300 ms, non-overlapping version: 600 ms) and thus, predicted onset and occurrence of visual targets. Non-informative sounds only preceded half of the targets and sound-target intervals jittered. Mean target-to-target interval was kept constant (1600 ms).

Participants performed four successive blocks with overlapping and for blocks with the non-overlapping sound-target interval version. Order of interval versions was counterbalanced. Each interval version contained 64 neutral and 64 negative novel trials (16 unique neutral and negative novels per block, respectively) and 512 standard trials. Novels were presented randomly except that at least two standards followed a novel and one block separated a novel repetition (one repetition of a novel per interval-version). A block started with at least two standard sounds in order to allow building up a memory trace.

After the experiment we presented sounds again in random order. Participant rated sound valence (negative 5-neutral 1), and arousal (high arousing 5- neither calm nor arousing 1), identified sounds by naming them, and stated their confidence in identification (very sure 1- very unsure 5) according to the procedure described by Mecklinger et al. (1997). We used five-point scales for valence and arousal ratings because we included only unpleasant and neutral sounds and because all sounds were evaluated as at least moderately arousing in the pilot study. Please note that a discrepancy between arousal ratings of neutral sounds and neutral pictures, with pictures being commonly rated as low in arousal (i.e. with means smaller than three on a nine-point scale), was already reported by Bradley and Lang (2007) for the International Affective Digitized Sounds. Only one of these 167 sounds has a mean arousal of less than three (2.88, a yawn). Finally, participants completed the German version (Wiltink, Vogelsang, & Beutel, 2006) of the Effortful Control Scale of the short from of the Adult Temperament Questionnaire (Evans & Rothbart, 2006), the German version of the State-Trait Anxiety Inventory (Laux, Glanzmann, Schaffner, & Spielberg, 1981), and the German version (Hautzinger, Keller, & Kühner, 2009) of the Beck Depression Inventory (Beck, Steer, & Brown, 1996). The experiment including breaks lasted about 45 minutes and the whole sessions about 1.5 hrs.

Analysis

Reaction times and hit rates for the picture categorization task were calculated separately for standard trials and negative and neutral novel trials. In order to analyze the modulation of distraction/ facilitation by novels' emotional arousal, the respective novel-minus-standard differences were calculated and subjected to repeated measures analysis of variance (rmANOVA) with the between-participant factor information (informative, non-informative) and the within-participant factors arousal (moderate, high) and sound-target interval (overlapping, non-overlapping). The first two standard trials in a block and the first two trials following novel trials were excluded from analysis. Further, only trials which were correctly answered within a time window from 100 ms to 950 ms after picture onset were counted as hits and taken into account for the reaction time analysis. The alpha level was set to .05. The influence of anxiety, depression, and effortful control on the emotional arousal effect was analyzed by means of Spearman's rank correlation. For this purpose we calculated the emotional arousal effect as the difference in reaction times and hit rates between negative and neutral trials.

Results

Sound ratings

Following the experiment participants evaluated sounds (Table 1). As expected neutral novels differed significantly in their valence and arousal ratings from negative novels, independent t-test, valence $t(63) = 12.8$, $p < .0001$, arousal $t(63) = 10.8$, $p < .0001$, but not in how well they could be identified, $p = .42$. The sound used as the repeatedly presented standard (gong of a bell) was of neutral valence (4.0) with moderate arousal (1.8).

Table 1. Mean results of the post-experimental rating (n = 48 participants) for novel sounds. Sounds differed in their valence and arousal ratings (t-test: ***$p < .0001$), but not in how confident participants were in identifying them ($p = .42$). See Appendix for a list of all sounds.

	Neutral (SD)		Negative (SD)
Valence	mean = 4.01 (0.6)	***	mean = 2.2 (0.6)
Arousal	mean = 2.1 (0.4)	***	mean = 3.3 (0.5)
Identifiability	mean = 2.9 (0.6)		mean = 2.8 (0.6)

Scales: valence (unpleasant 1 - neutral 5), arousal (neither arousing nor calm 1 - arousing 5), confidence in identification (very uncertain 1 - very certain 4), SD = standard deviation.

Reaction times and hit rates

As expected, participants responded faster when sounds were informative and signaled onset and occurrence of targets (Table 2; Parmentier, et al., 2010; Wetzel, et al., 2012). In order to analyze performance in the categorization task as a function of arousal we calculated novel-minus-standard differences separately for negative and neutral novel trials, informative and non-informative sounds, and overlapping and non-overlapping sound target intervals, respectively (see Table 2). Repeated measures analysis of variance (rmANOVA) for reaction time differences with the between-subject factor information (informative, non-informative) and the within-subject factors arousal (moderate, high) and sound-target interval (overlapping, non-overlapping) revealed main effects of information, $F(1,46) = 13.4$, $p = .001$, and arousal, $F(1,46) = 5.2$, $p = .027$. The main effect of information was due to larger distraction elicited by informative novels (11.98 ms) as compared with uninformative novels (−0.05 ms). The main effect of arousal reflects reduced distraction in high arousing negative (3.9 ms) relative to moderately arousing neutral novel trials (8 ms), that is participants categorized pictures on average about 4 ms faster in negative trials. Sound-target intervals did not significantly modulate distraction effects, $F(1,46) = 2.7$, $p = .107$. Importantly, the interaction of information and arousal was not significant, $F(1,46) = 0.6$, $p = .44$, and no further interaction reached significance, information and sound-target interval $F(1,46) = 0.1$, $p = .73$, arousal and sound-target interval $F(1,46) = 0.2$, $p = .68$, information and arousal and sound-target interval $F(1,46) = 0.9$, $p = .36$.

Mean hit rate was 97%. As shown in table 3, participants were more accurate when sounds were non-informative. The rmANOVA for the respective novel-minus-standard hit rates revealed a main effect of information $F(1,46) = 5.8$, $p = .02$, which was due to higher accuracy in informative relative to uninformative novel trials (about 1%). There was also a trend towards a significant main effect of sound-target interval, $F(1,46) = 3.4$, $p = .07$, pointing at higher hit rates when sound and target onset overlapped. The arousal effect was not significant ($F(1,46) = 0.4$, $p = .53$) and no interaction reached significance (all $p < .2$).

Table 2. Reaction times (ms).

	Negative novel	Neutral novel	Standard	Difference (negative-standard)	Difference (neutral-standard)
Informative sounds					
Overlapping interval	453.8	458.3	446.8	6.7	11.5
Non-overlapping interval	452.2	458.7	440.7	11.5	18
Non-informative sounds					
Overlapping interval	476.2	481.5	480.7	−4.5	0.8
Non-overlapping interval	491.2	491.2	489.5	1.7	1.8

Table 3. Hit rates (%).

	Negative novel	Neutral novel	Standard	Difference (negative-standard)	Difference (neutral- standard)
Informative sounds					
Overlapping interval	97.5	97.3	96.1	1.4	1.2
Non-overlapping interval	96	96.1	95.4	0.6	0.7
Non-informative sounds					
Overlapping interval	98.4	98.6	98.3	0.1	0.3
Non-overlapping interval	98	97.2	98	0.09	−0.7

Influence of effortful control and subclinical anxiety and depression

We used the negative-minus-neutral novel difference to measure the emotional arousal effect. The reduction of reaction times in negative as compared with neutral trials was significantly related to effortful control, $r_s = .35$, $p = .015$. That is, participants scoring low in effortful control showed the greatest reaction time benefit in negative relative to neutral novel trials (Figure 5, Panel A). No other correlation reached significance (all $p < .1$). Analysis of the emotional arousal effect as reflected in hit rates was negatively correlated with state anxiety, $r_s = -.42$, $p = .003$, trait anxiety, $r_s = -.42$, $p = .003$, and with depression, $r_s = -.39$, $p = .007$, showing that participants scoring low in anxiety and depression were more likely to benefit from negative as compared with neutral novel trials, that is to increase accuracy (Figure 5, Panel B). General distraction effects by informative novels were not related to individual differences (Table 4).

Table 4. Spearman's rho correlation coefficient for the correlation of effortful control, subclinical anxiety and depression with reaction time differences for the distraction/faciliation effect (novel-standard) and the effect of emotional arousal (negative-neutral). *$p > .05$, **$p < .01$.

	Difference (novel-standard)		Difference (negative-neutral)	
	Reaction time	Hit rate	Reaction time	Hit rate
Effortful control	.103	.026	.349*	.202
State anxiety	−.038	.111	−.236	−.422**
Trait anxiety	.022	−.08	−.159	−.421**
Depression	−.014	−.054	−.187	−.389**

Discussion

Most research on the impact of emotional distraction on behavior focusses on the fact that task-irrelevant emotional stimuli trigger enhanced attentional orienting, often at the cost of concurrently presented neutral targets. However, more arousing emotional stimuli may also yield benefits because they increase phasic alertness and enhance response readiness and thus, improve performance in an unrelated task. Here, we aimed to separate benefits by arousal and costs of attentional orienting. We contrasted performance in a picture categorization task as a function of novels' emotional arousal (moderately arousing neutral, high arousing negative) and informational content of sounds regarding onset and occurrence of preceding pictures (informative, non-informative). Novels were environmental sounds, such as screeching tires (negative) or a ringing telephone (neutral), and presented as oddballs ($p = .1$, respectively) amongst a repetitive neutral standard sound (gong of a bell).

Nonspecific benefits of arousal

Do task-irrelevant negative novels facilitate or distract performance in the visual task? Negative as well as neutral novels yielded distraction in the current paradigm. Importantly, the main effect of novel type shows that negative novels cause less distraction than neutral novels (−4.1 ms on average), irrespective of whether they were informative with respect to the target (Figure 3, Panel B). This supports the hypothesis that alertness causes a non-specific bias towards facilitation. Wetzel et al. (2012) found that unexpectedly occurring task-irrelevant environmental novel sounds, relative to meaningless bursts of white noise (deviants), yield faster responses. They suggested that this bias towards facilitation by novels is due to a stronger activation of the locus coeruleus-norepinephrine (LC-NE) system because of novels' greater motivational significance (Nieuwenhuis, 2012). LC-NE system activity has been related to improved response readiness and thus, faster reaction times (e.g. Aston-Jones & Cohen, 2005). Our results support the proposed hypothesis since they show that high arousing negative relative to moderately arousing neutral novels improve performance and reduce distraction effects. Other authors (e.g. Kanske, 2012; Pessoa, 2009) suggested that a key factor determining the direction (hindering or facilitating) of the impact of emotional distracters is task relevance. The reasoning is that peripherally presented, task-irrelevant emotional distracters capture attention away from the main task and leave fewer resources for target processing. In our paradigm emotional stimuli and targets were presented separately in different modalities. Sounds were always irrelevant for the categorization task. Thus, our results show that task-irrelevant emotional stimuli might also yield benefits of arousal. Hence, the alerting effect needs to be taken into account when determining whether task-irrelevant emotion hinders or facilitates task performance.

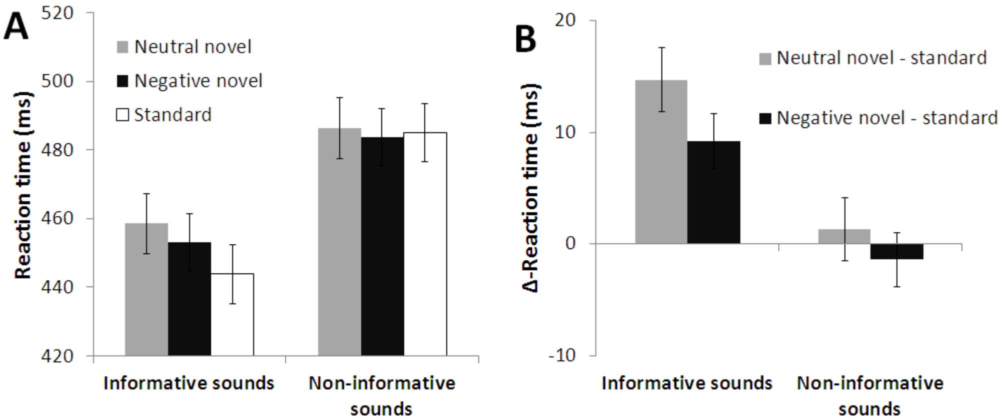

Figure 3. Reaction times. Data are averaged over the non-significant factor sound-target-interval. Panel A shows that information speeded up reactions and Panel B shows the modulation of distraction/facilitation by the factors information and arousal: 1.) informative novels yielded enhanced distraction, and 2.) responses in negative novel trials were faster than in neutral trials irrespective of information. Factors did not significantly interact. Error bars show two standard errors of the mean (one up, one down).

The beneficial effect of arousal is also in line with results by Ljungberg and Parmentier (2012). The authors investigated how valence and intonation of words modulate performance in a visual categorization task. Urgently spoken novel words relative to calmly spoken words decreased distraction effects in a visual task whereas valence did not affect performance. Subjective ratings regarding urgency supported their findings, with urgent words being perceived as more arousing than non-urgently spoken words. This also points to the possibility that it might be motivational relevance per se rather than emotion that triggers the beneficial effect. Furthermore, it remains an interesting question for future research where the beneficial effect of negative novels originates. For example Phelps et al. (2006) found evidence for enhanced contrast sensitivity in the presence of emotional stimuli. They concluded that "people actually see better in the presence of emotional stimuli" (p. 7), giving raise to the opportunity that emotionally arousing novels might not only heighten response readiness but also directly facilitate visual stimulus processing, leading to faster categorization of pictures.

We further found no evidence for a modulation of the novel type effects by sound-target interval. Zeelenberg and Bocanegra (2010) compared effects of task-irrelevant visual and auditory emotional cues on performance in an unrelated task. They found that spoken emotional distracter words improved identification accuracy whereas accuracy was reduced when words were presented visually. The authors suggested that temporal competition is reduced when distracters are presented in a different modality, leading to the facilitating effect of emotion. We modulated temporal competition by presenting sound and target with an overlapping interval (300 ms SOA) and a non-overlapping interval (600 ms SOA). That there was no significant modulation of the novel type effect by sound-target interval implies that a 300-ms SOA was already sufficient to extract the motivational significance of sounds and to modulate behavioral performance. This is in line with an ERP study on emotional sound processing by Czigler et al. (2007). The authors suggested that physical cues inherent in negative sounds may activate a broader neural network including limbic structures already after 150 ms. Appraisal and further evaluation of negative sounds were suggested to be reflected in a later positive potential, starting from about 370 ms after stimulus onset.

General benefits by information and specific costs of attentional orienting

As expected, informative relative to uninformative sounds generally speeded up responses (−41.3 ms), showing that information about target onset and occurrence is used by the participants in order to optimize behavior (Figure 3, Panel A). Furthermore, only informative novels (negative and neutral) yielded prolonged reaction times in the picture task as compared with standard sounds, as shown by a main effect of information for distraction effects (Figure 3, Panel B). This replicates results of previous studies (Parmentier, et al., 2010; Wetzel, et al., 2012) and is in line with the idea that novels call for attention (e.g. Escera, et al., 2003) which may in turn draw attentional resources away from the visual task and impair performance. Uninformative sounds, however, do not have to be processed so intensely since they do not carry any information related to the task or to the target, so that the cognitive system can more effectively shield itself from distractor-related processing (Wetzel, et al., 2012). Distraction effects by informative novels (12 ms on average) were counteracted by increased hit rates (about 1% on average, Table 3). Whereas Wetzel and colleagues (2012) reported no significant increase in hit rates by informative novels, Parmentier (2010) reported significant facilitation by informative deviants (bursts of white noise) when only deviants (and not standards) were informative. Thus, information may have either none or a slightly facilitating influence on accuracy in novel relative to standard trials.

A quantification of benefits of emotional arousal and information and costs of orienting

Further, we were asking whether the novel type effect is contingent upon novels' target-relevance. We take the missing interaction of information and arousal (given the very low F-value) as indication that target relevance and motivational significance are evaluated independently. In other words, motivational significance seems to be evaluated even when novels do not yield impaired performance since they are non-informative with respect to the target. This is an interesting finding since it suggests that the control of distraction by non-informative novels occurs after the motivational significance of a sound has been determined.

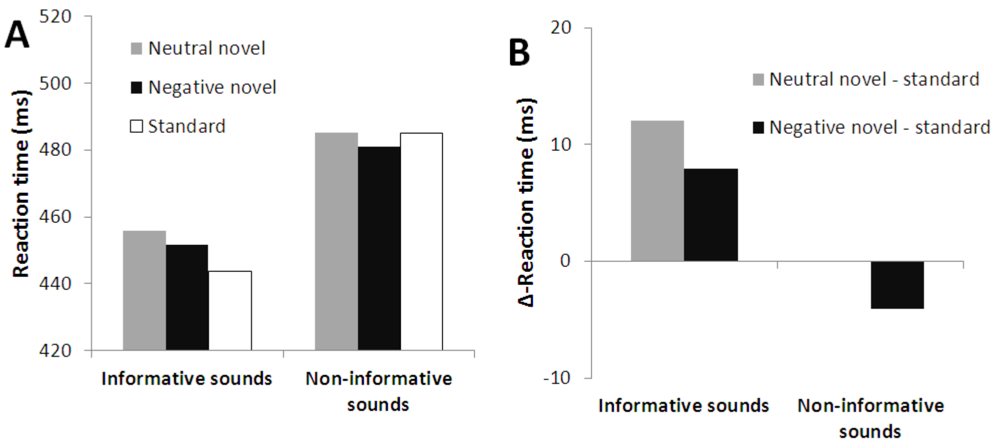

Figure 4. Reaction times (Panel A) und distraction/facilitation effects (Panel B) according to a linear a posteriori model. We estimated non-specific benefits of increased arousal in trials with high arousing negative novels (−4.1 ms), benefits of information (−41.3 ms) and costs of attentional orienting for non-informative novels (12 ms) as parameters for the model. Predicted reaction times well explain the observed pattern of results (Figure 3).

Similar as suggested by Wetzel et al. (2012), the observed pattern of reaction times in this paradigm can mostly be explained by three relevant variables: by benefits of emotional arousal and information and by costs of attentional orienting. We quantified the effects and used them as parameters for a linear model.

For simplicity data were pooled over both sound-target intervals, since reaction times were not significantly modulated by this factor. We estimated the specific benefit of information of −41.3 ms as the mean difference between informative and uninformative sounds (averaged across trials with negative novels, neutral novels, and standards). The unspecific benefit of emotional arousal of −4.1 ms was estimated from the mean difference between negative and neutral novel trials (averaged across informative and uninformative sounds) and the specific costs of involuntary attentional orienting of 12 ms were estimated as the mean difference between novel (averaged across negative and neutral novel trials) and standard trials in the informative condition. We took the reaction time in uninformative standard trials (485 ms) as a baseline. Figure 3 shows the modeled pattern of reaction times which well predicts the observed results (Figure 4).

Influence of individual differences in anxiety, depression, and effortful control

Participants scoring low in depression and anxiety benefitted most from trials with negative relative to neutral novels with respect to accuracy. In other words, low anxiety and depression were associated with greater accuracy in the categorization task when negative novels preceded pictures. In contrast, high anxiety and depression were associated with poorer accuracy in trials with negative novels (Figure 5, B). This fits the assumption by attention control theory that subclinical anxiety may lead to a deficient evaluation of emotional stimuli, reflected in enhanced attention to negative emotion and lowed disengagement (Eysenck, Derakshan, Santos, & Calvo, 2007). While there was no correlation of reaction time with anxiety or depression, effortful control was positively related to the negative-minus-neutral novel difference. Low scores in effortful control were associated with faster reactions in negative relative to neutral trials whereas for high scores this difference was on average smaller (figure 5, A). High effortful control is associated with high self-regulating abilities. These are the abilities to focus attention on desired stimuli, especially in the presence of emotional distraction (Evans & Rothbart, 2006) and to inhibit pre-potent emotional reactions and action tendencies (Wiltink, et al., 2006). Thus, one speculative explanation might be that individuals scoring high in effortful control could not only better control attentional orienting to emotional distractors, but also activation by emotional arousal leading to the reduced reaction time benefit in trials with negative relative to neutral novels. Correlations were not significant for the general distraction effect, suggesting that subclinical differences in anxiety, depression, or effortful control did not modulate distraction per se.

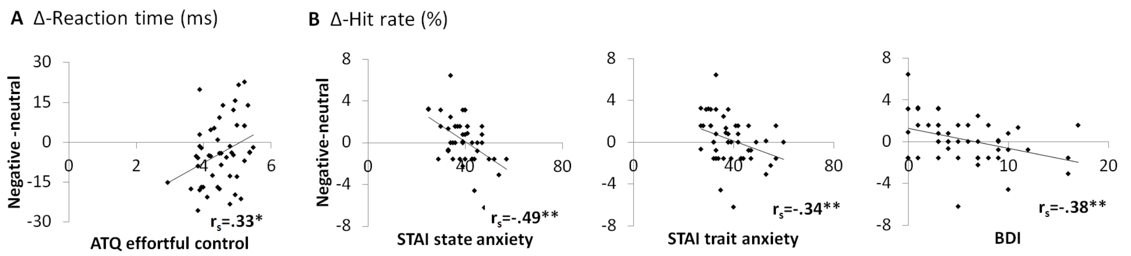

Figure 5. Significant correlations of negative-minus-neutral novel differences with scores in effortful control and subclinical anxiety and depression. Panel A: Individuals scoring low in effortful control showed the greatest reaction time benefit from emotional arousal. Panel B: Hit rate was negatively correlated with anxiety and depression, indicating that less anxious and depressive individuals were more accurate in trials with negative novels whereas individuals scoring high in anxiety and depression were more accurate in trials with neutral novels. Please note that positive values in reaction time reflect slower responses in trials with negative novels (costs), whereas positive values in hit rates reflect increased accuracy in trials with negative novels (benefits). *$p > .05$, **$p < .01$.

Conclusion

In sum, both novel types impaired performance in the picture-categorization task. However, high arousing negative relative to low arousing neutral novels cross-modally reduced this distraction effect. Thus, data supports the assumption that performance in novel trials results from costs of attentional orienting when sounds are informative and non-specific benefits of arousal. The fact that benefits of arousal are independent of the novels' target relevance suggest that distraction by non-informative novels is controlled after their motivational significance has been determined. This is in line with the idea of a prioritized processing of motivationally significant stimuli.

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