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# Emotional processing modulates attentional capture of irrelevant sound input in adolescents

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ABSTRACT

The main goal of this study was to investigate how emotional processing modulates the allocation of attention to irrelevant background sound events in adolescence. We examined the effect of viewing positively and negatively valenced video clips on components of event-related brain potentials (ERPs), while irrelevant sounds were presented to the ears. All sounds evoked the P1, N1, P2, and N2 components. The infrequent, randomly occurring novel environmental sounds evoked the P3a component in all trial types. The main finding was that the P3a component was larger in amplitude when evoked by salient, distracting background sound events when participants were watching negatively charged video clips, compared to when viewing of the positive or neutral video clips. The results suggest that the threshold for involuntary attention to the novel sounds was lowered during viewing of the negative movie contexts. This indicates a survival mechanism, which would be needed for more automatic processing of irrelevant sounds to monitor the unattended environment in situations perceived as more threatening.


## 1. Introduction

Emotional valence influences how attention is allocated and perceptual information is processed (Cuthbert et al., 1998; Lang et al., 1990, 1998; Wong et al., 2012). Two intertwined systems are proposed to be engaged in perceiving environmental events (Hopfinger and West, 2006; Oray et al., 2002; Sugimoto et al., 2007). One is an exogenous system, generating involuntary responses to external events (e.g., a car honking), and the other is an endogenous system, driving responses to the environment by a current internal state (e.g., sadness). The manner in which these interacting systems are modulated by emotional state is not fully clear.

Imagine being in a darkened movie theater, watching the protagonist on the screen clamber to the end of a long hallway, unaware that the enemy waits just around the corner. Suddenly, "crinkle, crinkle", the sound of your seat mate opening a candy bar and you jump out of your seat. In all likelihood, any salient, unexpected sound occurring during this type of heightened state would lead to a similar response. That is, the negative valence induced by the context of the movie would affect the exogenous response to an irrelevant sound event (Cuthbert et al., 1998; Lang et al., 1990). The purpose for a mechanism that lowers the threshold for detecting unattended sensory information is to expeditiously alert to potentially threatening events. External events are more likely to be perceived as imminent during a portentous situation or negative emotional state. However, evidence to the contrary suggests that any emotional state (negative or positive) lowers the threshold for detecting unattended environmental events when compared to a neutral state (Cuthbert et al., 1998; Keil et al., 2002; Smith et al., 2003). The purpose of the current study was to test the influence of a visually induced emotional state, such as described in the example of the movie theater, in altering neurophysiologic processes of sound detection for irrelevant but attention-capturing auditory events. To that end, we tested the hypothesis that a negatively induced state lowers the threshold for detecting unattended sound events compared to positive or neutral states.

Processing irrelevant auditory events can be affected by the context in which they are heard (Alexandrov et al., 2007; Domínguez-Borrás et al., 2008; Johnson and Zatorre, 2005; Katayama and Polich, 1998; Sussman and Steinschneider, 2006; Wronka et al., 2008), and by the emotional state of the induced context, even if the irrelevant sounds themselves do not carry any particular emotional value (Alexandrov et al., 2007). Moreover, negative emotional stimuli have been shown to garner an attentional bias, in that responses to negatively charged information are processed more automatically than positively charged (Alexandrov and Sams, 2005; Alexandrov et al., 2007; Carretié et al., 2001; Domínguez-Borrás et al., 2008; Eastwood et al., 2003; Hajcak and Olvet, 2008; Hansen and Hansen, 1988; Lang and Bradley, 2010; Pratto and John, 1991; Schupp et al., 2004, 2007; Smith et al., 2003).

There are contradictory results, however, regarding the effects of emotional state on brain processes associated with unattended sound detection. Specifically with regard to whether emotional engagement

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enhances or detracts from exogenous processing of unexpected input. Activation of more extensive brain areas and larger amplitude responses during emotional engagement induced by external input have been reported (Cuthbert et al., 1998). This enhancement of brain responses has been demonstrated in larger amplitude event-related brain potentials (ERPs), such as P1 (Smith et al., 2003), N1 (Keil et al., 2002; Sugimoto et al., 2007; Suzuki et al., 2005), P2 (Sugimoto et al., 2007), and P3 (Fichtenholtz et al., 2007; Keil et al., 2002). Although a negative response bias has been repeatedly demonstrated by response enhancement occurring only for negatively charged input compared to positive and neutral (Alexandrov et al., 2007; Domínguez-Borrás et al., 2008), other studies have shown that any emotionally charged input (positive and negative) produces enhanced responses compared to neutral or other control-type stimuli (Keil et al., 2002; Smith et al., 2003; Surakka et al., 1998). Moreover, differential timing effects of response enhancement have additionally been demonstrated. Some of the studies showed only early effects, reflected in enhancement of the P1 (Smith et al., 2003) or the N1 components (Cuthbert et al., 1998; Sugimoto et al., 2007); others showed only later enhancement effects reflected in the P3 component (Fichtenholtz et al., 2007); whereas others demonstrated both early and late enhancements to irrelevant stimuli (Keil et al., 2002). Some of the disparities among results of these studies are likely due to the considerable variation in experimental paradigms used to engage emotion in participants.

Response reductions, rather than enhancements, to irrelevant stimuli have also been reported (Oray et al., 2002; Rosenfeld et al., 1992; Suzuki et al., 2005; Vardi et al., 2006). In these studies, reduction of evoked responses was attributed to an attention bias, suggesting that attention to emotionally charged stimuli reduced the exogenous responses rather than enhanced them (Suzuki et al., 2005; Rosenfeld et al., 1992; Vardi et al., 2006). Suzuki et al., for example, found that when subjects viewed video clips that were 'interesting', the P3 amplitude was reduced compared to when the viewed video clips were neutral. They suggested that less attention was allocated to the irrelevant sound probes when the clips were interesting compared to when they were not, which then resulted in a smaller P3 component amplitude during viewing of the interesting clips.

Responses to irrelevant auditory events can reflect the ability to regulate ones' actions (Andrés et al., 2006). Neural mechanisms associated with self-regulation are subject to maturational changes that extend into adolescence, and are thought to depend on the interaction between affect and cognitive control (Berger et al., 2007; Dolcos and McCarthy, 2006; Ladouceur et al., 2010; Posner and Rothbart, 1998). Emotions have also been shown to impair cognition (Dolcos and McCarthy, 2006; Singhal et al., 2012), which could have detrimental effects during development. In line with this, cognitive and behavioral disorders in adolescence have reportedly involved interactions between emotional and attentional states (Dolcos and McCarthy, 2006; Singhal et al., 2012). To delineate the aspects of attentional control that may be aberrant in clinical populations it is necessary to first identify links between specific types of attention, in this case attentional capture, and emotional engagement in non-affected adolescents. The continued changes in neural activity to sounds, neurophysiologically observed during adolescence (Ponton et al., 2000; Sussman et al., 2008), further illustrates their potential as a unique age group for investigating the development of attention and emotions.

The current study tested the hypothesis that unattended environmental events garner attention depending upon the type of context that induces an emotional state. Participants watched video clips and rated them according to whether they were perceived as negative, positive, or neutral. Novel environmental sounds were presented randomly among standard sounds and used to investigate how perceived emotional state influences processing of attention-capturing irrelevant sound events via the P3a component of ERPs. ERPs elicited by the standard tones were additionally used to assess the obligatory responses (P1, N1, P2, and N2 components) during viewing of the different types of video clips. We predicted that emotional processing would alter the threshold for detecting unattended sounds, such that a negatively induced state would produce the most heightened automatic surveillance of the unattended background, consistent with the idea of a survival mechanism. When in a threatening situation, a higher degree of vigilance is needed to assess threatening events. Thus, we expected that ERP indices would be more robust during negative viewing than less threatening situations perceived as positive or neutral.

## 2. Methods

### 2.1. Participants

Twelve healthy adolescents, ages 15–21 years (8 males) volunteered into the study. Participants over 18 years gave informed consent. Participants under 18 years gave written assent, and their accompanying parents gave written consent after the protocol was explained to them. The protocol was approved by the Committee for Clinical Investigations at the Albert Einstein College of Medicine where the study was conducted, and all procedures were carried out according to the Declaration of Helsinki.

Participants were right handed and had no reported history of neurological disorders, were in age-appropriate grades in school, and no report of special educational services. All participants passed a hearing screen (hearing threshold ≤20 dB HL for pure tones at 500, 1000, 2000, & 4000 Hz, bilaterally) and were paid for their participation ($10 per hour). Two participants' data were rejected due to excessive EEG artifact. The data from the remaining ten participants are reported ($M = 17$ years).

## 3. Stimuli

### 3.1. Visual stimuli

Video clips were excerpted from Disney™ films that had a G rating according to the Motion Picture Association of America (meaning that the movie is appropriate for audiences of all ages), using Microsoft Windows Movie Maker (2007, Version 5.1). The clips were chosen to evoke a positive, neutral, or negative feeling in participants. Clips with negative valence included images of mild violence or lamentation; those with positive valence included images of merriment and smiling characters; and those intended to be neutral, to evoke no emotion, contained images of abstract art or nature (Fig. 1). Clips were played silently for approximately 40 s each. To verify the association between the video clip and intended emotion to be evoked, a behavioral pilot test was conducted in which nine participants, none of whom participated in the main study, rated 90 video clips as either evoking a positive, neutral, or negative feeling. Fifty-four of the 90 video clips were used in the main experiment, those that demonstrated at least 88% agreement in the emotions they evoked.

Sound sequences (described below) were paired with the video sequences (Fig. 1). The paired video clips were presented in a randomized order across the three trial types (positive, negative, and neutral) in six stimulus blocks. The order of the six blocks was also randomized in presentation across participants. During the experiment, each of the video clips was separated by a blank screen of approximately 5 s. No sounds were presented during the blank screen period (Fig. 1).

### 3.2. Auditory stimuli

Three auditory stimuli were used, two pure tones and one complex environmental sound. The two pure tones differed in frequency and probability. One tone had a frequency of 880 Hz ($p = 0.80$) and the other a frequency of 988 HZ ($p = 0.10$). Tones were created using Adobe Audition® 1 software (Adobe Systems, Inc., San Jose, CA). The environmental sounds ("novels", $p = 0.10$) were sounds from nature and