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The effects of emotionally salient unimodal and multimodal stimuli on low-level visual perception

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Abstract

Sensory information can both impair and enhance low-level visual feature processing, and this can be significantly modulated depending on whether this information matches the visual sensory modality. Emotionally significant visual and auditory stimuli can have opposing effects on attention. While task-irrelevant emotionally salient visual stimuli can often impair task attention, task-irrelevant emotionally salient auditory stimuli have been shown to enhance aspects of attention. To date, no study has directly compared how emotionally salient information presented to different sensory modalities can affect low-level vision. Using Gabor patches of differing contrasts to measure the threshold of visual perception, we hypothesized that emotionally salient visual stimuli would impair low-level vision, while emotionally salient auditory stimuli would enhance low-level vision. We found that sensory modulation may be dependant on matched sensory domain presentation, as visual emotional stimuli impaired low-level vision, but emotional auditory stimuli did not affect low-level vision.

Keywords

emotional attention, emotional distractors, psychophysics, visual perception, affective neuroscience, cognitive neuroscience, unimodal, multimodal, biased competition.

Co-Authorship Statement

All experimental work was performed by Stephen Pierzchajlo except for the following:

As my supervisor, Dr. Derek Mitchell greatly contributed to all components of both experiments I performed for my thesis. This included consultation when designing the tasks for Experiment 1 and Experiment 2, acquiring the data, analysis and interpretation, manuscript preparation, and editing.

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- Tamara Tavares selected and gathered statistical data for the visual and auditory stimuli that were used for Experiment 1 and Experiment 2.
- Rebecca Kozak helped with some technical aspects for generating the Gabor patches for Experiment 1 and Experiment 2.

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CHAPTER 1

1 Introduction

The human nervous system is equipped to simultaneously process many stimuli through the integration of multiple sensory modalities (Shams & Kim, 2010). However, vision is traditionally considered the dominant human sense (Colavita, 1974), and visual perception allows for the decoding of sensory information very efficiently. While stimulus properties like object size (Jonides & Yantis, 1988) or movement (Treisman & Gormican, 1988) may aid in attending to important visual cues in the environment, emotionally salient visual stimuli are especially good at capturing attention and influencing behaviour. For instance, a car accident occurring in a person's periphery might prime the visual and motor systems to respond rapidly to the sudden danger cue. Likewise, the sound of an ambulance behind a car, even in the absence of any visual cue, could prime the driver to respond vigilantly to find a route out of its path. While the impact that emotionally salient visual stimuli have on visual attention has been studied extensively in the past few decades (Yiend, 2010), the extent to which emotionally salient auditory stimuli might differentially influence visual perception remains much less clear (Schirmer & Kotz, 2006).

1.1 Visual and auditory attention

According to the biased competition model of attention (Desimone & Duncan, 1995), visual stimuli encountered in daily life are not processed additively, nor can the brain continue to process multiple visual stimuli with an infinite amount of processing power. Rather, visual stimuli are treated by the brain as mutually inhibitory competitors: Each additional visual stimulus sharing the candidate stimuli's visual space is considered for neural representation by competing with it for the brain's limited visual processing resources. When two visual stimuli are identified simultaneously, the net gain associated with the attentionally selected visual stimulus directly facilitates a net loss for the other non-attentionally selected visual stimulus (Olshausen & Anderson, 1995). Attentionally biasing visual features can influence sensory representations of visual stimuli so that the visual properties of the stimuli themselves intrinsically bias neural competition in their favor (Katsuki & Constantinidis, 2014). Likewise, attention related cognitive processes can enhance attention to specific visual features and is motivated by consciously defined visual properties (Noudoost, Chang, Steinmetz, & Moore, 2010).

A large body of both electrophysiology (Britten & Heuer, 1999; Luck, Chelazzi, Hillyard, & Desimone, 1997; Miller, Gochin, & Gross, 1993; Recanzone, Wurtz, & Schwarz, 1997; Reynolds, Chelazzi, & Desimone, 1999; Rolls & Tovee, 1995; Snowden, Treue, Erickson, & Andersen, 1991) and neuroimaging (Beck & Kastner, 2007; Kastner, De Weerd, Desimone, & Ungerleider, 1998; Kastner et al., 2001) literature exists supporting the notion that simple properties of visual stimuli bias attention for their neural representation in the visual cortex. For instance, line orientation (Lavie & Driver, 1996), the size of the stimulus (Jonides & Yantis, 1988), the context of a visual scene (Bundesen & Pedersen, 1983) or whether the stimulus is moving (Treisman & Gormican, 1988) can all enhance visual competition. Additionally, visual competition has been shown to affect early visual processing areas of the brain including V1/ V2/VP, V4, TEO, V3A, and area MT (Beck & Kastner, 2009).

Top-down visual attention refers to the cognitive demands of a task or the motivation of the participant and exists irrespective of, or in addition to, the physical features of the intrinsic attentional biasing of a stimuli (Carrasco, 2011; Corbetta & Shulman, 2002; Kastner & Ungerleider, 2000). For instance, research has shown that people are faster at detecting visual objects already stored in short-term memory (Vecera & Farah, 1997). Likewise, perceptual sets allow people to use instructional information to bias attention to specific features of visual stimuli (Baylis, 1994; Baylis & Driver, 1993; Duncan, 1984; Neisser & Becklen, 1975). While top-down attentional tasks have been shown to affect lower level visual systems like V2/VP, V4, TEO, V3A, and area MT (Kastner et al., 1998), neural regions implicated in higher-order cognition are additionally affected. For instance, prefrontal cortex lesions have been shown to delay working memory performance with visual objects in primates (Curtis, 2006; Fuster, 1997), while the prefrontal cortex is activated during these same tasks in humans (Courtney, Ungerleider, Keil, & Haxby, 1997; Sakai, Rowe, & Passingham, 2002). Areas important for spatial attention, like the intraparietal sulcus and posterior parietal cortex, have been shown to modulate competitive interactions in the visual cortex (Recanzone & Wurtz, 2000; Reynolds et al., 1999). Additionally, the superior parietal lobule and intraparietal sulcus are also implicated in attention of visual stimuli (Beck & Kastner, 2009)**.**

The extent to which attention is influenced by the properties of auditory stimuli has also been investigated. Studies using a wide array of auditory cortex imaging techniques like electro-corticography (Golumbic et al., 2013; Golumbic, Cogan, Schroeder, & Poeppel, 2013; Mesgarani & Chang, 2012), magneto-encephalography (Ding & Simon, 2012a, 2012b; Kerlin, Shahin, & Miller, 2010), and electro-encephalography (Horton, D'Zmura, & Srinivasan, 2013; O'Sullivan et al., 2015) all demonstrate that auditory cortex activation can be biased towards specific auditory stimuli among auditory distractor stimuli (Atiani, Elhilali, David, Fritz, & Shamma, 2009). For instance, a number of studies have shown that auditory cortex activation can be modulated (via attention related frontal regions of the brain) by specific voices among an array of many voices (Ding & Simon, 2012b; Golumbic, Poeppel, & Schroeder, 2013). Additionally, areas of the brain responsible for attentional control (e.g. fronto-parietal network) can also bias attention towards specific auditory stimuli. (Corbetta, Patel, & Shulman, 2008; Snapp-Childs & Corbetta, 2002). For instance, areas of the brain like the ventral (Cromer, Roy, & Miller, 2010; Freedman, Riesenhuber, Poggio, & Miller, 2001) and dorsal (Arnott, Binns, Grady, & Alain, 2004; Cusack, 2005; Teki, Chait, Kumar, von Kriegstein, & Griffiths, 2011; Zatorre, Bouffard, Ahad, & Belin, 2002) prefrontal cortices are activated when participants try to segregate simultaneously presented auditory stimuli from one another. Furthermore, Hausfeld, Riecke, and Formisano (2018) found attention-related activation in the temporal cortex that depended on the stimulus the participant was selectively attending to. Taken together, these studies suggest that attention to auditory stimuli is biased both at the level of the auditory cortex and at the level of attention-related prefrontal areas of the brain in much the same way that visual stimuli are.

Summary: The biased competition model of attention predicts that visual stimuli capture our attention by competing for neural representation in the brain. Visual competition can be driven by physical properties of the stimuli that influence early visual processing systems in the brain. Likewise, attentional influences utilize cognition to bias attention towards specific visual properties and is mediated by higher-order neural regions like the frontoparietal network. Like visual stimuli, auditory stimuli have also been shown to compete for representation in sensory areas associated with auditory processing (like the auditory cortex). This auditory competition can be biased by the input from prefrontal areas as well.

1.2 Emotional visual attention

Emotional visual stimuli intrinsically capture attention, resulting in the elicitation of a state brought about by an aversive/appetitive reinforcer like a spider you avoid or food you crave. Importantly, attentional biases to emotionally significant visual stimuli in this context are thought to be driven by an interaction between the visual/temporal cortex and amygdala (LeDoux, 2000). Likewise, an emotionally salient visual stimulus can be classically conditioned, a process whereby a neutral stimulus is paired with an intrinsically aversive stimulus until the neutral stimulus becomes an aversive stimulus by way of unconscious association (Delgado, Nearing, LeDoux, & Phelps, 2008). In the same way that intrinsic physical properties influence neural responses to capture attention, visual stimuli that come to be associated with valence information can bias attention largely through reciprocal amygdala-temporal/visual cortex feedback loops. This explains why visual stimuli gain their emotional saliency and capture our attention so efficiently: their visual neural representations get additional weighting via sensory enhancement (Blair & Mitchell, 2009).

Several authors (e.g. Blair & Mitchell, 2009; Pessoa & Ungerleider, 2003; Vuilleumier, 2005) have hypothesized neural mechanisms that might explain how emotionally salient visual information can further bias neural representations of competing visual stimuli. At baseline, when cognitive motivations are absent only intrinsic properties of a stimulus will capture attention (Desimone & Duncan, 1995). However, when properties of the visual stimulus are emotionally salient, a neural system responsible for emotional attention is thought to be responsible for mediating their effects (Blair & Mitchell, 2009; Pessoa & Ungerleider, 2003; Vuilleumier, 2005). Therefore, the neural representation of an emotionally salient visual stimulus in the visual and temporal cortices activate the amygdala via reciprocal neural connectivity. This amygdala-temporal/visual cortex reciprocity further enhances the neural representation of the emotionally salient stimulus at the cost of representations of other competing visual stimuli (Blair & Mitchell, 2009). In the absence of any cognitive strategy, the emotionally salient stimulus becomes more strongly represented in the brain and at the level of conscious awareness. Evidence suggests that emotional stimuli that capture attention are driven by interactions between the visual cortex, amygdala and orbitofrontal cortex (Anderson & Phelps, 2001; Bar et al., 2006; Lim, Padmala, & Pessoa, 2009), and is not thought to rely on executive attention (i.e., top-down modulation of visual cortex via frontoparietal areas) (Vuilleumier & Driver, 2007; Amting, Greening, & Mitchell, 2010). The influence of emotional stimuli can manifest behaviourally like when, for instance, emotional stimuli are detected faster and more accurately compared to neutral stimuli when they are the target of attention (Yiend, 2010, Fox et al., 2000; Ohman, Lundqvist, & Esteves, 2001). However, emotionally significant visual stimuli can also elicit slower responding when they distract participants during a cognitive task (Schimmack, 2005; Williams, Mathews, & MacLeod, 1996). Even emotionally salient visual stimuli presented in the periphery have been shown to competently bias attention in their favor (Armony & Dolan, 2002; Mogg & Bradley, 1999). Studies like these suggest that, in addition to Desimone and Duncan (1995)'s predictions, intrinsic properties of visual stimuli can include emotionally salient information.

Summary: While visual stimuli can garner emotional significance for many reasons, the amygdala's role in the sensory enhancement of neural competition has been well substantiated in the literature. Just as the biased competition model of attention highlights the important role of attention and competition, emotionally salient visual information can also impact competitive attentional mechanisms.

1.3 Emotional auditory attention

Auditory stimuli are considerably more dynamic than static visual stimuli (Zhao, Sun, Chen, & Yang, 2018), in that they require time to unfold before they can be fully processed. However, the nature of what makes an auditory stimulus emotionally salient has been explored to some extent. For example, amygdala neurons have been shown to respond similarly to emotionally salient facial and vocal stimuli (Kuraoka & Nakamura, 2007; Remedios, Logothetis, & Kayser, 2009), fearful sounds (Kumar, von Kriegstein, Friston, & Griffiths, 2012; Phillips et al., 1998), emotional human voices (Sander & Scheich, 2001, Sander & Scheich, 2005), and negative environmental noises (Zald & Pardo, 2002). While animate emotional visual stimuli evoke very strong amygdala activation (White et al., 2014), animate emotional auditory stimuli have been shown to additionally activate the superior temporal sulcus/superior temporal gyrus (Leaver & Rauschecker, 2010; Lewis, Brefczynski, Phinney, Janik, & DeYoe, 2005; Sharda & Singh, 2012). Sensory characteristics of emotionally salient auditory components can also bias attention in much the same way that emotional components of visual stimuli can (Schirmer & Kotz, 2006).

Happy and sad emotional tones can be decomposed into bottom-up auditory properties like amplitude, timing, and frequency (Banse & Scherer, 1996). These tonal-specific emotional signatures are differentially processed by neural systems responsible for bottom-up auditory processing (Schirmer & Kotz, 2006). The core of the auditory cortex is structured to tonotopically organize bottom-up auditory properties, which means that specific combinations of tones, including tones thought to be more associated with or predictive of emotional events, activate specific neurons in the auditory cortex (Kaas & Hackett, 2000). This suggests that the tonal composition of different bottom-up auditory vocal properties differentially modulate neural firing rates in the auditory cortex (Rauschecker, Tian, & Hauser, 1995). Because properties of auditory stimuli like sound intensity can increase neural firing rates in the auditory cortex (Hart, Hall, & Palmer, 2003), this suggests that the auditory cortex is modulated by sound intensity (Schirmer & Kotz, 2006). Once complex tones are decomposed, the auditory pathway extending from the bilateral superior temporal gyrus to the anterior superior temporal gyrus is thought to encode “what” the auditory stimulus is and is segregated from another pathway responsible for encoding “where” an auditory stimulus is (Liebenthal et al., 2005; Parker et al., 2005; Scott & Wise, 2004). Auditory segregation of the “what” pathway is thought to allow humans to take bottom-up auditory cortex organized tonal patterns and use that information to make evaluations about them (Schirmer & Kotz, 2006).

While neural encoding of emotionally salient auditory stimuli is important, the neural mechanisms involved with visual integration of emotionally salient auditory information can inform how emotional auditory information is integrated with vision. Most of the research exploring this area has largely focused on the integration of visual faces and emotional voices. For instance, Li et al. (2015) compared neural responses in the posterior superior temporal sulcus/medial temporal gyrus (pSTS/MTG) to visual (faces) and auditory (laughing and crying) emotional stimuli either on their own (unimodal), or simultaneously (multimodal). The pSTS/MTG is an area known to be important for audiovisual integration, and the authors found that there was significantly greater activation of the pSTS/MTG during the emotional multimodal condition than during either unimodal condition. The role of the pSTS/MTG in audiovisual emotional integration has been further supported by Muller, Cieslik, Turetsky, and Eickhoff (2012) who used Bayesian model selection via Dynamic Causal Modelling (DCM) with fMRI data where participants looked at faces of different emotions either on their own, or in the presence of an emotional or neutral auditory stimulus. Again, all winning DCM models had bilateral pSTS/MTG influences from the amygdala during multimodal emotional events. Studies like these suggest that visual-auditory integration of emotional stimuli is a very real phenomenon at the neural level, and that there is some important role of the pSTS/MTG in integrating audiovisual emotional information. As will be discussed, the visual system is very apt at integrating auditory information to its advantage.

Summary: The auditory cortex has been shown to respond differentially to bottom-up auditory patterns indicative of different vocal emotions. Segregated neural pathways allow the decoding of the nature and meaning of the auditory stimulus, and only then can we begin making top-down evaluations of the emotional nature of the auditory stimulus.

1.4 Crossmodal auditory enhancement of visual cognition

Another line of inquiry used in auditory attentional processing research has been to investigate how the presence of irrelevant auditory stimuli enhance visual perception. When two stimuli are concurrently presented to different sensory modalities, like simultaneous visual-auditory stimulus presentations, this is often referred to as a crossmodal sensory pairing (Cayco-Gajic & Sweeney, 2018; Jessen & Kotz, 2013; Muller et al., 2012). Visual enhancement during crossmodal stimulus pairings can manifest in various measurable ways, like faster reaction times to visual stimuli in the presence of concurrently presented auditory stimuli (Hollensteiner, Pieper, Engler, Konig, & Engel, 2015) or improved visual perception via greater visual detection accuracy in the presence of irrelevant auditory stimuli (Gleiss & Kayser, 2014). A multitude of studies highlight the advantage that concurrently presented auditory stimuli have on visual perception. For instance, Stein, London, Wilkinson, and Price (1996), found that participants rated a light’s visual intensity more strongly if it was accompanied by an auditory stimulus than when the light was presented by itself. Lippert, Logothetis, and Kayser (2007) replicated this effect, but noted that the auditory-induced visual enhancement was only present when the auditory stimulus was synchronized in time with the visual stimulus. Both Frassinetti, Bolognini, and Ladavas (2002) and Bolognini, Frassinetti, Serino, and Ladavas (2005) found that auditory stimuli that appeared synchronously at the same spatial location as a visual stimulus enhanced perceptual sensitivity of the visual stimulus location compared to when the auditory stimulus appeared at a different spatial location. In fact, even when auditory stimuli are not temporally synchronized with a visual stimulus, participants are still faster at identifying the location of the visual target (Doyle & Snowden, 2001).

One important methodology employed by researchers studying visual perception enhancement is psychophysical curve fitting (Simpson, 1988). Here, researchers pick several nearly identical visual stimuli whose properties differ only in how easily discriminable they are (Kingdom & Prins, 2010). For instance, a researcher might pick a series of Gabor patches (sinusoidal gratings with a Gaussian filter envelope) that become incrementally more visually salient via increases in the Gabor patches visual contrast level. By varying the Gabor patches systematically this way, experimenters can index an individual’s visual perceptual threshold: The halfway point between chance performance (no detection of the Gabor patch) and performance at the highest level of contrast (topped out performance) (Read, 2015). A variety of response methods can be employed to study an individual’s visual perception threshold, each changing various properties of the psychometric function (Figure 1). For example, in an *n*-alternative forced choice paradigm (*n*AFC), a Gabor patch may be displayed in one of *n* possible locations, with participants forced each time to respond with where they think the stimulus was displayed (Klein, 2001). Another method of response is a Yes-No paradigm whereby participants are instructed to respond each time they think detect the Gabor patch (Nachmias, 1981). A hallmark of visual threshold enhancement is seen when the entire psychophysical curve is shifted leftward on the x-axis without having the slope of the curve change. Because the threshold of visual perception is determined by a value on the x-axis, shifting the function further toward zero on this axis means the threshold value needed to reach a certain level of performance accuracy has been lowered. A lower threshold value without a changing slope is dually important, as it means whatever influence precision of responding had on the threshold of visual perception has been ruled out as a potential reason for sensory enhancement. Under these conditions, a wide variety of manipulations can be employed to impair or enhance visual perception.

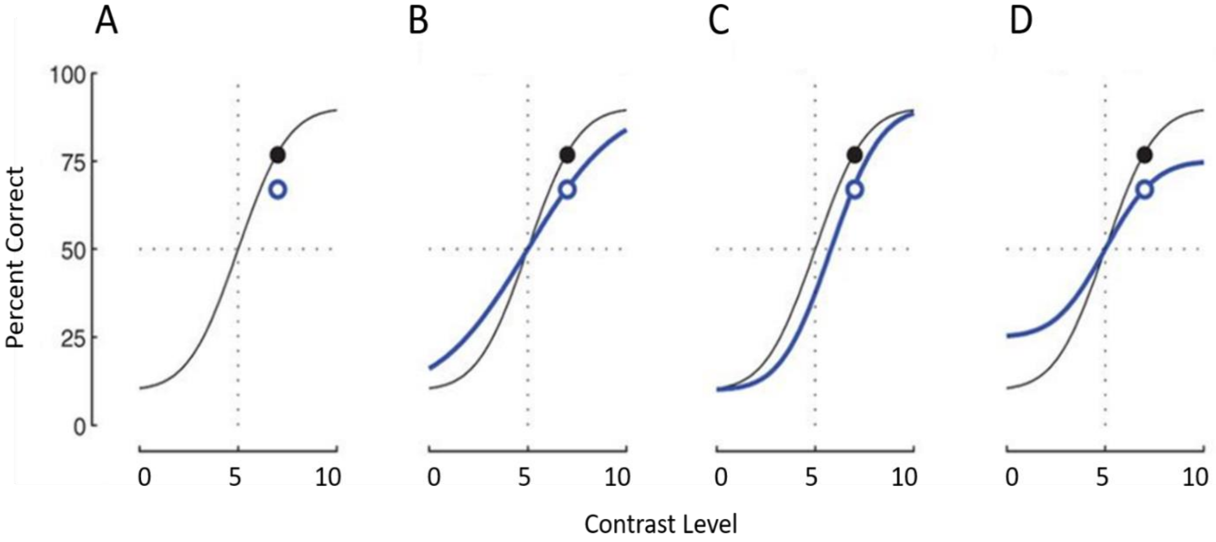


Figure 1. The psychometric curve is a 4-parameter function representing visual perception sensitivity. Each parameter represents some aspect of visual perception, and changes to each parameter will change some aspect of the shape of the function. The x-axis represents how easily detectable a stimulus is. The y-axis represents performance accuracy. A. Single psychometric function with parameters alpha (visual threshold), beta (slope), gamma (guess rate) and lambda (lapse rate) contributing in some way to the shape of the function. Each subsequent image represents a change in one parameter of the function while holding all other parameters constant. B. The blue function represents a change to only the beta (slope) parameter while hold all other parameters constant. The precision/sensitivity of responding is noticeably different. C. The blue function represents a change to only the alpha (threshold) parameter while holding all other parameters constant. Notice that the position of the blue function has been shifted along the x-axis to the right indicating a change in the threshold of visual perception. The blue function suggests a reduced threshold of visual perception as a higher contrast level is required. D. The blue function represents a change to the upper lambda (lapse rate) and lower gamma (guess rate) parameter while holding all other parameters constant. Notice that both the upper and lower portions of the function have been shifted towards the middle of the y-axis indicating a change in the accuracy of responding to stimuli that are either easy to detect (lapse rate) or very difficult to detect (guess rate). The lapse and guess rate do not typically contribute to visual perception and instead reflect attentional or decisional processes governed by other cognitive mechanisms.

Researchers have begun using Gabor patches in the presence of auditory stimuli to investigate the influence crossmodal presentation has on the threshold of visual detection. For instance, Gleiss and Kayser (2014) used a visual psychophysics paradigm to demonstrate that Gabor patch-locked auditory stimuli shifted the psychometric curve leftward without changing the slope. Additionally, EEG recordings also revealed both transient and stimulus-locked auditory stimuli modulated activity in the occipital cortex, suggesting sound may improve visual perception by enhancing visual processing regions of the brain (Gleiss & Kayser, 2014). Hollensteiner et al. (2015) found that ferrets were significantly more accurate at detecting Gabor patches when they were simultaneously presented with auditory stimuli, and they were significantly faster at detecting the Gabor patches under these conditions as well. Finally, Kayser, Philiastides, and Kayser (2017) demonstrated that simple features of visual stimuli (visual motion of a visually degraded Gabor patch) could be enhanced when an auditory stimulus was spatially locked to the direction the visual target was moving. Again, congruent visual-auditory motion enhanced areas of the occipital cortex as well (Kayser et al., 2017). These studies suggest that crossmodal stimulation can enhance low-level visual perception via occipital cortex modulation.

The exact nature of visual enhancement via concurrent auditory stimulus presentation has been studied extensively (Jaekl, Perez-Bellido, & Soto-Faraco, 2014). Most classical theories emphasize sensory based measurements such as subjectivity of stimulus properties (Stein et al., 1996) or visual detection threshold (Andersen & Mamassian, 2008; Bolognini et al., 2005; Caclin et al., 2011; Frassinetti et al., 2002; Manjarrez, Mendez, Martineza, Flores, & Mirasso, 2007), but have also been criticized for ignoring higher-level influences like attentional states and decision making (Ngo & Spence, 2012). Multimodal sensory interaction is known to influence low-level processing (Driver & Noesselt, 2008; Kayser, Petkov, Augath, & Logothetis, 2005; Lakatos, Chen, O'Connell, Mills, & Schroeder, 2007; Lehmann & Murray, 2005; Meredith & Stein, 1983; Molholm, Ritter, Javitt, & Foxe, 2002; Wallace, Meredith, & Stein, 1998; Wilkinson, Meredith, & Stein, 1996), and has well defined connections between sensory regions in the brain (Cappe & Barone, 2005; Falchier, Clavagnier, Barone, & Kennedy, 2002; Lewis & Noppeney, 2010; Meredith, Allman, Keniston, & Clemo, 2009; Rockland & Ojima, 2003;

Smiley & Falchier, 2009). However, some authors argue that higher level cognitive influences should be further studied rather than be ignored (Ngo & Spence, 2012).

Summary: Irrelevant auditory stimuli can cross-modally enhance visual perception. Using Gabor patches, researchers have demonstrated that the threshold of visual perception can also be enhanced using irrelevant auditory stimuli. Recently, some authors argue aspects of auditory processing that don't assume only basic sensory features should be studied in relation to cross-modal enhancement.

1.5 Crossmodal/unimodal enhancement via emotional salience

To date, only a handful of studies have investigated the influence emotionally salient visual stimuli have on low-level visual perception. For instance, because amygdala-occipital projections carry information that is predominantly low spatial frequency (Amaral, Behniea, & Kelly, 2003), Bocanegra and Zeelenberg (2009) found an opposing effect of Gabor patch detection; accuracy was significantly greater with low spatial frequency Gabor patches when cued with fearful faces, and significantly worse with high spatial frequency Gabor patches when cued with negative faces. When participants were cued to the spatial location of a Gabor patch, Barbot and Carrasco (2018) found that with 40ms onset asynchronies participants' subjective perception of the Gabor patches were significantly enhanced in the presence of the fearful faces, but that there was no change with a 500ms onset asynchrony. Again using a cuing paradigm, Ferneyhough, Kim, Phelps, and Carrasco (2013) found that only participants with high trait anxiety exhibited reduced visual contrast sensitivity when invalidly cued with fearful faces, and that anxiety scores also correlated negatively with the degree of visual impairment. Finally, Phelps, Ling, and Carrasco (2006) found that participants threshold of visual detection was significantly enhanced in the presence of centrally presented fearful faces, indicating enhanced visual perception when processing fearful expressions.

While the effects emotionally salient auditory stimuli have on the threshold of visual perception have not been investigated, recent studies suggest these classes of stimuli may have beneficial influences on attention. For instance, Zeelenberg and Bocanegra (2010) cued participants with an auditory or visual word that was either negative or neutral, displayed a brief neutral target word, and then had participants attempt to find the target word among it and a neutral distractor word. Participants were significantly more accurate at identifying the target word when it was preceded by a negative auditory cue, and significantly less accurate when the target word was preceded by a negative visual cue. Kryklywy and Mitchell (2014) found that participants were significantly more accurate at estimating the location of a visual target in the presence of negative sounds compared to positive or neutral sounds. Finally, Max et al. (2015) found that participants responded more quickly to visual stimuli in the presence of emotional auditory distractor stimuli compared to neutral stimuli but that, unlike non-emotional crossmodal visual enhancement, the synchrony of the target and distractor did not matter. These studies suggest a need to explore recent recommendations (Ngo & Spence, 2012) to further test cognitive influences like emotional salience on visual perception, and the neural mechanisms associated with it.

Summary: Emotionally salient visual stimuli can enhance or impair the threshold of visual perception depending on their attentional relevance. Emotionally salient auditory stimuli have also been shown to enhance certain aspects of visual attention and cognition. However, whether emotionally salient auditory stimuli influence low-level visual perception remains largely unexplored.

1.6 Thesis objectives and hypotheses

This review highlights several issues that remain to be addressed regarding how low-level visual perception might be enhanced or impaired by different classes of modality-specific emotionally salient stimuli. The threshold of visual perception has been shown to be enhanced and impaired depending on the processing channel being indexed (Bocanegra & Zeelenberg, 2009), and whether the emotional distractor is a spatial cue or not (Ferneyhough et al., 2013). Finally, emotionally salient auditory stimuli have been shown to enhance certain aspects of visual cognition. The hypotheses governing how low-level visual feature processing might be influenced by different classes of non-spatially cued emotionally salient visual stimuli, and how low-level visual feature processing might be influenced by different classes of emotionally salient auditory stimuli will be discussed briefly.

1.6.1 Objectives

The specific objectives and hypotheses of this project are as follows:

1) The first objective of this thesis is to determine how informative, stimulus-locked emotionally salient visual and auditory stimuli differentially influence the threshold of visual perception. Specifically, we tested the hypothesis that emotionally salient visual stimuli would impair the threshold of visual perception relative to neutral visual stimuli, while emotionally salient auditory stimuli would enhance visual perception relative to neutral auditory stimuli.

It is hypothesized that emotionally salient visual stimuli will increase neural competition more strongly than neutral visual stimuli, increasing the visual contrast level required to reach the threshold of visual perception. We predict that, when the Gabor patch and visual stimulus are synchronized, participants will require a higher contrast Gabor patch at the threshold of visual perception in the presence of emotionally salient visual stimuli compared to neutral visual stimuli. We also predict lower overall accuracy and slower reaction times in the presence of emotionally salient visual stimuli compared to neutral visual stimuli. Conversely, we hypothesize that emotionally salient auditory stimuli will augment the visual signal compared with neutral auditory stimuli leading to a decrease in the visual contrast level needed to reach the threshold of visual perception. We predict that, when the Gabor patch and auditory stimulus are synchronized, participants will require a lower Gabor patch contrast at the threshold of visual perception in the presence of emotionally salient auditory stimuli compared to neutral auditory stimuli. Additionally, we predict higher overall accuracy and faster reaction times in the presence of emotionally salient auditory stimuli compared to neutral auditory stimuli.

2) The second objective of this thesis is to determine whether the length of time between the presentation of the emotionally salient visual or auditory stimuli and the onset of the Gabor patch differentially affect the threshold of visual perception. Specifically, we tested the hypothesis that emotionally salient visual stimuli would foster sustained visual impairment of the Gabor patches in the presence of emotionally salient visual stimuli, and that emotionally salient auditory stimuli would enhance visual perception for Gabor patches presented after the irrelevant auditory stimulus has been presented. More specifically, when three Gabor patches (spaced by 1000ms

each) are presented with an irrelevant emotionally salient stimulus, all Gabor patches will receive similar impairment in the presence of emotionally salient visual stimuli, while the third Gabor patch will receive the most behavioural enhancement in the presence of emotionally salient auditory stimuli.

Emotionally salient visual stimuli have been shown to impair behavioural performance and neural responding at a sustained rate. For instance, Pateraki, Spentza, and Nega (2018) found that working memory was impaired in the presence of emotionally salient faces regardless of whether they were presented for 200ms or 1000ms. Likewise, Hajcak and Olvet (2008) found that EEG recorded neural potentials lasted longer in the presence of emotionally salient (more than 1000ms) relative to neutral visual stimuli, suggesting a more persistent neural effect of emotional stimuli. Therefore, we would expect the threshold of visual perception to be impaired at a sustained rate as well, with no Gabor patch presentation time affecting visual competition most strongly. We predict that participants' threshold of visual perception will be more strongly impaired in the presence of emotionally salient visual stimuli, and that this effect will be sustained and not influenced by when the Gabor patch is presented. Additionally, we predict that participants will be less accurate overall at detecting the Gabor patches in the presence of emotionally salient visual stimuli and will have slower reaction times as well. It has also been suggested that informative auditory stimuli require more processing time than informative, static visual stimuli (Schirmer & Kotz, 2006) before the brain can decode the nature of what they represent. Therefore, we expect to see visual perception enhancement in the presence of emotionally salient auditory stimuli most strongly for the third Gabor patch presentation relative to the first or second presentations. We predict that the threshold of visual perception will be more strongly enhanced when Gabor patches are presented further from the onset of an emotionally salient auditory stimulus than when presented near its onset. Additionally, we predict that participants will be more accurate overall at detecting the Gabor patches in the presence of emotionally salient auditory stimuli and will have faster reaction times as well.

Finally, trait anxiety questionnaires were collected for Experiment 1 and Experiment 2 to determine whether accuracy and reaction time measures correlated with individual trait anxiety levels. We hypothesized that participants' accuracy and reaction time would be negatively correlated with trait anxiety levels.

Little is known about how different classes of un-cued emotionally salient visual and auditory stimuli might influence visual perception, and even less is known regarding how temporal synchronization might play a role in the hypothesized impairment and enhancement. The current study aims to disentangle the hypothesized opposing effects emotionally salient visual and auditory information have on low-level visual feature processing.

Chapter 2

Experiment 1

2.1 Methods

2.1.1 Participants

Thirty participants (Male = 11, Female = 19; Caucasian = 16, Asian = 12, Brazilian = 1, NA = 1) completed the study. During visual distractor blocks, some participants could not significantly detect any Gabor patches above chance level. Therefore, data from these seven participants was removed during the analysis of accuracy and reaction time data for the image distractor blocks only. As such, data for 23 healthy participants (male = 9, female = 14) with a mean age of 25 (age range = 19-35; standard deviation = 4.79) were analysed for the image distractor blocks. All participants could detect the Gabor patches in the sound distractor blocks, so all were included in those analyses. All participants were pre-screened to ensure they had no past or current psychiatric history, were in good physical health, and had no neurological disease or head injury. All participants granted informed consent and were shown one disturbing auditory and one disturbing visual stimulus prior to the experiment to ensure they were comfortable participating in the study. All participants indicated they had normal or corrected to normal vision. All participants were right handed as determined by the Edinburgh handedness inventory. All participants completed the State-Trait Anxiety Inventory for Adults (STAI) (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983) to determine trait anxiety levels (mean trait anxiety score = 40.02; median = 39.00, range = 23-62). The STAI was randomly conducted either before or after the experimental task (15 received the STAI before the task, and 15 received it afterwards). The study was approved by the Health Sciences Research Ethics Board at the University of Western Ontario, London, Ontario, Canada.

2.1.2 Stimuli

A modified “emotional interrupt task” was designed for both visual and auditory emotional interruption. Participants had to detect Gabor patches while being distracted by irrelevant visual and auditory stimuli. A total of 16 Gabor patches were generated using MATLAB, and then converted to a .bmp file so they could be read into E-Prime. All Gabor patches were vertically oriented at 0° with no difference in visual angle. To ensure an accurate visual threshold estimate, Gabor patches are typically selected so that the first few are very difficult to detect, and the last few are very easy to detect. Visual contrast level is the variable typically manipulated to control how easy or difficult it is to detect a Gabor patch. Therefore, all visual properties of the Gabor patches were identical except for the visual contrast level. Eight Gabor patches were used for visual distraction trials (contrast levels: 1%, 2%, 4%, 5%, 6%, 7%, 9%, 10%), and the other eight Gabor patches were used for auditory distraction trials (contrast levels: 0.70%, 1.40%, 2.10%, 2.80%, 3.50%, 4.20%, 4.90%, 5.60%). While piloting the study, we found that participants had a harder time detecting the same Gabor patch contrast in the presence of irrelevant visual compared to irrelevant auditory stimuli. Therefore, we used a broader range of contrast levels for the irrelevant visual stimulus portion of the experiment and a tighter range for the irrelevant auditory stimulus portion to estimate a stable psychometric function in both conditions. All visual and auditory stimuli were selected from the International Affective Picture System and International Affective Digital Sounds databases. Both databases contain mean ratings for valence (ranging from 1= *low pleasure* to 9 = *high pleasure*) and arousal (ranging from 1 = *low arousal* to 9 = *high arousal*). All stimuli were rated by Bradley & Lang (2007). Each visual and auditory stimulus was rated by at least 100 participants. Normative valence, arousal and dominance ratings were collected over several experiments.

Forty visual stimuli (1,017.6 pixels x 820.8 pixels) were selected for the visual distraction trials. All visual stimuli were selected based on their mean valence and arousal ratings, with negative and neutral pictures significantly differing in terms of their mean valence ($t(27.71) = 21.70$; $p < 0.001$) and arousal ratings ($t(38) = -11.24$; $p < 0.001$). Negative pictures were characterized as having lower valence and higher arousal ratings than neutral pictures (negative pictures: *valence*: mean = 2.31, standard deviation = 0.51, range = 1.79–3.46; *arousal*: mean = 6.10, standard deviation = 0.70, range = 5.06–7.16; neutral pictures: *valence*: mean = 5.09, standard deviation = 0.25, range = 4.72–5.50; *arousal:* mean = 3.52, standard deviation = 0.75, range = 2.41–4.93). Additionally, ten neutral images were selected for the practice trials only (*valence*: mean = 4.94, standard deviation = 0.11, range = 4.63–5.04; *arousal*: mean = 2.75, standard deviation = 0.70, range = 1.76–4.17). To ensure that there were no differences between low-level properties of the visual stimuli, and that the only differences between them were the valences, a wavelet analysis was conducted. Luminance values between visual negative and neutral stimuli were not significantly different ($t(38) = 0.17$; $p = 0.87$). A wavelet analysis (Delplanque, N'Diaye, Scherer, & Grandjean, 2007) was also performed to determine whether spatial frequencies of the negative and neutral images differed significantly. Eight spatial frequency bands (512, 256, 128, 64, 32, 16, 8, 4) were produced by decomposing the red, green, blue layers of each image. No significant differences of the energy in each band were found (all p's > 0.05 *uncorrected*).

Forty auditory stimuli were selected. All auditory stimuli were selected based on their mean valence and arousal ratings, with negative and neutral sounds significantly differing in terms of their mean valence ($t(39) = -7.31$; $p < 0.001$) and arousal ratings ($t(39) = -29.53$; $p < 0.001$). Negative sounds were characterized as having lower valence and higher arousal ratings than neutral sounds (negative sounds: *valence*: mean = 2.37, standard deviation = 0.47, range = 1.63-3.59; *arousal*: mean = 7.03, standard deviation = 0.76, range = 5.39–8.16; neutral sounds: *valence*: mean = 4.90, standard deviation = 0.49, range = 4.01–5.96; *arousal:* mean = 4.68, standard deviation = 0.51, range = 2.88–5.48). Additionally, ten neutral sounds were selected for the practice trials only (*valence*: mean = 4.83, standard deviation = 0.38, range = 4.30–5.35; *arousal*: mean = 4.69, standard deviation = 0.76, range = 3.51–5.89).

Negative and neutral visual and auditory stimuli were also compared to ensure they were matched across sensory modalities. Taken together, negative and neutral images and sounds significantly differed in terms of their mean valence ($t(39) = -28.425$; $p < 0.001$) and arousal ($t(39) = 16.691$; $p < 0.001$) ratings. Overall, negative stimuli had lower valence and higher arousal ratings than neutral stimuli (negative stimuli: *valence*: mean = 2.38, standard deviation = 0.53, range = 1.63-3.65; *arousal*: mean = 6.54, standard deviation = 0.88, range = 5.06-8.16; and neutral stimuli: *valence*: mean = 5.04, standard deviation = 0.39 range = 4.01-5.96; *arousal:* mean = 4.15, standard deviation = 0.94, range = 2.41-5.89). See Appendix B for a list of all stimuli used. Negative images vs negative sounds and neutral images vs neutral sounds were compared to determine whether they differed significantly in terms of valence and arousal. Negative images and negative sounds did not significantly differ in terms of valence ($t(19) = -0.88$; $p = 0.39$) but negative sounds had significantly greater arousal ratings than negative images ($t(19) = -3.81$; $p = 0.001$). Likewise, neutral images and neutral sounds did not significantly differ in terms of valence ($t(19) = 0.83$; $p = 0.42$) but neutral sounds did have significantly greater arousal ratings than neutral images ($t(19) = -5.04$; $p < 0.001$).

2.1.3 Task design

Participants were given detailed introductions before beginning the task and completed a practice block prior to the start of each experimental modality. Participants completed four visual distraction blocks, and four auditory distraction blocks. Participants were randomized to start with a visual or auditory distraction block and completed all four blocks before switching to the other distractor modality. Participants completed the task on a Predator G9-791 laptop. Participants rested their chin on a head mount apparatus, with the laptop screen 24 inches from their forehead. The chinrest of the head mount was 9 inches from the table. Participants had a viewing angle of 11°. To ensure consistent viewing among experimental sessions, participants were able to adjust the height of the chair for comfort, but not the position of the head mount, or position of the laptop.

Each trial began with a fixation point in the center of the screen (jittered from 500-1000ms). Participants were instructed to maintain fixation on the fixation cross throughout the experiment and to avoid moving their eyes away from fixation. Depending on the trial, either a visual or auditory distractor stimulus (valence: negative, neutral) was displayed (jittered from 400-700ms). Auditory stimuli were set to a volume of 88-90 hertz. A Gabor patch was concurrently displayed with the distractor stimulus on either the left or right side of the screen for ~32ms. Participants had to wait until two questions marks were displayed in the two possible locations the Gabor patch could be located before responding. Participants used their right hand to respond, pressing 1 with their right index finger if they detected the Gabor patch on the left side, and 2 with their right middle finger if they detected the Gabor patch on the right side. Participants were told to respond as quickly and accurately as they could. The participant was also instructed that if they did not see the Gabor patch in either location, they were to respond anyway with a guess. After each response, participants either saw a blank screen (indicating a correct response), the word “Wrong” in red letters (indicating an incorrect response), or the words “No response detected” in red letters (indicating the participant either failed to respond or responded outside of the designated response window). Importantly, the pilot version of the task discovered participants had a very difficult time detecting the Gabor patches in the presence of the visual distractors. However, once verbally instructed about the synchronous relationship between the Gabor patch and visual distractor, participants were able to competently perform the task. Therefore, all participants were made aware of the relationship between the onset of the Gabor patch and visual/auditory distractor stimulus.

There were a total of 40 visual and 40 auditory distractor trials per block, with 5 visual distractor blocks and 5 auditory distractor blocks for the experiment. A total of 200 visual and 200 auditory distractor stimuli were displayed for the entire experiment. Each distractor stimulus was presented 10 times per modality, and each Gabor patch was displayed 200 times on the left and 200 times on the right per modality. There were a total of 400 Gabor patch presentations total per modality, with 50 presentations per contrast level. The task was programmed using E-Prime software (Schneider et al., 2002).

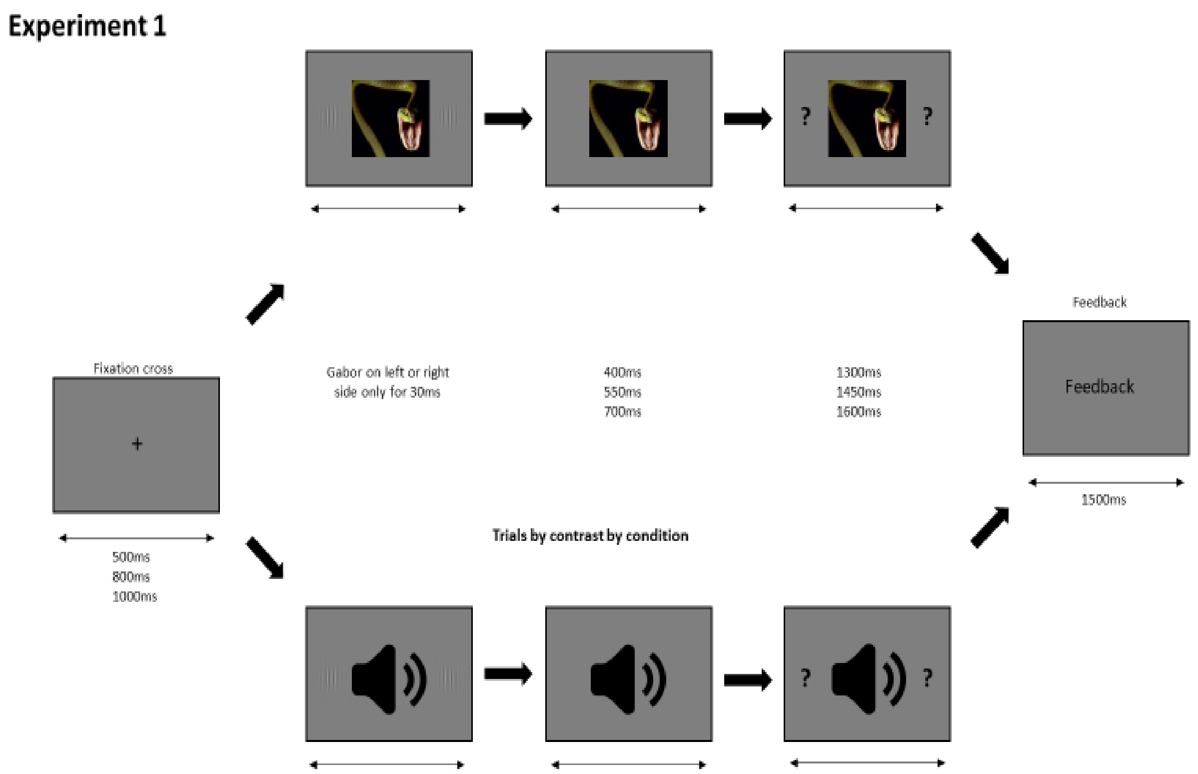


Figure 2. A schematic of the task used for Experiment 1. At the beginning of each trial, participants stare at a fixation cross (500ms-1000ms). An image or sound that is either emotionally salient or neutral is displayed (400ms-700ms) concurrently with a 30ms Gabor patch (varying between 8 levels of detectability) that is displayed on the left or right side of the screen. Participants are then forced to guess which side of the screen the Gabor patch was displayed on (1300ms-1600ms limit for response) and receive feedback on after each guess.

2.1.4 Behavioral data analysis

For response accuracy data, we first removed any trials where the reaction time data was recorded as zero as this indicated the participant responded too early, too late, or that no response had been made. Additionally, all trials where participants responded faster than 150ms were removed since these were likely too fast to be indicative of a real Gabor patch detection. Finally, trials where reaction time responses were above or below 2.5 standard deviations from the overall mean were treated as outliers and removed from the analysis. Accuracy data was analyzed using R.

For reaction time data, we determined for each participant which Gabor patch contrast levels were sufficient to enable them to detect the Gabor patch at significantly above chance (50% accuracy) levels. To do this, we removed contrast levels where participants were either significantly below 50% response accuracy, or not significantly different from 50% response accuracy. Only the remaining contrast levels were used for each participant when analyzing the reaction time data. Outliers were removed the same way accuracy outliers were removed (description above). Additionally, only correct response accuracy trials were included when analyzing reaction time data. Finally, some contrast levels had to be removed entirely (image contrasts removed: 1%, 2%, 4%, 5%, 6%; sound contrasts removed: 0.70%, 1.40%, 2.10%, 2.80) to balance the reaction time ANOVA because participants differed in which contrasts they could perceive significantly greater than 50% of the time. Therefore, image reaction time data was analyzed with a 2 (image valence: negative, neutral) X 3 (contrast level: 7%, 9%, 10%) repeated measures ANOVA, and sound reaction time data was analyzed with a 2 (sound valence: negative, neutral) X 4 (contrast level: 3.5%, 4.2%, 4.9%, 5.6%) repeated measures ANOVA. Reaction time data was analyzed using R.

For visual and auditory distractor psychophysics data, accuracy data were fitted to a psychometric function. Briefly, the psychometric function allows the fitting of accuracy data to a model with four parameters that represent a participants' sensory perception (Klein, 2001). The threshold parameter (alpha) represents the threshold of visual perception, i.e., the point at which the participant dramatically improves from chance performance to ceiling performance. The slope parameter (beta) controls the steepness of the psychometric curve. The guess rate parameter (gamma) fixes the lower portion of the curve to a specific value. In an *n*AFC paradigm, the guess rate parameter is fixed at 1/*n*. In a yes/no paradigm (regarding whether the target is present), the guess rate parameter is fixed at zero. Finally, the lapse rate parameter (lambda) fixes the upper portion of the curve to a specific value and represents mistakes in performance when the Gabor patches should be easily detected. The parameters are then multiplied to a two-parameter sigmoid function that creates the characteristic shape of the psychometric curve. While the present study fitted data to a Weibull function, other functions may be used should the analyst believe they fit the data more accurately (i.e. cumulative normal, logistic, reverse Gumbel, t-distribution, etc.).

Alpha, beta, and lambda were estimated via a maximum likelihood algorithm that computes a combination of the three parameters that most probabilistically generated the data. In Experiment 1, the gamma parameter was fixed at 0.50 because it is assumed that when participants guess from a selection of two choices, they do so with a 50% probability. Importantly, a yes/no paradigm (like in Experiment 2) fixes gamma at zero since, regardless of the number of items needed to make a guess from, a guess requires the withholding of a response. 95% confidence intervals were calculated for each individual threshold at 75% accuracy for Experiment 1, and 50% accuracy for Experiment 2. This was accomplished through data bootstrapping, and significance was inferred based on whether the confidence intervals of the bootstrapped parameters overlapped.

A nested model hypothesis test was also performed, a method that allows for Bayesian-like model comparison. With this approach, two models are estimated: one representing a model of no difference between thresholds (null hypothesis model), and one representing a model indicating a difference between thresholds (alternative hypothesis model). By running data simulations comparing the two models, we can compute how much more likely one model is compared to the other. For example, if 1000 data simulations were run and the percentage of simulations that supported the null hypothesis model were below 5% (less than 50/1000 simulation), we might say this is analogous to a p-value which rejects the null hypothesis at $\alpha = 0.05$. Therefore, we could reject the null hypothesis in favor of the alternative. Psychophysics data was bootstrapped using the R package ’quickpsy’, and model comparison (nested model hypothesis test) was performed using the 'Palamedes' toolbox in MATLAB. For a detailed explanation of model estimation and bootstrapping of the psychometric function, see Appendix A.

2.2 Results

2.2.1 Image Behavioural Results

A 2 (image valence: negative, neutral) X 8 (contrast level: 1, 2, 4, 5, 6, 7, 9, 10) repeated measures ANOVA was performed on participants accuracy data. The analysis yielded a significant main effect of image valence ($F(1, 22) = 6.30$; $p = 0.02$), whereby participants made significantly more errors for emotional relative to neutral images. A significant main effect of contrast was also observed ($F(7, 154) = 53.80$; $p < 0.001$) characterized by an improvement in Gabor patch detection accuracy as the Gabor patch contrast level increased. Finally, a significant image valence X contrast interaction ($F(7, 154) = 2.22$; $p = 0.04$) was observed. To elucidate the nature of the interaction, eight pairwise comparisons were done for the two valence categories at each contrast level with a Holm-Bonferroni correction. A significant difference was found for Gabor patch detection performance in the presence of negative compared to neutral stimuli at the fourth contrast level only ($p < 0.05$) meaning participants were significantly less accurate in the presence of irrelevant emotionally salient visual stimuli. As will be seen below, this coincides quite closely with our threshold of detection estimates. There were no significant differences for Gabor patch detection performance in the presence of negative compared to neutral images for the other 7 contrast levels. The influence that an individuals' level of trait anxiety had on image accuracy was investigated by correlating accuracy difference scores (negative image accuracy – neutral image accuracy) as a function of individual trait anxiety. Results showed a significant correlation meaning that the more anxious a person was, the more accurate they were in the presence of negative compared to neutral images ($r = 0.51$; $p = 0.01$, CI = [0.13, 0.76]).

To properly balance the ANOVA for reaction time data analysis, only contrast levels where all participants' accuracy performance was significantly above chance level were used. Therefore, a 2 (image valence: negative, neutral) X 3 (contrast level: 7, 9, 10) repeated measures ANOVA was performed on participant reaction time data. The analysis of reaction time data did not yield a significant main effect of image valence ($F(1, 22) = 1.97$; $p = 0.18$) or a significant image valence X contrast interaction (*F*(2, 44) = 0.88; $p = 0.42$). As expected, a significant main effect of contrast (*F*(2, 44) = 9.40; $p < 0.001$) was observed. The influence that an individuals' level of trait anxiety had on image reaction time was investigated by correlating reaction time difference scores (negative image reaction time – neutral image reaction time) as a function of individual trait anxiety. No significant correlation was observed (r = .25; $p = 0.26$; CI = [-0.19, 0.60]).

2.2.2 Image Psychophysics Results

Accuracy data was fitted to a Weibull function to compare threshold, slope, and lapse rate parameters at the 75% performance level in the presence of negative [threshold = 4.14 (3.75, 4.59); slope = 2.28 (1.77, 2.96); lapse rate = 0.10 (0.08, 0.13)] and neutral [threshold = 3.44 (3.00, 3.82); slope = 2.17 (1.70, 2.74); lapse rate = 0.10 (0.08, 0.12)] visual stimuli. Confidence intervals were determined by bootstrapping data using maximum likelihood estimation of parameters. Results show that thresholds were significantly lower for negative compared to neutral visual stimuli [dif = 0.70 (0.16, 1.31)] presentations indicating that the threshold of visual perception was impaired by the presence of irrelevant emotionally salient visual stimuli. No significant differences between negative and neutral slopes [dif = 0.11 (-0.71, 0.96)] or negative and neutral lapse rates [dif = 0.002 (-0.03, 0.03)] were present. A nested model hypothesis test revealed the two psychophysical curves were significantly different (pTLR < 0.05).), indicating less than 5% of simulated model comparisons favored the null hypothesis model of no difference between psychometric functions. Therefore, the data were more probable under the alternative hypothesis model which indicates a difference between negative and neutral thresholds of visual perception. This means more than 95% of simulated model comparisons favored the alternative hypothesis.

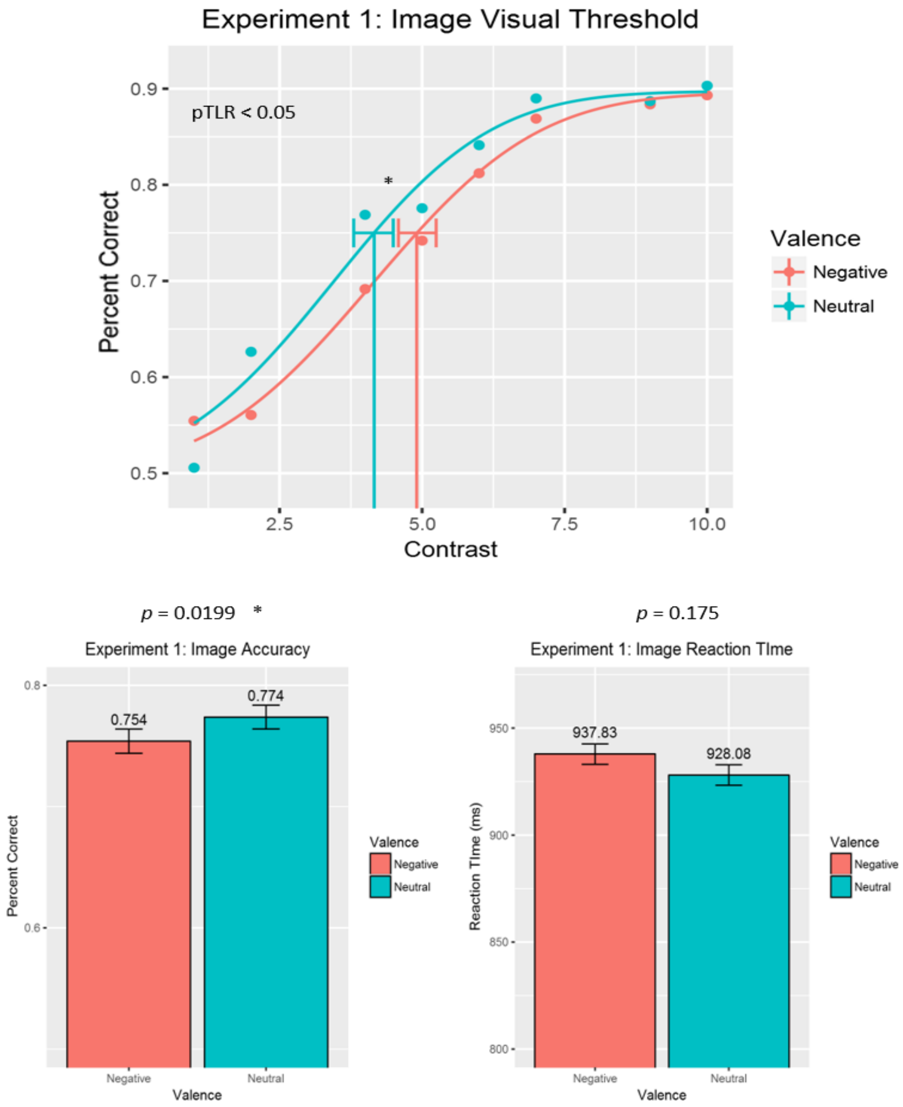


Figure 3. Top: Data fitted to psychometric curves for accuracy in the presence of negative (red) and neutral (blue) visual stimuli. Bootstrapped confidence intervals did not overlap for threshold estimates, indicating the threshold of visual perception was impaired in the presence of negative, relative to neutral, images. A nested model hypothesis test supported the null hypothesis model for less than 5% of data simulations (pTLR < 0.05). Bottom left: A significant main effect of valence indicates participants were less accurate at detecting the Gabor patches in the presence of negative visual stimuli. A significant interaction was also noted, indicating accuracy was significantly different at the 4% Gabor patch contrast level. Bottom right: Differences in reaction time were not significantly different in the presence of negative and neutral visual stimuli.

2.2.3 Sound Behavioural Results

A 2 (sound valence: negative, neutral) X 8 (contrast level: 0.70, 1.40, 2.10, 2.80, 3.50, 4.20, 4.90, 5.60) repeated measures ANOVA was performed on participants accuracy data. The analysis showed no significant main effect of sound valence ($F(1, 29) = 0.09$; $p = 0.77$) or sound valence X contrast interaction ($F(7, 203) = 0.88$; $p = 0.52$). A significant main effect of contrast was noted ($F(7, 203) = 176.50$; $p < 0.001$), indicating that participants responded more quickly as the Gabor patches became easier to detect. The influence that an individuals' level of trait anxiety had on sound accuracy was investigated by correlating accuracy difference scores (negative sound accuracy – neutral sound accuracy) as a function of individual trait anxiety. No significant correlation was observed (r = 0.19; $p = 0.31$; CI = [-0.18, 0.52]).

To properly balance the ANOVA for reaction time data, only contrast levels where all participants' accuracy performance was significantly above chance level were used. Therefore, a 2 (sound valence: negative, neutral) X 4 (contrast level: 3.5, 4.2, 4.9, 5.6) repeated measures ANOVA was performed on participant reaction time data. The behavioural results did not yield a significant main effect of sound valence ($F(1, 29) = 2.20$; $p = 0.15$) or a significant sound valence X contrast interaction ($F(3, 87) = 0.46$; $p = 0.71$). A significant main effect of contrast ($F(3, 87) = 4.99$; $p < 0.01$) was noted which indicated that participants responded more quickly as the Gabor patches became easier to detect. The influence that an individuals' level of trait anxiety had on sound reaction time was investigated by correlating reaction time difference scores (negative sound reaction time – neutral sound reaction time) as a function of individual trait anxiety. No significant correlation was observed (r = 0.31; $p = 0.10$; CI = [-0.06, 0.60]).

2.2.4 Sound Psychophysics Results

Accuracy data was fitted to a Weibull function to compare threshold, slope, and lapse rate parameters at the 75% performance level in the presence of negative [threshold = 2.26 (2.14, 2.38); slope = 0.96 (0.81, 1.12); lapse rate = 0.023 (0.01, 0.03)] and neutral [threshold = 2.17 (2.06, 2.28); slope = 0.81 (0.67, 0.95); lapse rate = 0.03 (0.02, 0.03)] visual stimuli. Confidence intervals were determined by bootstrapping data using maximum likelihood estimation of parameters. Results show that there were no significant differences for negative compared to neutral thresholds [dif = 0.09 (-0.09, 0.25)], slopes [dif = 0.15 (-0.06, 0.37)], or lapse rates [dif = -0.004 (-0.01, 0.01)]. A nested model hypothesis test revealed the two psychophysical curves were not significantly different (pTLR > 0.05), indicating the null hypothesis model of no difference between psychometric functions was favored for more than 5% of simulations.

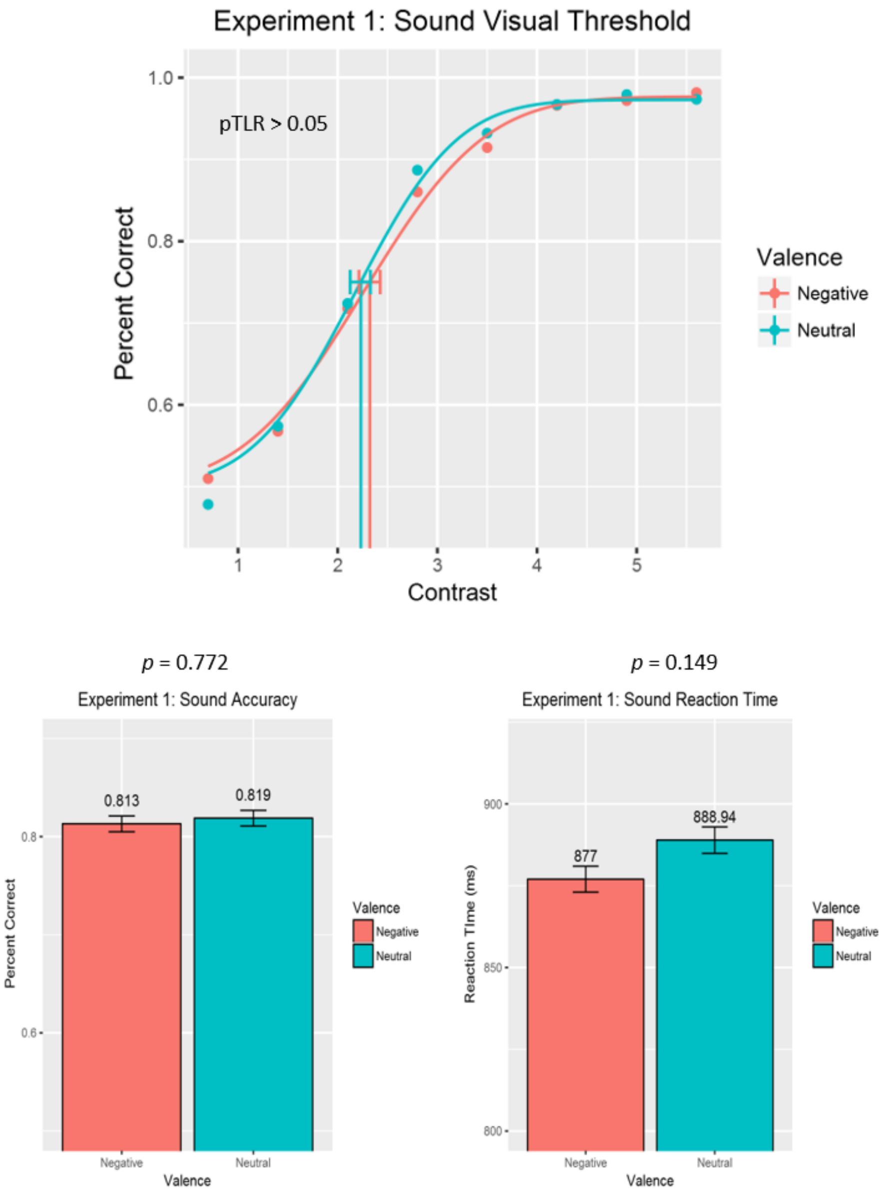


Figure 4. Top: Data fitted to psychometric curves for accuracy in the presence of negative (red) and neutral (blue) auditory stimuli. Bootstrapped confidence intervals overlapped for threshold estimates, indicating participants' threshold of visual perception was not different in the presence of negative or neutral sounds. A nested model hypothesis test supported the null hypothesis model for more than 5% of data simulations (pTLR > 0.05). Bottom left: There is no significant difference for accuracy scores in the presence of negative or neutral auditory stimuli. Bottom right: Differences in reaction time were not significantly different in the presence of negative and neutral auditory stimuli.

Experiment 2

Experiment 2 was conducted to elucidate some of the effects found in Experiment 1. In Experiment 1, we confirmed the hypothesis that emotionally salient visual stimuli would impair the threshold of visual perception. However, our hypothesis that emotionally salient auditory stimuli would modulate the threshold of visual perception in an enhancing manner was not supported by our data. We expected to find improvements based on a previous report which indicated enhanced visual stimulus localization in the presence of irrelevant emotionally salient auditory stimuli (Kryklywy et al., 2014). We considered the possibility that visual modulation via emotionally salient auditory stimuli is not as robust as previous studies would indicate. However, we also considered the possibility that the effects that emotionally salient auditory stimuli have on visual perception may vary due to their dynamic and temporal nature. We reasoned that the timing of the visual Gabor patch relative to the irrelevant auditory stimulus may play an important factor in modulating visual perception. Specifically, a recent model proposes that auditory information deemed emotionally salient at the "what" pathway level is made available for cognitive evaluation at 400ms or greater duration (Schirmer & Kotz, 2006). We hypothesized that emotionally salient visual distractors would impair the threshold of visual perception at a sustained, constant level and would not be impacted by the asynchrony of the Gabor patch presentation. Crucially, because of the dynamic nature of the irrelevant auditory stimuli used, we hypothesized that emotionally salient auditory distractors would enhance visual perception more strongly at later, transient presentation times. Therefore, Experiment 2 differed from Experiment 1 on two dimensions. First, the irrelevant visual and auditory stimuli were now displayed for 3600ms instead of a jittered 400-700ms interval. Additionally, three Gabor patches were displayed per irrelevant visual/auditory stimulus instead of one Gabor patch. This was based off recent papers indicating dynamic auditory stimuli require more time to decode their meaning, compared to static visual stimuli (Schirmer & Kotz, 2006). This approach allowed us to index whether the irrelevant auditory stimuli required more time to process, and whether dynamic auditory valence could affect low-level visual perception once enough time had passed to process everything.

2.3 Methods

2.3.1 Participants

Thirty participants (Male = 11, Female = 19; Caucasian = 7, African = 1, Asian = 14, Middle Eastern = 5, NA = 3) participated in the study. One participant could not perform either the visual or auditory version of the task, so their data was removed from both analyses. Two additional participants could not perform the visual version of the task, so their data was removed from those blocks only. Finally, two other participants could not perform the auditory version of the task, so their data was removed from those blocks only. Therefore, data for 27 healthy participants was analyzed for the visual version of the task (Male = 9, Female = 18; mean age = 23.25; standard deviation = 5.46; age range = 18–36), and data from 27 healthy participants was analyzed for the auditory version of the task (Male = 9, Female = 18; mean age = 22.83; standard deviation = 4.97; age range = 18-36). The same pre-screening, informed consent, and questionnaires administered in Experiment 1 were also given to participants in Experiment 2. The study was approved by the Health Sciences Research Ethics Board at the University of Western Ontario, London, Ontario, Canada.

2.3.2 Stimuli

A modified emotional interrupt task was designed for both visual and auditory emotional interruption. Participants had to detect Gabor patches while being distracted by irrelevant images and sounds. A total of 16 Gabor patches were generated using MATLAB in the same manner described in Experiment 1. Eight Gabor patches were used for concurrent image presentation (contrast levels: 1%, 2%, 3%, 4%, 5%, 6%, 6%, 8%), and the other eight Gabor patches were used for concurrent sound presentation (contrast levels: 0.70%, 1.40%, 2.10%, 2.80%, 3.50%, 4.20%, 4.90%, 5.60%). The Gabor patches used in the presence of irrelevant visual stimuli did not exactly match the level of contrast used in Experiment 1. We decided to make them slightly more difficult to detect to account for how much easier the second and third Gabor patch were to detect compared to the first. Different contrast levels were experimented with to try and create a balance between how much more difficult the first Gabor patch was to detect compared to the second and third.

Forty distractor stimuli were selected, with 20 of neutral valence and 20 of negative valence. The visual and auditory stimuli used in Experiment 2 were identical to those used in Experiment 1. See Experiment 1 for detailed analysis of the IAPS and IADS pictures used in Experiment 2.

2.3.3 Task design

Participants were given a detailed introduction to the task and completed a practice version prior to the start of each modality. Participants completed five visual distraction blocks, and five auditory distraction blocks. Participants were randomized to start with visual or auditory distraction and completed all five blocks before switching to the other distractor modality. Participants rested their chin on a head mount apparatus, with the computer screen 24 inches from their forehead. The chinrest of the head mount was 9 inches from the table. Participants had a viewing angle of 11°. To ensure consistent viewing among experimental sessions, participants were able to adjust the height of the chair, but not the head mount. Participants completed the task on a Predator G9-791 laptop.

Each trial began with a fixation point in the center of the screen (500ms). Participants were instructed to maintain fixation on the fixation cross throughout the experiment and to avoid moving their eyes. Depending on the trial, either a visual or auditory stimulus (negative or neutral) was displayed for 3600ms. Three Gabor patches were displayed (~32ms each) randomly on either the left or right side of the screen. The first Gabor patch displayed concurrently with the distractor, the second 1200ms post distractor onset, and the third 2400ms post distractor onset. Participants were told that the Gabor patches would be displayed three times per distractor randomly on the left or right side of the screen. Participants were instructed to respond every time they thought they detected a Gabor patch. No information about the synchronous relationship between the stimuli was given. Participants used their right hand to respond, pressing 1 with their right index finger if they detected the Gabor patch on the left side, and 2 with their right middle finger if they detected the Gabor patch on the right side. Participants were told to respond as quickly and accurately as they could. At the end of each block, each participant was shown the percentage of Gabor patches they correctly identified. Percentages were adjusted by adding 15% to them to account for low contrast Gabor patches that are not detectable.

There were a total of 64 visual and 64 auditory distractors trials per block, with 5 visual distractor blocks and 5 auditory distractor blocks for the experiment. A total of 320 visual and 320 auditory distractor stimuli were used for the entire experiment. Each distractor stimulus was viewed 8 times per modality, and each Gabor patch was displayed 480 time on the left and 480 times on the right per modality. There were a total of 960 Gabor patch presentations per modality, with 120 presentations per contrast level. On each trial, the 3 Gabor patches presented were the same contrast level. The task was programmed using E-Prime software (Schneider et al., 2002).

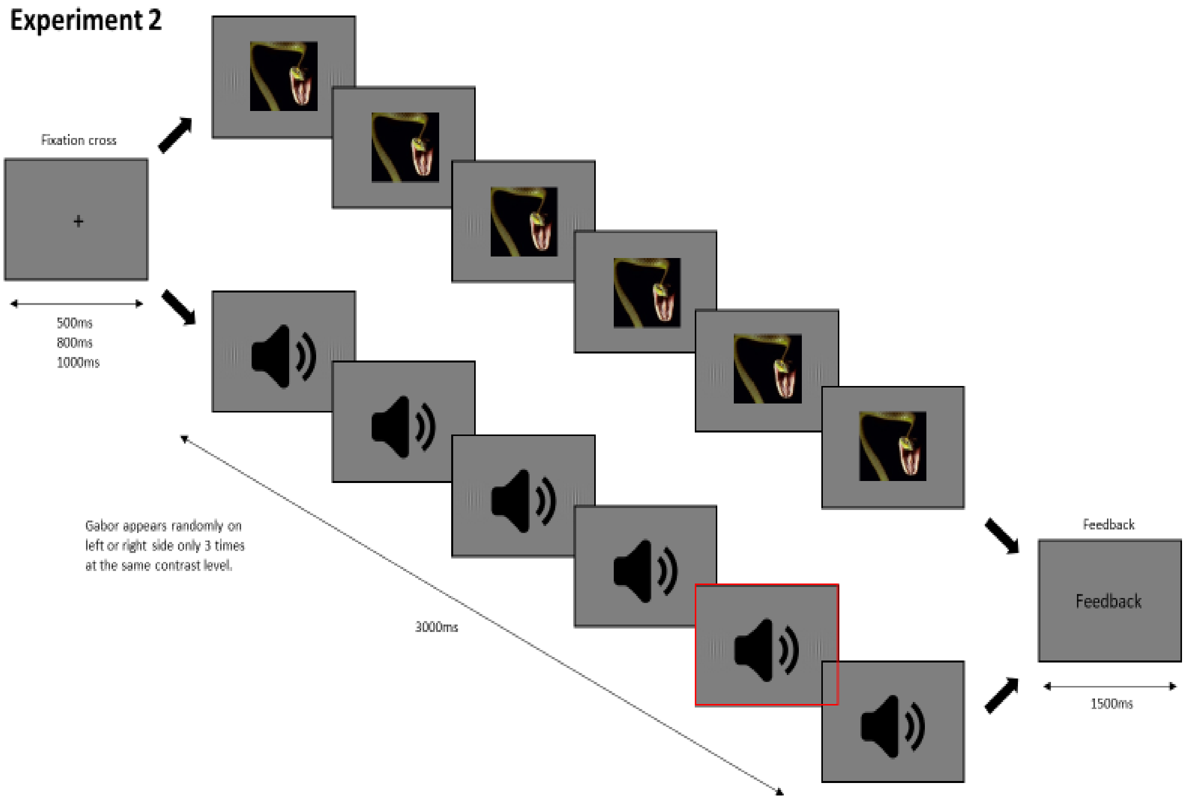


Figure 3. A schematic of the task used for Experiment 2. At the beginning of each trial, participants stare at a fixation cross (500ms-1000ms). An image or sound that is either emotionally salient or neutral is displayed continuously for 3000ms. Three Gabor patches (30ms each; 8 different contrast levels) are presented with the visual or auditory stimuli onset, 1000ms after stimulus onset, and 2000ms after stimulus onset. Participants were instructed to respond each time they thought they detected a Gabor patch. No feedback is given until the end of the block.

2.3.4 Behavioral data analysis

For response accuracy data, we removed trials where participants either failed to respond, or responded outside the allotted time window. Accuracy data was pre-processed using the same quality control used in Experiment 1. Accuracy data was analyzed using R.

For reaction time data, we determined for each participant which Gabor patch contrast levels were either significantly below 50% response accuracy, or not significantly different from 50% response accuracy. This was done separately for each Gabor patch presentation time (first, second, third). Outliers were removed the same way accuracy outliers were. Those contrast levels were removed for each participant when analyzing the reaction time data. Additionally, only correct response accuracy trials were included when analyzing reaction time data. Some contrast levels had to be removed entirely (image contrasts removed: 1%, 2%, 3%, 4%, 5%, 6%; sound contrasts removed: 0.70%, 1.40%, 2.10%, 2.80%, 3.60%, 4.20%) to balance the reaction time ANOVA because participants differed in which contrasts they could perceive significantly greater than 50% of the time. Finally, first Gabor patch presentation times were removed entirely due to none being performed significantly above chance by all participants. Therefore, image reaction time data was analyzed with a 2 (image valence: negative, neutral) X 2 (contrast level: 7%, 8%) X 2(Gabor patch presentation time: second, third) repeated measures ANOVA, and sound reaction time data was analyzed with a 2 (sound valence: negative, neutral) X 2 (contrast level: 4.9%, 5.6%) X 2 (Gabor patch presentation time: second, third) repeated measures ANOVA. Reaction time data was analyzed using R.

For visual and auditory distractor psychophysics data, 95% confidence intervals were obtained for thresholds at 50% accuracy, and significance was determined based on whether the confidence intervals of the bootstrapped parameters overlapped. All other psychometric curve fitting analyses were identical to those conducted in Experiment 1. For visual distraction trials, only the second and third Gabor patch presentations were estimated because accuracy for the first Gabor patch presentation did not reach 50% and was not possible to calculate. For auditory distractor trials, all three Gabor patch presentation times (first, second, third) were analyzed. Psychophysics data was analyzed using the R package ’quickpsy’, and the MATLAB toolbox ‘Palamedes’.

2.4 Results

2.4.1 Image Behavioural Results

A 2 (image valence: negative, neutral) X 8 (contrast level: 1, 2, 4, 5, 6, 7, 9, 10) X 3 (Gabor patch presentation time: first, second, third) repeated measures ANOVA was performed on participant accuracy data. The behavioural results yielded a significant main effect of image valence (*F*(1, 26) = 5.334; $p = 0.0291$), indicating participants made more Gabor patch detection errors in the presence of emotionally salient visual stimuli. A significant main effect of contrast was also noted (*F*(7, 182) = 200.5; $p < 0.0001$), indicating that participants made less Gabor patch detection errors as the Gabor patches got easier to detect. A significant main effect of Gabor patch presentation time (*F*(2, 52) = 151.1; $p < 0.0001$) was observed. This was not surprising, given that participants could not detect the first Gabor patch at an accuracy greater than 50%. No significant image valence X Gabor patch presentation time interaction (*F*(2, 52) = 2.17; $p = 12.5$) or significant image valence X contrast X Gabor patch presentation time interaction (*F*(14, 364) = 0.67; $p = 0.81$) was found.

A significant image valence X contrast interaction (*F*(7, 182) = 2.82; $p = 0.008$) was observed. To unpack these results, t-tests were performed to compare negative and neutral accuracy performance at each contrast level. Eight pairwise comparisons with a Holms-Bonferroni correction indicated participants were significantly less accurate at Gabor patch detection for contrasts 6% ($p < 0.05$), 7% ($p < 0.05$), and 8% ($p < 0.05$). There were no significant differences in Gabor patch detection accuracy for the other contrast levels.

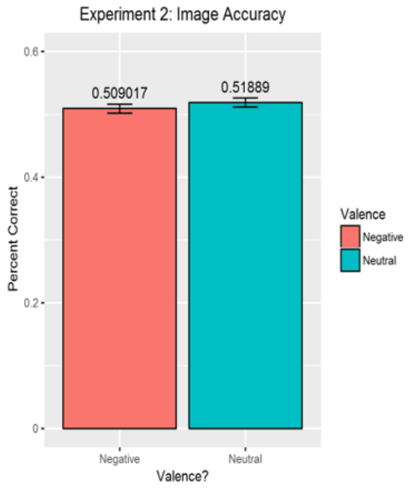
A significant contrast X Gabor patch presentation time interaction (*F*(14, 364) = 20.78; $p < 0.0001$) was yielded. To further unpack the interaction, eight one-way ANOVAs were conducted looking at the effect of presentation time at each contrast level. There was a significant main effect of presentation time for all eight contrast levels: 1% (*F*(2, 52) = 23.41, $p < 0.001$), 2% (*F*(2, 52) = 63.91, $p < 0.001$), 3% (*F*(2, 52) = 87.97, $p < 0.001$), 4% (*F*(2, 52) = 111.5, $p < 0.001$), 5% (*F*(2, 52) = 111.5, $p < 0.001$), 6% (*F*(2, 52) = 90.05, $p < 0.001$), 7% (*F*(2, 52) = 84.41, $p < 0.001$), and 8% (*F*(2, 52) = 64.45, $p < 0.001$). To further elucidate the interaction between presentation time and contrast level, eight pairwise comparisons were done for the three presentation times at each contrast level with a Holm-Bonferroni correction. The first Gabor patch was detected with significantly less accuracy than the second Gabor patch for all eight contrast levels: 1% ($p < 0.01$), 2% ($p < 0.001$), 3% ($p < 0.001$), 4 % ($p < 0.001$), 5% ($p < 0.001$), 6% ($p < 0.001$), 7% ($p < 0.001$), and 8% ($p < 0.01$). The first Gabor patch was also detected with significantly less accuracy than the third Gabor patch for all eight contrast levels: 1% ($p < 0.001$), 2% ($p < 0.001$), 3% ($p < 0.001$), 4 % ($p < 0.001$), 5% ($p < 0.001$), 6% ($p < 0.001$), 7% ($p < 0.001$), and 8% ($p < 0.01$). Finally, the second Gabor patch and third Gabor patch detection accuracy did not differ significantly for all eight contrast levels: 1% ($p = 0.40$), 2% ($p = 0.53$), 3% ($p = 0.98$), 4 % ($p = 0.92$), 5% ($p = 0.72$), 6% ($p = 0.57$), 7% ($p = 0.71$), and 8% ($p = 0.61$).

The influence that an individuals' level of trait anxiety had on image accuracy was investigated by correlating accuracy difference scores (negative image accuracy – neutral image accuracy) for pooled Gabor patches (first, second, third) as a function of individual trait anxiety. No significant correlation was observed (r = -0.002; $p = 0.99$; CI = [-0.38, 0.38]).

To balance the ANOVA, reaction time data was only considered for contrasts where all participants' accuracy data was significantly above chance. To determine the overall effect on reaction time, a 2 (image valence: negative, neutral) X 2 (contrast level: 7, 8) X 2 (Gabor patch presentation time: second, third) repeated measures ANOVA was performed on pooled (first, second, third Gabor patch presentation) reaction time data. The behavioural results did not yield a significant main effect of image valence ($F(1, 26) = 1.96$; $p = 0.17$) but did yield a significant main effect of contrast ($F(1, 26) = 7.75$; $p = 0.01$) and presentation time ($F(1, 26) = 55.99$; $p < 0.001$). No significant image valence X contrast ($F(1, 26) = 0.79$; $p = 0.38$), image valence X Gabor patch presentation time ($F(1, 26) = 0.02$; $p = 0.88$), contrast X Gabor patch presentation time ($F(1, 26) = 0.00$; $p = 0.99$), or image valence X contrast X Gabor patch presentation time ($F(1, 26) = 0.48$; $p = 0.49$) were found. The influence that an individuals' level of trait anxiety had on image reaction was investigated by correlating reaction time difference scores (negative image reaction time – neutral image reaction time) for pooled Gabor patches (second, third) and for the final two contrast levels (7, 8) as a function of individual trait anxiety. No significant correlation was observed (r = 0.18; $p = 0.47$; CI = [-0.31, 0.60]).

2.4.2 Image Psychophysics Results

Accuracy data was fitted to a Weibull function to compare threshold, slope, and lapse rate parameters at the 50% performance level in the presence of negative and neutral stimuli. Confidence intervals were determined by bootstrapping data using a maximum likelihood procedure. Participants were not significantly above chance for any contrast for the first Gabor patch presentation, so those responses were not included in the analysis. Accuracy data from the second [negative: threshold = 2.52 (2.39, 2.67); slope = 1.84 (1.65, 2.05); lapse rate = 0.15 (0.13, 0.17); neutral: threshold = 2.73 (2.60, 2.88); slope = 1.95 (1.75, 2.18); lapse rate = 0.12 (0.10, 0.14)] and third [negative: threshold = 2.53 (2.39, 2.68); slope = 1.97 (1.73, 2.20); lapse rate = 0.13 (0.11, 0.15); neutral: threshold = 2.69 (2.52, 2.85); slope = 2.12 (1.91, 2.37); lapse rate = 0.09 (0.07, 0.11)] Gabor patch presentations were first analyzed to determine whether there was an overall effect of image valence on visual threshold. For the second Gabor patch presentation, there were significant differences in thresholds for negative compared to neutral Gabor patch presentations [dif = -0.21 (-0.42, -0.02)], but not slopes [dif = -0.10 (-0.40, 0.20)] or lapse rates [dif = 0.03 (-0.001, 0.06)]. A nested model hypothesis test revealed the two psychophysical curves were not significantly different (pTLR > 0.05). For the third Gabor patch presentation time, there were no significant differences in thresholds [dif = -0.16 (-0.37, 0.08)] or slopes [dif = -0.15 (-0.49, 0.14)] between negative and neutral visual distractor trials. However, there were significant lapse rate differences [dif = 0.04 (-0.01, 0.05)], indicating participants made more mistakes at high Gabor patch contrast levels in the presence of emotionally salient visual stimuli. A nested model hypothesis test revealed the two psychophysical curves were not significantly different (pTLR > 0.05), indicating visual perception did not differ in the presence of negative and neutral visual stimuli.



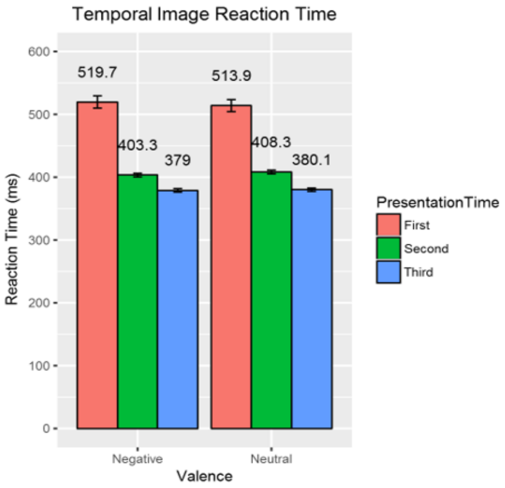


Figure 6. Top: Data fitted to psychometric curves for accuracy in the presence of negative (red) and neutral (blue) visual stimuli for the second and third Gabor patch. Bootstrapped confidence intervals overlapped for all threshold estimates, indicating participants' threshold of visual perception was not impaired in the presence of negative, relative to neutral, images. A nested model hypothesis test supported the null hypothesis model for more than 5% of data simulations (pTLR > 0.05). Bottom left: A significant main effect of valence indicates participants were less accurate at detecting the Gabor patches in the presence of negative visual stimuli. A significant interaction was also noted, indicating accuracy was significantly different at the 6%, 7%, and 8% Gabor patch contrast levels. Bottom right: Differences in reaction time were not significantly different in the presence of negative and neutral visual stimuli.

2.4.3 Sound Behavioural Result

A 2 (sound valence: negative, neutral) X 8 (contrast level: 1, 2, 4, 5, 6, 7, 9, 10) X 3 (Gabor patch presentation time: first, second, third) repeated measures ANOVA was performed on participant accuracy data. The behavioural results did not yield a significant main effect of sound valence ($F(1, 26) = 0.08$; $p = 0.78$). However, a significant main effect of contrast was noted ($F(7, 182) = 302.2$; $p < 0.001$), which was not surprising given participants were expected to improve in accuracy as the Gabor patches became easier to detect. We also found a main effect of presentation time ($F(2, 52) = 10.32$; $p = 0.0002$), indicating that participants were significantly less accurate during the first Gabor patch presentation. Additionally, there was no significant interaction found for sound valence X contrast ($F(7, 182) = 1.11$; $p = 0.36$), sound valence X presentation time ($F(2, 52) = 0.75$; $p = 0.48$), contrast X presentation time ($F(14, 364) = 0.97$; $p = 0.48$), or sound valence X contrast X presentation time ($F(14, 364) = 0.62$; $p = 0.84$). The influence that an individuals' level of trait anxiety had on sound accuracy was investigated by correlating accuracy difference scores (negative sound accuracy – neutral sound accuracy) for pooled Gabor patches (first, second, third) as a function of individual trait anxiety. No significant correlation was observed (r = 0.05; $p = 0.80$; CI = [-0.34, 0.42]).

To balance the ANOVA, reaction time data was only considered for contrasts where all participants' accuracy data was significantly above chance. To determine the overall effect on reaction time, a 2 (sound valence: negative, neutral) X 2 (contrast level: 7, 8) X 2 (Gabor patch presentation time: second, third) repeated measures ANOVA was performed on pooled (first, second, third Gabor patch presentation) reaction time data. The behavioural results did not yield a significant main effect of sound valence ($F(1, 26) = 2.22$; $p = 0.15$) or presentation time ($F(1, 26) = 0.14$; $p = 0.71$), but did yield a significant main effect of contrast ($F(1, 26) = 28.15$; $p < 0.001$). No significant sound valence X contrast ($F(1, 26) = 0.01$; $p = 0.91$), sound valence X Gabor patch presentation time ($F(1, 26) = 2.84$; $p = 0.10$), contrast X Gabor patch presentation time ($F(1, 26) = 0.54$; $p = 0.47$), or sound valence X contrast X Gabor patch presentation time ($F(1, 26) = 0.82$; $p = 0.37$) were found. The influence that an individuals' level of trait anxiety had on sound reaction time was investigated by correlating accuracy difference scores (negative sound reaction time – neutral sound reaction time) for pooled Gabor patches (second, third) for the final two contrasts (4.9, 5.6) as a function of individual trait anxiety. No significant correlation was observed (r = -0.02; $p = 0.94$; CI = [-0.39, 0.37]).

2.4.4 Sound Psychophysics Results

Accuracy data was fitted to a Weibull function to compare threshold, slope, and lapse rate parameters at the 50% performance level in the presence of negative and neutral stimuli. Confidence intervals were determined by bootstrapping data using maximum likelihood parameters. Accuracy data was then split so that thresholds for the first, second, and third Gabor patch presentation could be analysed separately to determine if an effect of stimulus timing was present. For the first Gabor patch presentation [negative: threshold = 2.56 (2.46, 2.67), slope = 1.26 (1.16, 1.39), lapse rate = 0.12 (0.09, 0.15); neutral: threshold = 2.58 (2.46, 2.70), slope = 1.35 (1.23, 1.49), lapse rate = 0.12 (0.09, 0.15)], results show that there were no significant differences for negative compared to neutral thresholds [dif = -0.02 (-0.18, 0.13)] slopes [dif = -0.09 (-0.27, 0.08)], or lapse rates [dif = 0.0001 (-0.04, 0.04)]. A nested model hypothesis test revealed the two psychophysical curves were not significantly different (pTLR > 0.05). For the second Gabor patch presentation [negative: threshold = 2.29 (2.20, 2.38), slope = 1.30 (1.19, 1.43), lapse rate = 0.08 (0.06, 0.10); neutral: threshold = 2.36 (2.26, 2.47), slope = 1.32 (1.21, 1.45), lapse rate = 0.07 (0.05, 0.09)], results show that there were no significant differences for negative compared to neutral thresholds [dif = -0.08 (-0.21, 0.06)] slopes [dif = -0.02 (-0.19, 0.15)], or lapse rates [dif = 0.01 (-0.02, 0.04)]. A nested model hypothesis test revealed the two psychophysical curves were not significantly different (pTLR > 0.05). Likewise, for the third Gabor patch presentation (negative: threshold = 2.44 (2.34, 2.54), slope = 1.38 (1.27, 1.51), lapse rate = 0.07 (0.05, 0.10); neutral: threshold = 2.48 (2.38, 2.58), slope = 1.39 (1.27, 1.53), lapse rate = 0.05 (0.03, 0.08), results again show that there were no significant differences for negative compared to neutral thresholds [dif = -0.04 (-0.18, 0.10)], slopes [dif = -0.01 (-0.20, 0.17)], or lapse rates [dif = 0.02 (-0.01, 0.05)]. A nested model hypothesis test revealed the two psychophysical curves were not significantly different (pTLR > 0.05), indicating visual perception did not differ in the presence of negative and neutral auditory stimuli.

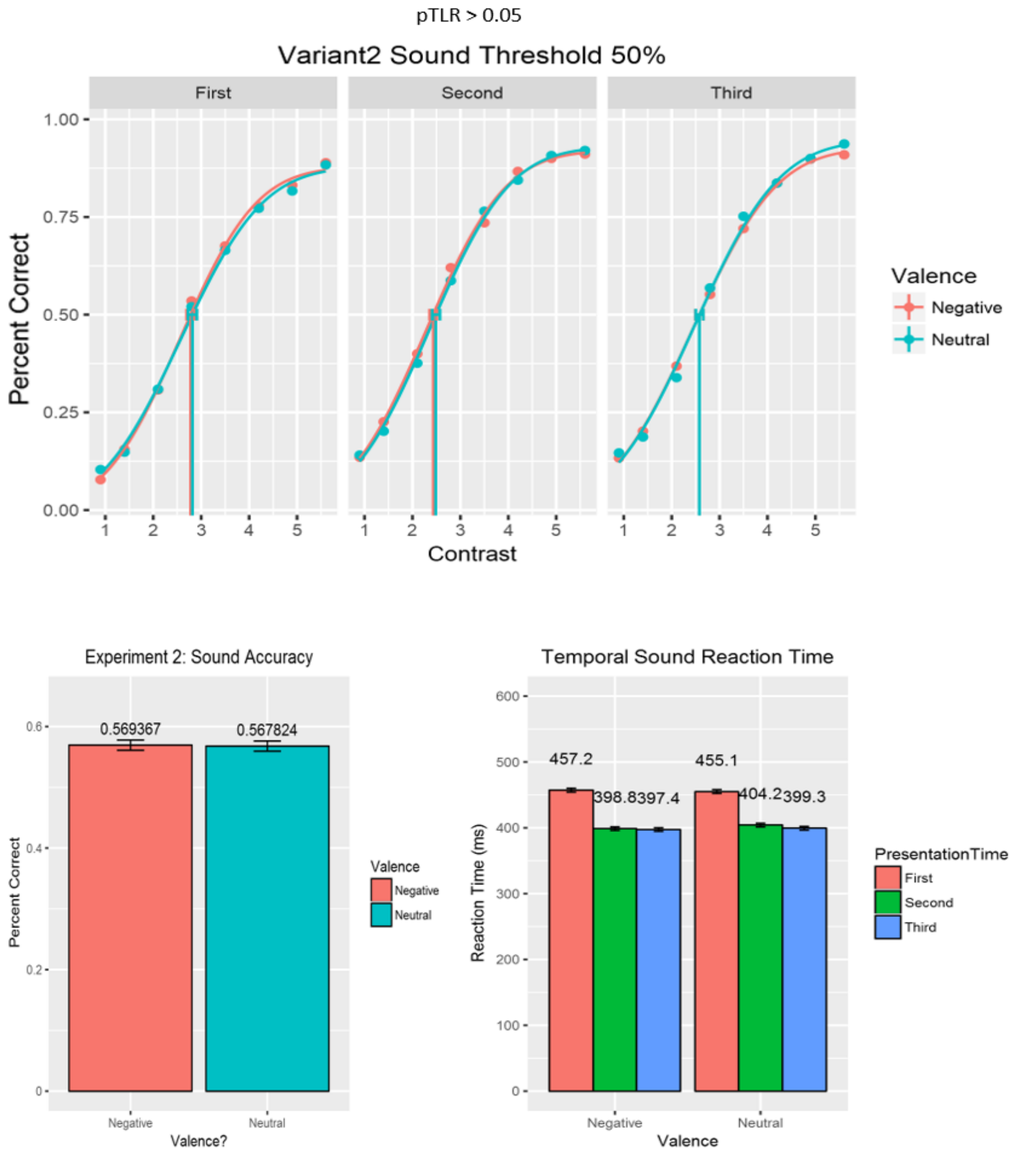


Figure 7. Top: Data fitted to 3 psychometric curves for accuracy in the presence of negative (red) and neutral (blue) auditory stimuli for the first, second, and third Gabor patch. Bootstrapped confidence intervals overlapped for threshold estimates for all 3 Gabor patch presentation times, indicating participants' threshold of visual perception was not different in the presence of negative or neutral sounds. A nested model hypothesis test supported the null hypothesis model for more than 5% of data simulations (pTLR > 0.05). Bottom left: There is no significant difference for accuracy scores in the presence of negative or neutral auditory stimuli. Bottom right: Differences in reaction time were not significantly different in the presence of negative and neutral auditory stimuli.

CHAPTER 3

3 Discussion

The objective of Experiment 1 was to test whether Gabor patch detection could be impaired in the presence of concurrently presented irrelevant visual stimuli and enhanced in the presence of concurrently presented irrelevant auditory stimuli. Experiment 2 tested whether Gabor patch presentation asynchrony relative to the onset of an emotionally salient auditory stimuli could affect the threshold of visual perception. Experiment 2 also tested whether visual perception impairment via irrelevant emotionally salient visual stimuli could produce a sustained impairment effect regardless of the presentation asynchrony.

3.1 Experiment 1

Consistent with our hypothesis, we found that the threshold of visual perception increased in the presence of emotionally salient, relative to neutral, irrelevant visual stimuli. Using a confidence interval bootstrapping approach and fixing the visual threshold to 75% detection accuracy (See Appendix A for details on this method), the threshold of visual perception was estimated at 4.41% contrast in the presence of negative visual stimuli, and only 3.44% percent contrast in the presence of neutral visual stimuli. Importantly, there were no estimated differences in slope or lapse rate between the conditions, indicating participants made all responses with the same precision and same number of lapses. The additional nested model hypothesis test also indicated that, using likelihood ratio simulations, the data were more likely to have been generated under the null hypothesis model for less than 5% of likelihood comparisons. Also, in line with our predictions, Gabor patch detection accuracy was significantly reduced in the presence of emotionally salient visual stimuli. A significant valence X contrast interaction was observed, and subsequent comparisons indicated that Gabor patch detection accuracy between conditions was only significantly different at the 4% contrast level. This further supported our psychophysics results as the threshold of visual perception was also estimated near 4% contrast. Additionally, the hypothesis that participants would be significantly slower at detecting the Gabor patches in the presence of emotionally salient visual stimuli was unsupported by the data. Finally, a significant correlation was found for the difference between negative and neutral accuracy scores and individual levels of trait anxiety, with participants becoming significantly more accurate in the presence of negative images as individual trait anxiety increased. No significant correlations were found for negative-neutral difference scores and participant reaction time.

Contrary to our hypotheses, emotionally salient auditory stimuli did not enhance the threshold of visual perception, improve Gabor patch detection accuracy, or reduce reaction times to target stimuli. In the presence of emotionally salient auditory stimuli, we predicted an enhancement of the threshold of visual perception, improved Gabor patch detection accuracy, and a reduction in Gabor patch detection reaction time. First, contrary to our hypothesis, the confidence interval bootstrapping approach did not yield differences at the threshold of visual perception. Likewise, the nested model hypothesis test did not support our prediction either, as the data were found to be more likely under the null hypothesis in more than 5% of data simulations. Overall Gabor patch detection accuracy did not significantly differ between emotional conditions, and we found no significant differences in reaction time between conditions either. Finally, the negative-neutral difference correlation with trait anxiety levels did not reveal any significant correlations for either accuracy or reaction time.

3.1.1 Low-level visual perception and emotionally salient visual stimuli

According to the biased competition model of attention, when multiple visual stimuli are present, the brain prioritizes their neural representation based on the salient physical features of the visual stimuli (Desimone & Duncan, 1995). Emotional information is thought to be modulated via amygdala enhancement of neural sensory regions (Blair & Mitchell, 2009; Pessoa & Ungerleider, 2003; Vuilleumier, 2005), suggesting that emotionally salient visual stimuli might affect visual perception at its earliest processing stages. This impairment in the presence of emotionally salient visual stimuli was most pronounced when examining the threshold of visual perception between visual conditions and was further supported by significantly different accuracy at the 4% contrast level only. This may suggest that the amygdala exacerbated the sensory representation of the emotionally salient visual stimuli, which led to stronger sensory competition with the Gabor patches in early visual areas. This suggests that, perhaps, emotional modulation of low-level vision is at least partially driven by neural competition as the unimodal stimuli presentations would have had to compete for visual representation at a neural level.

Our results differ from Phelps et al. (2006), who found that when emotionally salient faces directed covert attention to a spatial location, there was enhancement of the threshold of visual perception. It is thought that emotion can enhance activation of the visual cortex (Kapp et al., 1994; Kosslyn et al., 1996) through feedback from the amygdala (Anderson & Phelps, 2001), suggesting emotional stimulus processing in the visual stream may be modulated by the amygdala (Morris et al., 1998). Because covert attention has also been shown to enhance activation in the visual cortex (Brefczynski & DeYoe, 1999; Corbetta & Shulman, 2002; Martinez-Trujillo & Treue, 2002; McAdams & Maunsell, 1999; Reynolds et al., 2000; Saenz, Buracas, & Boynton, 2003), Phelps et al. (2006) reasoned that the peripheral emotional stimuli used in their task were enhancing visual perception because they cued attention away from central fixation to the peripheral location of the Gabor patches, exacerbating amygdala responsiveness to stimuli in the periphery. The current study differs because the emotionally salient visual stimuli were now the focus of attention. Therefore, in Phelps et al. (2006)'s study, the emotionally salient stimuli were cuing attention to relevant Gabor patch locations, while in the current study the emotionally salient visual stimuli were competing for visual attention and reducing perception of the peripheral Gabor patches. Therefore, the opposing pattern of behavioural results are not surprising, given they are not incompatible with our predictions.

3.1.2 Low-level visual perception and emotionally salient auditory stimuli

Previous studies suggest time-locked (Hollensteiner et al., 2015) or transient (Gleiss & Kayser, 2014) auditory stimuli can enhance visual perception by reducing the perceptual threshold needed to detect a visual stimulus. Past research also indicates that emotionally salient auditory stimuli can enhance performance in certain visual cognitive tasks (Zeelenberg & Bocanegra, 2010; Kryklywy & Mitchell, 2014). Our data do not provide combined evidence of visual perception threshold enhancement when emotionally salient auditory stimuli are presented concurrently with a Gabor patch. Auditory stimuli are thought to modulate activity in the occipital cortex (Gleiss & Kayser, 2014), and the amygdala has been shown to become activated in the presence of emotionally salient auditory stimuli (Gerdes, Wieser, & Alpers, 2014). One hypothesis concerning emotionally salient auditory stimuli is that they initiate a vigilant, alerting response that is non-specific (Zeelenberg & Bocanegra, 2010). Because the emotionally salient auditory stimulus is processed in the auditory cortex, the visual system may become nonspecifically enhanced and enable greater alertness to exogenous environmental stimuli. One explanation for irrelevant auditory benefit on visual perception involves an interplay between the cost of orienting to an auditory stimulus and the benefit of the alerting response triggered by said stimulus (Max et al., 2015). Some authors suggest the alerting benefit of the auditory stimulus is tied to its novelty and motivational significance (Wetzel et al., 2012). Because emotionally salient auditory stimuli could be considered both novel and motivational stimuli, they may briefly increase alertness (Aston-Jones & Cohen, 2005), and heighten response readiness (Sturm & Willmes, 2001). Mechanistically, Wetzel et al. (2012) suggested that novel auditory stimuli activate the locus coeruleus norepinephrine (LC-NE) system. Additionally, response readiness is enhanced through the LC-NE system (Aston-Jones & Cohen, 2005). One reason we did not see visual threshold enhancement may have been that our auditory stimuli were dynamic and more complex than the static visual stimuli (Schirmer & Kotz, 2006). Therefore, the amount of time needed to process the auditory stimuli might have been greater than the time needed for the visual stimuli. While visual stimuli have been shown to affect visual cognition even at very short presentation times (Vieira et al., 2017), the auditory stimuli may not have been processed the same way due to their short presentation time. By cutting the IADS stimuli from 6000ms to 450-700ms short clips, the auditory clips would not have been experienced the same way they were when participants initially rated them. This suggested additional time may have been needed to process the emotional significance of the auditory stimuli and prompted the following study.

3.2 Experiment 2

Inconsistent with our hypothesis, the confidence interval bootstrapping results and nested model hypothesis test failed to support the hypothesis that emotionally salient irrelevant visual stimuli would produce sustained visual impairment at the threshold of visual perception, and thus, an impaired threshold of visual perception for all three Gabor patch presentations. However, consistent with our hypothesis, we found a significant main effect of image valence on detection accuracy, meaning participants were significantly less accurate in the presence of emotionally salient irrelevant visual stimuli. A significant image valence X contrast level interaction was unpacked, indicating that the overall effect of valence on response accuracy was greatest for higher levels of contrast (6%, 7%, and 8% contrast). This suggests that Gabor patch detection accuracy was not related to the threshold of visual perception, and instead indicates potentially more lapses in the presence of transient emotional visual stimuli. This indicates that the relevant number of mistakes participants were making in the presence of emotionally salient, relative to neutral, stimuli was greatest when the Gabor patches were easier to detect. Additionally, valence did not significantly interact with presentation, supporting our hypothesis that the effect would be sustained across presentation times. For reaction time data, no results indicated performance impairment in the presence of emotionally salient visual stimuli. Likewise, exploratory analyses did not yield significant results when trait anxiety was used as a covariate.

Like Experiment 1, we did not observe an effect of auditory stimuli on visual threshold, accuracy, or reaction time measurements for Experiment 2. We predicted an enhancement of the threshold of visual perception, improved Gabor patch detection accuracy, and a reduction in Gabor patch detection reaction time for Gabor patches further in time from the onset of the emotionally salient auditory stimulus. First, contrary to our hypothesis, the confidence interval bootstrapping approach did not yield differences in at the threshold of visual perception in the presence of emotionally salient and neutral auditory stimuli for any of the Gabor patch presentation times. Likewise, the nested model hypothesis test did not support our prediction either, with data more than 5% likely under the null model for all Gabor patch presentation times. Gabor patch detection accuracy did not significantly differ for any Gabor patch presentation time between emotion conditions. An interaction involving presentation time with visual threshold modulation was hypothesized to exist. Therefore, we would have expected to see greater improvement in accuracy for the third Gabor patch relative to the second, and the second relative to the first. We also found no significant differences in reaction time between emotionally salient and neutral auditory stimuli for any Gabor patch presentation time. Finally, the exploratory analysis using trait anxiety as a covariate did not reveal any significant differences in any performance measure between emotionally salient and neutral auditory stimuli.

3.2.1 Low-level perception and sustained impairment via visual stimuli

We found a significant main effect of valence on accuracy that did not interact with presentation time, indicating a sustained effect of emotion on visual perception. Barbot & Carrasco (2018) considered the effects of emotionally salient stimuli and temporal Gabor patch synchronization however and found that fearful faces enhanced the threshold required to discriminate two Gabor patches of different contrast levels when the onset of the Gabor patch came 40ms after to offset of the emotionally salient image. However, the effect disappeared when the emotional stimulus offset-Gabor patch onset was increased to 500ms. Contrary to Barbot & Carrasco (2018), our main effect of valence that did not depend on the presentation time of the Gabor patch. However, our study differed in that the emotionally salient irrelevant visual stimulus did not disappear at any point during the Gabor patch detection, so neural competition should have been greater throughout. The interaction between valence and contrast indicated significant differences at the 6%, 7%, and 8% Gabor patch contrast levels. This sustained visual effect may not be related to the threshold of visual perception and may instead indicate decision or judgement-based impairments. This is evident because the lambda parameters of the psychometric functions were significantly higher for neutral compared to negative stimuli, suggesting worse performance in the presence of negative visual stimuli. The lambda parameter controls for lapse rate: Errors made that do not reflect threshold perception, and instead reflect participant errors when stimuli are easily perceptible (Klein, 2001). Given the complimentary accuracy data and lapse rate differences, this impairment may not be related to the threshold of visual perception and may instead indicate decision or judgement-based impairments (Klein, 2001).

3.2.2 Low-level perception and lack of delayed enhancement via auditory stimuli

We developed Experiment 2 to test the hypothesis that longer auditory stimulus presentation times would enhance the threshold of visual perception in the presence of emotionally salient auditory stimuli. However, no significant differences were found in any measures we used. While evidence suggests the auditory cortex requires as much as 100ms to processes auditory stimuli (Gage, Poeppel, Roberts, & Hickok, 1998), other research suggests that dynamic auditory stimuli require as much as 400ms processing time before the nature of the stimulus can be decoded (Pateraki, Spentza, & Nega, 2018; Hajcak & Olvet, 2008). We allowed the irrelevant auditory stimuli to play for nearly 3000ms per 3 Gabor patch presentations which should have provided ample processing time should visual perception modulation require it. Zhao et al. (2018) found that while the amygdala responded more to negative human vocalization than negative animal vocalization, inanimate objects were less likely to differentially affect amygdala function. Experiment 2 used emotionally salient auditory clips containing human (n = 14; negative = 10; neutral = 4), animal (n = 5; negative = 2; neutral = 3), and inanimate objects (n = 21; negative = 8; neutral = 13). Given half our auditory stimuli were inanimate objects it would suggest that regardless of temporal conditions, the brain may have treated the inanimate objects in relatively the same way. Additionally, the auditory stimuli we used did not contain equal groupings of our three categories, and the weighting of stimuli more strongly contained with inanimate objects may have dampened any visual perception effects that could exist.

3.3 Limitations

We failed to find an effect in Experiment 1 that supported our auditory hypothesis. The literature on emotionally salient auditory stimuli and visual cognition is scarce at the present date, so it may be the case that the effect is not as robust as we initially expected. However, the lack of significant results may have also been attributed to our use of modified IADS sounds. IADS stimuli consist of 6 second auditory clips that are psychometrically validated by thousands of participants on several dimensions (arousal, valence, dominance). Validators listened carefully to the entire 6 second clip, then considered how emotional the sound was. Experiment 1 used cut 400ms - 700ms samples from each 6 second clip and presented those while participants performed the task. When experienced this way, some sounds are ambiguous and difficult to discern. It is possible the brain could not interpret the valence of the sounds due to this ambiguity, and instead treated all the auditory stimuli as the same category. While Experiment 2 used longer sound presentation times (3000ms), that is still only half as long as the 6000ms IADS clips participants rated. Additionally, the visual stimuli used were static IAPS images, as opposed to dynamic IADS sounds. Therefore, we may have had effective visual stimuli, but sub-optimal auditory stimuli. To our knowledge, this was the first experiment to use IADS sounds to address low-level visual perception in this way.

Changes we made with Experiment 2 that affected task difficulty may also have contributed to the pattern of results. We used a 2AFC paradigm for Experiment 1, and a yes/no paradigm for Experiment 2. The 2AFC paradigm forces participants to respond after every Gabor patch presentation, while the yes/no paradigm allows participants to respond only when they think they have detected the Gabor patch. In this sense, Experiment 2’s unusable first Gabor patch threshold data may have been a casualty of reduced vigilance or a heightened lapse rate in Experiment 2. In Experiment 1, participants were also made aware that the Gabor patch and irrelevant stimulus would be presented concurrently, but no such information was presented in Experiment 2. It is therefore entirely possible that a new decision criterion was used, and that the first Gabor patch was simply not processed, or not acted upon.

While valence was similar across sensory modalities, arousal ratings of negative and neutral IAPS and IADS stimuli were significantly different. While the current study was not designed to compare performance across sensory modalities, arousal ratings for irrelevant visual stimuli (negative mean = 6.10; neutral mean = 3.52) were significantly lower than for irrelevant auditory stimuli (negative mean = 7.03; neutral mean = 4.68). Because we had a significant effect of in Experiment 1 with visual but not auditory stimuli, it could be argued that unmatched arousal ratings between modalities could have acted as an unforeseen confound. However, given that negative auditory stimuli have a greater mean arousal rating than negative images, one would expect this issue to manifest behaviourally in the opposite direction.

It is also important to note that we used a number of different measurements to index perceptual enhancement and impairment in both experiments. While many researchers assume accuracy and reaction time index the same cognitive processes, a recent model proposed by Ede, Lange, and Maris (2012) suggests that reaction time requires additional cognitive processes compared to accuracy. Likewise, the psychometric function does not have parameters which index response time, and instead can only assess binary yes-no/present-absent responding. Additionally, the most influential psychophysics papers (Wichmann & Hill, 2001a; Wichmann & Hill, 2001b) and recent textbooks (Kingdom & Prins, 2010) place a major emphasis on accuracy measurement analysis. Finally, like previous work (Bocanegra & Zeelenberg, 2009; Barbot & Carrasco, 2018, Ferneyhough, Kim, Phelps, & Carrasco, 2013; Phelps, Ling, & Carrasco, 2006), the current study was primarily set up to use accuracy as an outcome measurement. Because our significant results pertained only to accuracy and visual threshold, the present study may not have been optimized for reaction time measurements. Future studies may wish to modify this paradigm to account for the measurement of reaction time.

3.4 Future Directions

The visual portion of the task was more difficult than the auditory portion, and we believe this was due to the increased visual competition introduced by the irrelevant visual stimuli. Therefore, different contrast levels had to be used between modalities which may have introduced an unknown confound. There are several methods researchers could use to ensure Gabor patches are similar across modalities. For instance, scrambled images displayed during irrelevant auditory trials, and scrambled sounds during irrelevant image trials would provide the same overall visual competition and auditory enhancement and would allow identical Gabor patch contrasts to be used in both conditions. Some participants were also unable to detect any of the Gabor patches, and had to be removed from the analysis which may have biased the results in favor of participants with more competent visual perception. In the future, steps should be taken to ensure participants can make consistently accurate detections of the Gabor patches. Researchers could mitigate this factor by using an adaptive staircase procedure, rather than the method of constant stimulus to present the Gabor patches. This would allow participants who have a great level of difficulty at Gabor patch detection to have a wider range of contrast levels used on them, and thus, all participant data could be used and would not be biased away from participants who had trouble performing the task. Future studies may also wish to consider using simpler auditory stimuli, or dynamic stimuli that have been pilot tested under shorter sound durations. In the future, simpler auditory stimuli may be more complimentary to the static visual stimuli so that they are more properly matched. Additionally, researchers may wish to select dynamic auditory stimuli that use human and animal vocalization as those have been shown to activate the amygdala more than inanimate objects. Researchers may also wish to match arousal ratings between modalities as well to mitigate potential confounds which may arise when arousal is unmatched. Finally, future studies may also want to employ jitters, and other variable that might add more randomness to the paradigm.

3.5 Conclusion

We hypothesized that emotionally salient visual stimuli would impair low-level visual perception, while emotionally salient auditory stimuli would enhance low-level visual perception. Emotionally salient visual stimuli were found to disrupt visual perception, whether presented concurrently and briefly with a target stimulus, or in a sustained manner. However, emotionally salient auditory stimuli did not affect visual perception on any measures taken. The results from Experiment 1 and Experiment 2 suggest that emotionally significant unimodal stimulus experiences can impair low-level visual perception. However, neither Experiment 1 nor Experiment 2 were able to demonstrate that emotionally salient auditory stimuli affect low-level visual perception, at least in a way that was measurable in our experimental paradigms. While previous studies have found an effect of emotionally salient auditory stimuli on other areas of visual cognition, it may be the case that emotionally salient auditory stimuli simply do not affect basic low-level processes as deeply as we had predicted. However, given what we know about how emotionally salient auditory stimuli affect the brain and behaviour and given the lack of research specifically concerning low-level visual perception and emotionally salient auditory stimuli, our null results may reflect a need to reassess our behavioural paradigm to better index the hypothesized effect.

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Appendices

Appendix A: Visual threshold analysis explanation

The probability of successfully responding to a given stimulus intensity is a binary process and follows a Bernoulli distribution (Knoblauch & Maloney, 2012). The psychometric function is used to model the Bernoulli process by mapping correct and incorrect responses to a given stimulus intensity (Summers & Meese, 2007). The psychometric function is defined by four parameters: alpha, beta, gamma, lambda, and an additional two parameter sigmoid function (e.g. Weibull cumulative distribution function, cumulative normal, logistic, etc.) (Treutwein & Strasburger, 1999). The alpha parameter controls the position of the psychometric function along the x-axis. It is the most important parameter in the present study as it defines the threshold of visual perception at a given performance level. The beta parameter controls how steep or narrow the psychometric function is spread, often characterized as a measure of precision. The gamma parameter is commonly called the guess rate and controls the lower asymptote of the y-intercept of the psychometric function. In an nAFC paradigm, gamma is 1/n and is assumed to be the rate at which a participant is guessing. For instance, in a 2AFC experiment, the rate of guessing is fixed at 1/2 (0.5, or 50%). Finally, the lambda parameter controls the upper asymptote of the psychometric function and is commonly called the lapse rate. The lapse rate is the rate at which participants respond incorrectly at high stimulus intensity levels. For our purposes, the lapse rate could vary during parameter estimation as participants did not exhibit perfect performance at high stimulus intensities. By estimating all parameters simultaneously, a curve can be fitted through the data that represents a combination of the most probable values of the estimated parameters.

We chose to model the data using a Weibull sigmoid function, as it was the same function used by Phelps et al. (2006) and Gleiss and Kayser (2014). This was considered advantageous as it allowed us to more directly compare our results with studies that were most influential for our study design. A maximum likelihood procedure was used to estimate the alpha, beta, and lambda parameters, while keeping gamma fixed at 0.5. Only lambda had a uniform Bayesian prior constraining it to values ranging from 0 to 0.3. Alpha and beta were free to vary without any constraints during parameter estimation as is typically recommended. The maximum likelihood procedure searches for a three-dimensional joint distribution of the parameters that are most likely to generate the data we observed.

A Nelder-Mead Simplex Search algorithm (Nelder & Mead, 1965) was employed to determine the joint values of alpha, beta, and lambda that are the most likely data generation mechanism that produced the observed data. Briefly, the algorithm generates a simplex on a 3-dimensional grid containing the joint probability of the parameters (in our case this was alpha, beta, and lambda). The position of each simplex edge is a combination of the parameter values and represents three distinct psychometric functions. The simplex calculates the likelihood associated with the three psychometric functions and tries to switch a lower function with a higher one. Using a set of rules developed by Nelder and Mead (1965), the simplex moves the lower edge parameterized function to a higher one until it reaches a stationary tolerance point. There are two tolerance values that are assessed at the tolerance point, one related to the values of the parameters in the simplex, and the other related to the extra-dimensional maximum likelihood values. If the search grid the simplex uses is a three-dimensional parameter space (as is the case with the present study), then a fourth dimension is used to represent the maximum likelihood of the three-dimensional parameters. The search algorithm stops once the simplex arrives in a 3-dimensional box with a length and width no larger than the tolerance value associated with the parameters, and a height no larger than the fourth dimensional maximum likelihood estimate.

To test whether two or more Nelder-Mead Simplex Search estimated threshold values are significantly different from each other, the ‘quickpsy’ package in R was used. P-values cannot be directly calculated from the estimated parameters of a psychometric function, but significance can be indirectly inferred using a confidence interval bootstrapping procedure. A brief explanation follows: Once the maximum likelihood joint probability of the three parameters for a single psychometric function are estimated via the Nelder-Mead Simplex Search algorithm, new data are generated by simulating synthetic response data from the parameter vector. These data will differ slightly from the real data, so new parameters are estimated on the synthetic data set using the same maximum likelihood estimation procedure. The new parameter values from the synthetic data are noted, and this procedure is again repeated. In the case of the present study, each psychometric function was bootstrapped 1000 times to generate 1000 different joint parameter estimations. Finally, a 95% confidence interval is calculated from the distribution of the values of the simulated parameters. Because p-values are inverse functions of confidence intervals, significance can be indirectly determined without knowing an actual p-value. If two confidence intervals from two distributions of synthetic parameters overlap, the p-value may or may not be significant. Therefore, if two confidence intervals from two estimated parameters of two psychometric functions overlap, we cannot be certain whether the differences are significant, and we withhold judgement. However, if a p-value is significant, then the confidence intervals for the two groups will never overlap. Therefore, if two confidence intervals over the simulated parameter distributions of two psychometric functions do not overlap, the difference between the parameters must be significant, even if the p-value is not directly known.

While p-values cannot be directly derived from psychometric functions, a nested model's hypothesis test between psychometric functions produces likelihood ratios that can be similarly interpreted like p-values. The nested model's hypothesis test was conducted using the MATLAB toolbox 'Palamedes'. Parameters are first estimated in the manner explained above but are done using a fuller and lesser model. The fuller model represents the alternative hypothesis that the two psychometric functions are different and is the maximum likelihood of the joint posterior probability distribution between the two psychometric functions. The lesser model represents the null hypothesis that the two psychometric functions are identical and is the maximum likelihood value of the parameters of the data for the two functions pooled into a single function. From here, a ratio is taken of the data conditional on the parameters of the full model over the data conditional on the parameters of the lesser model. This ratio represents how much more probable the fuller model is relative to the lesser model. Importantly, the order of the numerator and denominator can be flipped, provided they remain flipped through the entire process.

The likelihood ratio gives the odds of the fuller model fitting the data best versus the lesser model fitting the data best. However, it is not known whether these odds are due to chance or due to a real difference existing between the two psychometric functions. Therefore, a nested model's hypothesis test is performed. To test the efficacy of the lesser (null) model, this test only considers it and not the fuller (alternative) model. Data from the lesser (null) model is taken and sampled using Monte Carlo simulations. It is then randomly split again into a new fuller and lesser model. Likelihood ratios are again taken between the simulated lesser (simulated null) and fuller (simulated alternative) models, and the ratio is compared to the original likelihood ratio based on the real data. If the null hypothesis (represented by the lesser model) is true, we should not be able to produce likelihood ratios from the simulated data that are as large as or larger than the likelihood ratio obtained from the original data. If the number of simulated ratios that are larger than the original is less than 5% (for example, 50 simulations out of 1000), the psychometric functions are interpreted as being significantly different from one another. We performed this procedure 1000 times per model comparison.

Appendix B*:* Table containing IAPS and IADS stimuli descriptions

ID	Description	Modality	Category	Mean Valence Rating	Mean Arousal Rating
2190	Man	Visual	Neutral	4.83	2.41
2191	Farmer	Visual	Neutral	5.3	3.61
2200	Neutral Face	Visual	Neutral	4.79	3.18
2018	Veiled Woman	Visual	Neutral	5.47	4.76
2102	Neutral Man	Visual	Neutral	5.16	3.03
2377	Woman	Visual	Neutral	5.34	4.93
2038	Neutral Woman	Visual	Neutral	5.09	2.94
2480	Elderly Man	Visual	Neutral	4.77	2.66
2396	Couple	Visual	Neutral	4.91	3.34
2273	Boy	Visual	Neutral	5.41	3.52
2381	Girl	Visual	Neutral	5.25	3.04
2397	Man	Visual	Neutral	4.98	2.77
2411	Girl	Visual	Neutral	5.07	2.86
2383	Secretary	Visual	Neutral	4.72	3.41
2512	Man	Visual	Neutral	4.86	3.46
2595	Woman	Visual	Neutral	4.88	3.71
2745.1	Shopping	Visual	Neutral	5.31	3.26
1908	Jellyfish	Visual	Neutral	5.28	4.88
2309	Girl and Cow	Visual	Neutral	4.89	4.33
1903	Shrimp	Visual	Neutral	5.5	4.25
3100	Burn Victim	Visual	Negative	1.88	5.88
3130	Mutilation	Visual	Negative	1.9	6.56
6350	Attack	Visual	Negative	2.39	7.04
9635.1	Man on Fire	Visual	Negative	2.45	6.29
6510	Attack	Visual	Negative	2.06	7.16
3530	Attack	Visual	Negative	1.8	6.82
3180	Battered Female	Visual	Negative	1.92	5.77
3225	Mutilation	Visual	Negative	1.82	5.95
9332	Crying Woman	Visual	Negative	2.55	5.14
3051	Mutilation	Visual	Negative	2.3	5.62
2345.1	Black Eye	Visual	Negative	2.26	5.5
3060	Mutilation	Visual	Negative	1.79	7.12
3181	Battered Female	Visual	Negative	2.3	5.06
3059	Mutilation	Visual	Negative	2.26	6.39
2055.1	Man in Pool	Visual	Negative	2.84	5.23
3230	Dying Man	Visual	Negative	2.02	5.41

9412	Dead Man	Visual	Negative	1.83	6.72
1050	Snake	Visual	Negative	3.46	6.87
1202	Spider	Visual	Negative	3.27	6.02
1274	Roaches	Visual	Negative	3.17	5.39
7000	Rolling Pin	Visual	Practice	5	2.42
7002	Towel	Visual	Practice	4.97	3.16
7003	Disk	Visual	Practice	5	3.07
7004	Spoon	Visual	Practice	5.04	2
7009	Mug	Visual	Practice	4.93	3.01
7010	Basket	Visual	Practice	4.94	1.76
7012	Rubber Band	Visual	Practice	4.98	3
7020	Fan	Visual	Practice	4.97	2.17
7021	Whistle	Visual	Practice	4.97	4.17
7025	Stool	Visual	Practice	4.63	2.71
709	Alarm Clock	Auditory	Negative	2.78	7.54
285	Attack 2	Auditory	Negative	1.8	7.79
260	Babies Cry	Auditory	Negative	2.04	6.87
115	Bees	Auditory	Negative	2.16	7.03
699	Bomb	Auditory	Negative	3.59	6.15
712	Buzzer	Auditory	Negative	2.42	7.98
420	Car Horn	Auditory	Negative	2.34	7.08
719	Dentist Drill	Auditory	Negative	2.89	6.91
242	Female Cough	Auditory	Negative	2.8	5.39
276	Female Scream 2	Auditory	Negative	1.96	7.77
277	Female Scream 3	Auditory	Negative	1.63	7.79
241	Male Cough	Auditory	Negative	2.46	5.87
292	Male Scream	Auditory	Negative	1.99	7.28
501	Plane Crash	Auditory	Negative	2.74	6.93
105	Puppy	Auditory	Negative	2.88	6.4
275	Scream	Auditory	Negative	2.05	8.16
711	Siren 1	Auditory	Negative	2.61	7.39
422	Tire Skids	Auditory	Negative	2.22	7.52
255	Vomit	Auditory	Negative	2.08	6.59
296	Woman Crying	Auditory	Negative	3.65	5.33
364	Bar	Auditory	Neutral	5.19	5.62
720	Brush Teeth	Auditory	Neutral	4.88	4.18
102	Cat	Auditory	Neutral	4.63	4.91
724	Chewing	Auditory	Neutral	5.34	4.91
132	Chickens	Auditory	Neutral	5.64	4.77
225	Clap Game	Auditory	Neutral	5.96	4.83
113	Cows	Auditory	Neutral	5.45	4.88

410	Helicopter 2	Auditory	Neutral	4.88	5.89
376	Lawnmower	Auditory	Neutral	4.88	4.6
252	Male Snore	Auditory	Neutral	4.01	4.75
170	Night	Auditory	Neutral	5.31	4.6
251	Nose Blow	Auditory	Neutral	4.16	5.14
320	Office 1	Auditory	Neutral	4.23	5.48
373	Paint	Auditory	Neutral	5.09	4.65
627	Rain 1	Auditory	Neutral	4.83	4.65
361	Restaurant	Auditory	Neutral	5.36	5.01
700	Toilet	Auditory	Neutral	4.68	4.03
425	Train	Auditory	Neutral	5.09	5.15
322	Type Writer	Auditory	Neutral	5.01	4.79
262	Yawn	Auditory	Neutral	5.26	2.88
708	Clock	Auditory	Practice	4.34	3.51
701	Fan	Auditory	Practice	4.95	4.41
246	Heart Beat	Auditory	Practice	4.83	4.65
728	Paper 1	Auditory	Practice	4.72	4.35
729	Paper 2	Auditory	Practice	4.3	5.79
705	Phone 2	Auditory	Practice	5.35	4.15
723	Radio	Auditory	Practice	4.52	4.42
382	Shovel	Auditory	Practice	4.33	4.64
722	Walking	Auditory	Practice	4.83	4.97
358	Writing	Auditory	Practice	4.52	4.87

Curriculum Vitae

Stephen R. Pierzchajlo

Current Education

- MSc. in Neuroscience, Brain and Mind Institute, Department of Neuroscience, The Schulich School of Medicine and Dentistry, University of Western Ontario, London, Ontario, 2016 – present.

Past Education

- BSc. with Honors in Psychology, graduated with distinction, Grant MacEwan University, Edmonton, Alberta, 2011 - 2016.

Awards and Scholarships

- NSERC-USRA: Awarded $5624 from NSERC. This allowed me to work all summer as a full-time research assistant in Dr. Christopher Striemer's neuroscience laboratory at MacEwan University and Dr. Kyle Mathewson's EEG laboratory at the University of Alberta.
- MacEwan Internal Scholarship: Awarded $1700 for achieving a GPA of greater than 3.7 in the Bachelor of Science Program.
- MacEwan Internal Scholarship: Awarded $1300 for achieving a GPA of greater than 3.3 in the Bachelor of Science Program.
- Awarded best poster presentation at the 8th annual in-house bachelor's thesis conference for the department of psychology, MacEwan University.

Research Experience

1. Dr. Derek Mitchell, University of Western Ontario
    - I studied the effects of emotionally salient visual and auditory distractors on the brain and on human cognitive performance. I also used a threat of shock paradigm to investigate how induced anxiety influences the processing of low-level visual features. To index these effects, classical psychophysics techniques, as well as recent advances in psychophysical Bayesian model estimation were employed.
    - I investigated alternative methods of data analysis that do not involve the typical frequentist approaches (e.g., null hypothesis significant testing, p-values, etc.). These include Bayesian posterior parameter estimation, as well as various aspects of repeated-measures mixture modelling, likelihood ratios, and nested model’s hypothesis testing.

2. Dr. Christopher Striemer, Grant MacEwan University
    - I completed my honors thesis with Dr. Striemer titled "Can transcranial direct current stimulation affect the magnitude of attentional shift following prism adaptation?" Transcranial Direct-Current Stimulation (tDCS) was used to increase activity in the left and right posterior parietal cortices (PPC) to determine what effects prism adaptation

might have on exogenous attention. Our results indicated that anodal tDCS to the right PPC actually counteracted the effects of the prisms on both tasks compared to the sham (control) condition; and furthermore, anodal stimulation to the left PPC increased the rightward bias induced by prisms on the line bisection task causing the participant to bisect a line further to the right than before the anodal stimulation. These preliminary results are generally consistent with the idea that prisms may influence attention in healthy adults by decreasing activity in right PPC or by increasing activity within the left PPC Additionally, my work in Dr. Striemer's lab has more broadly consisted of investigating the effects of prism adaptation on attention and motor system function.

- I helped perform statistical analyses for a paper published in *Frontiers in Human Neuroscience* titled "Deficits in reflexive covert attention following cerebellar injury".

3. Dr. Kyle Mathewson, University of Alberta

- I helped Dr. Kyle Mathewson run a number of EEG and ERP studies in his laboratory at the University of Alberta. We used EEG to study whether there was greater alpha wave production during the presentation of emotionally charged words due to the increased attention devoted to these words. We also investigated whether alpha wave entrainment was affected by exercise, and whether it could affect our participants' abilities to detect certain entrained colors. Through this training, I learned how to independently run multiple EEG studies. I also helped one of Dr. Mathewson's graduate students create various experimental paradigms using MATLAB.

4. Dr. Rodney Schmaltz, Grant MacEwan University

- I worked with Dr. Schmaltz for an independent research project during my undergraduate degree. The title of our project was "The relationship between self-esteem and conspiracy theory belief as measured using the Generic Conspiracist Belief Scale". Our major focus was to demonstrate the efficacy of the Generic Conspiracist Belief Scale.

Submitted Manuscripts to a Refereed Journal

- Vieira, J.B., Pierzchajlo, S., & Mitchell, D.G.V. (2018). Neural correlates of social and non-social personal space intrusions: the role of the defensive and peripersonal space systems on interpersonal distance regulation (under review).

Manuscripts in Preparation

- Vieira, J.B., Pierzchajlo, S., Tavares, T.P., & Mitchell, D.G.V. Structural correlates of personal space preferences.

Teaching Assistant Experience

- 2015: TA at MacEwan University for Sciences Psychology 267: Perception and Sensation.
- 2016: TA at Western University for Anatomy and Cell Biology 4451: Integrative Neuroscience.
- 2017: TA at Western University for Anatomy and Cell Biology 4451: Integrative Neuroscience.

Conference Presentations

- Pierzchajlo, S.R., & Striemer, C. (2015). Can transcranial direct current stimulation affect the magnitude of attentional shift following prism adaptation? The First Annual Canadian Undergraduate Neuroscience Conference, University of Alberta, and June 24, 2015.
- Pierzchajlo, S.R., & Striemer, C. (2015). Can transcranial direct current stimulation affect the magnitude of attentional shift following prism adaptation? The 8th annual in-house bachelor's thesis conference for the department of psychology, MacEwan University.
- BASICS 2017: Banff annual seminar in cognitive science: The results of my tDCS study were presented by Adam Morril.
- Vieira, J.B., Tavares, T.P., Pierzchajlo, S.R., & Mitchell, D.G.V. (2017). Functional and neuroanatomical correlates of personal space preferences. Society for Neuroscience, Washington, DC, USA.
- Vieira, J.B., Pierzchajlo, S.R., & Mitchell, D.G.V. (2018). Neural correlates of social and non-social personal space intrusions: the role of the peripersonal space and defensive systems. Social and Affective Neuroscience Society Annual Meeting, New York, USA.
- Vieira, J.B., Pierzchajlo, S.R., & Mitchell, D.G.V. (2018). Neural correlates of social and non-social personal space intrusions: the role of the peripersonal space and defensive systems. Inaugural HBHL Research Day, Quebec, Montreal, Canada
- Vieira, J.B., Pierzchajlo, S.R., & Mitchell, D.G.V. (2018). Neural correlates of social and non-social personal space intrusions: the role of the peripersonal space and defensive systems. London Health Research Day, London, Ontario, Canada
- Pierzchajlo, S.R., & Mitchell, D.G.V. (2018). The impact of visual and auditory emotional stimuli on early visual perception. London Health Research Day, London, Ontario, Canada
- Compton, S., Ritchie, M., Gleiss, A., Pierzchajlo, S. R., & Mitchell, D. V.G. (2018). Violent video game play and social cognition: A preliminary exploration of the contribution of callous traits. London Health Research Day, London, Ontario, Canada
- Ritchie, M., Gleiss, A., Pierzchajlo, S. R., & Mitchell, D. V.G. (2018). A preliminary analysis of acute violent media exposure on social cognition as a function of trait empathy. London Health Research Day, London, Ontario, Canada

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Volunteer Experience

- Edmonton's Make-A-Wish Foundation (2014-2016).

Relevant Skills

- Proficiency in psychophysics including designing experiments in E-Prime and performing psychophysical curve fitting (both Bayesian and bootstrapping) using MATLAB and R.
- Trained to independently run EEG/ERP experiments using the EPOCH EMOTIV headset, as well as a 16 channel and 32 channel setup from Brain Products.
- Extensive training for 3 different EEG electrode setups: Active wet, passive wet, and passive dry.
- Experience running classical conditioning experiments and collecting physiological data (e.g., skin conductance response).

- Independently running laboratory experiments using transcranial Direct-Current Stimulation.
- Proficiency in the use of R, MATLAB, and SPSS for statistical analyses.
- Additional expertise using R and MATLAB to analyse data using Bayesian methodologies (Bayes factors, mixture models, nested model’s hypothesis testing, posterior parameter estimation, Markov Chain Monte Carlos Simulation, etc.).
- Competent theoretical and epistemic knowledge of Bayesian methodology.
- Capable of collecting experimental fMRI data, as well as analysing fMRI data using Brain Voyager.
- Extensive knowledge in using E-Prime to both build and run experiments.
- Independent work using Brain Vision Recorder to record EEG data as well as using the MATLAB toolbox ‘eeglab’ to analyse EEG data.
- As a TA, I have mentored several students over the past two years for the course Anatomy and Cell Biology 4451: Integrative Neuroscience.

References

- Dr. Derek Mitchell, Department of Anatomy and Cell Biology, Psychiatry, and Psychology, University of London Ontario.
- Dr. Christopher Striemer, Department of Psychology, MacEwan University.
- Dr. Rodney S. Schmaltz, Department of Psychology, MacEwan University.
- Dr. Kyle Mathewson, Department of Psychology, University of Alberta.