The Impact of Emotional Information on Task Performance in Unimodal vs. Cross-modal Paradigms

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Abstract

Emotional stimuli can disrupt or enhance task performance, and this may depend on the sensory modality involved. In unimodal paradigms (e.g. visual task-irrelevant stimuli during a visual task) emotional stimuli frequently produce distraction effects; it is unclear how emotion affects task performance in cross-modal paradigms (e.g. auditory stimuli during a visual task). This project explored task performance as a function of sensory modality and emotional valence. In Study 1, participants (N=50) completed a visual task in the presence of task-irrelevant negative and neutral images and sounds. Response times and accuracy were disrupted in the presence of visual but not auditory emotional stimuli, particularly when the target and task-irrelevant stimulus appeared simultaneously. In Study 2, participants (N=38) completed an equivalent auditory task. Response times and accuracy were enhanced in the presence of auditory emotional stimuli at the first timepoint but disrupted at later timepoints. There was no effect for visual stimuli.

Keywords

Emotional distraction, emotional enhancement, visual perception, auditory perception, attention, task performance.
Summary for Lay Audience

Emotional information (e.g. emotional facial expressions, threatening animals, explosions) is said to have preferential access to processing resources. This advantage makes it more likely to capture attention and be perceived effectively, compared to neutral information. Many studies have examined how emotional information impacts task performance, but a lot still remains unknown. In some cases, the presence of emotional information is detrimental to performance, while in others it is beneficial. This depends on many factors; one important factor might be the sensory modality through which the task and the task-irrelevant emotional information are presented. Specifically, in unimodal paradigms (e.g. visual task-irrelevant stimuli during a visual task) emotional stimuli frequently produce distraction effects; however, not many studies have examined the effect of emotional content in cross-modal paradigms (e.g. auditory task-irrelevant stimuli during a visual task).

This study is the first to directly compare the impact of emotional content on task performance in unimodal and cross-modal blocks, using realistic images and sounds. Participants were recruited to complete a visual perception task in the presence of task-irrelevant emotional and neutral images and sounds. On the visual detection task, participants indicated on which side of the screen a target stimulus appeared on each trial via button press. Response times and accuracy were worse in the presence of visual but not auditory emotional stimuli, especially when the target and task-irrelevant stimulus appeared at the same time.

A follow-up experiment used an auditory perception task to determine whether these findings extended to tasks presented through other modalities. Participants listened to white noise through headphones and were asked to indicate on which side there was a sound modulation. Accuracy was disrupted in the presence of auditory but not visual emotional stimuli. In the unimodal condition, when targets and task-irrelevant stimuli appeared at the same time, emotional stimuli actually enhanced performance; however, when the targets appeared slightly later, emotion caused a distracting effect. Overall, emotional content produced distraction effects in unimodal but not cross-modal blocks; however, this effect was not consistent over time, and future studies should further examine the time courses of emotional distraction and enhancement.
Co-Authorship Statement

Emma Stewart completed all experimental and written work for this thesis project. This included designing the study, recruiting participants, completing data collection, analyzing data, and writing the written work.

Dr. Derek Mitchell contributed to all aspects of this thesis project including the formulation of the research question, consultation with task design, data analysis, interpretation, and editing of the written work.
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Chapter 1

1 Introduction

As you go about your daily life, there are many different stimuli you could attend to at any given moment; however, certain objects and events are more likely to capture your attention than others. For example, if you were driving down the street and suddenly saw a fight break out nearby, your attention would likely be drawn to it, since it would evoke emotions in you such as fear or worry. Unfortunately, processing a stimulus like this leaves fewer resources for other stimuli. This is a problem if you’re trying to attend to other objects in order to drive safely. Alternatively, if instead of seeing the fight you heard a sound, like someone yelling, this would probably evoke a similar emotional response; however, it may not distract from your driving performance in the same way, since driving depends mostly on the visual modality, which is not directly competing with the sound. Therefore, you will likely be able to attend to what’s around you just as well as before, or maybe even slightly better since the emotional sound may increase arousal and alertness. Many different factors can impact how emotional experiences affect task performance, and understanding these factors is important in determining how real-world emotional situations impact behaviour.

The presence of emotional stimuli during a task has been shown to inhibit task performance in some cases, and enhance it in others. The reasons behind this dichotomy are not well understood; however, several factors appear to impact these distraction and enhancement effects. Distraction effects most likely occur when task-irrelevant emotional stimuli compete for attention with neutral target stimuli. Enhancement may occur because emotional content leads to heightened arousal, producing better overall attentional abilities. Although distraction effects have been well-documented in unimodal visual task paradigms (i.e. visual task-irrelevant stimuli during a visual task), the impact of emotional stimuli in cross-modal task paradigms (e.g. auditory task-irrelevant stimuli during a visual task) is less clear. Since most emotional situations in the real world would involve input from multiple sensory modalities, it is important to explore the impact that each of these would have on one’s ability to perform tasks requiring perception and
attention. Throughout this thesis, I will explore the distracting and enhancing effects of emotional content, how they differ based on the specifics of the task paradigm, and the impact that sensory modality can have in emotional paradigms.

2 Distraction Effects

2.1 Distraction Effects in Non-Emotional Paradigms

When two or more stimuli are presented simultaneously, they cannot both be processed to the same extent as if only one was presented. Instead, the representation of each stimulus (i.e. the neural firing that enables stimulus processing and perception) will suffer (Desimone & Duncan, 1995). For instance, the likelihood of correctly reporting a given target stimulus when it is the only target present is much higher than when other targets are present (Desimone & Duncan, 1995). Some bottom-up features, such as brightness, movement, and size, can impact the extent to which each stimulus representation is affected (Treisman & Gormican, 1988). Additionally, if top-down influence by attention is exerted, the representation of the attended stimulus will increase at the expense of the competing one (e.g. Reynolds, Chelazzi, & Desimone, 1999). Competition also occurs when stimuli are not simultaneous but are presented close in time to one another. One well-documented demonstration of this effect is called the attentional blink (Broadbent & Broadbent, 1987; Raymond, Shapiro, & Arnell, 1992; Reeves & Sperling, 1986). An attentional blink occurs when two stimuli are presented with a short inter-stimulus interval (roughly between 200 and 500ms) and can result in the second stimulus not being perceived (Broadbent & Broadbent, 1987; Raymond et al., 1992).

In unimodal paradigms, competition between stimuli consistently produces distraction effects and worse task performance; however, there have been conflicting findings regarding whether similar distraction effects occur in cross-modal paradigms. For instance, Arrighi, Lunardi, & Burr (2011) found that while the presence of stimuli presented in the same modality worsened performance on a perceptual task, stimuli of a different modality did not. This difference may suggest that separate sensory modalities
draw on separate attentional resources. Despite these results, other studies have observed distraction effects for cross-modal paradigms that are similar to those found in unimodal tasks (e.g. Arnell & Larson, 2002; Bendixen et al., 2010; Jolicoeur, 1999; Sanz, Vuilleumier, & Bourgeois, 2018; Shen, Vuvan, & Alain, 2018). Duncan, Martens, & Ward (1997) found a general distraction effect for any dual-task condition compared to when only one task was performed, but an additional dip in accuracy in the first few hundred milliseconds after presentation of a stimulus only when both tasks were performed in the same modality. Therefore, it is possible that some distraction still occurs across modalities but is reduced compared to unimodal task paradigms.

2.2 Distraction Effects in Unimodal Emotional Paradigms

One key determinant of how much a stimulus will compete for attentional resources is its motivational significance. Emotional information receives preferential access to processing resources, compared to neutral information (Anderson & Phelps, 2001; LeDoux & Phelps, 2008; Vuilleumier, 2005). This is demonstrated by the fact that emotional information is more likely to be processed than neutral information, unconsciously as well as consciously (Tamietto & de Gelder, 2010). For example, emotional facial expressions presented in visual flash suppression tasks are more likely to be perceived through “blindsight” (i.e. processing visual stimuli without conscious awareness) and more likely to reach conscious perception (Oliver, Mao, & Mitchell, 2015) than neutral expressions. This is also the case when the stimulus is a neutral facial expression but is given a negative emotional valence through fear conditioning, confirming that it is the motivational significance and not simply low-level visual features that produce this difference (Vieira, Wen, Oliver, & Mitchell, 2017).

This preferential processing means that emotional stimuli can pull attention away from competing stimuli and inhibit their representations (e.g. Kanske, 2012). As a result, emotional content in unimodal paradigms often produces distraction effects, above and beyond those elicited by non-emotional stimuli. Emotional distraction occurs when emotional, task-irrelevant stimuli pull attention away from neutral target stimuli, resulting
in worse perception of targets and interfering with task performance. For instance, as the

driving example above illustrates, seeing an emotional scene (e.g. a fight) at the side of
the road would likely lead to worse driving performance and an inability to perceive
neutral stimuli relevant to the task.

Emotional distraction effects have been observed in many research studies. For example,
emotional images presented before and after a target shape slowed down responses on a
forced-choice operant task in which participants were asked to indicate what shape they
saw on the screen (Mitchell et al., 2008). Similarly, participants were slower to perform
same-different judgements of neutral stimuli in the presence of task-irrelevant fearful
facial expressions, compared to neutral expressions (Vuilleumier, Armony, Driver, &
Dolan, 2001). They were also less accurate in identifying whether they had previously
viewed a face, in a working memory task, in the presence of emotional stimuli (Dolcos &
McCarthy, 2006). Studies have examined the “emotional attentional blink” or “emotion-
induced blindness,” by presenting an emotional word or image prior to a neutral target
stimulus in a rapid series of visually-presented stimuli. The emotional content
consistently decreases perception of the target and/or prolongs the attentional blink
(Ciesielski, Armstrong, Zald, & Olatunji, 2010; MacLeod, Stewart, Newman, & Arnell,
2017; Mathewson, Arnell, & Mansfield, 2008; Most, Chun, Widders, & Zald, 2005;
Most, Smith, Cooter, Levy, & Zald, 2007). This distraction effect can even occur
retroactively, when an emotional word is presented soon after a target (Choisdealbha,
Piech, Fuller, & Zald, 2017; Most & Jungé, 2008).

2.3 Neural Structures Involved in Unimodal Emotional Distraction Effects

The emotional distraction effects described above can be explained by neurocognitive
mechanisms involved in perception and emotion processing. Distraction effects within a
modality are thought to occur due to competition throughout several cortical and
subcortical regions, such as sensory and motor areas (Duncan, Humphreys, & Ward,
1997). Specifically, when two or more stimuli are shown at the same time, a reduction in
the neuronal firing rate produced by each representation will occur, presumably caused by inhibitory interneurons (Reynolds et al., 1999); however, one representation may be favoured at the expense of the other depending on attentional deployment (e.g. Desimone & Duncan, 1995). There are many neural regions involved in influencing which representation remains stronger, most notably those involved in emotion processing, emotion regulation, and attention (e.g. Amaral, Behniea, & Kelly, 2003; Armony & LeDoux, 1999; Mitchell & Greening, 2012).

Literature describing emotion-cognition interactions frequently identifies key neural networks, involved in executive functions and affective processing (e.g. Blair & Mitchell, 2009; Dolcos, Iordan, & Dolcos, 2011; Mitchell & Greening, 2012). Emotional distraction occurs when there is competition between these two systems (e.g. Moore, Shafer, Bakhtiar, Dolcos, & Singhal, 2019). The dorsal executive network is comprised of the dorsolateral prefrontal cortex (PFC) and the lateral parietal cortex (LPC), areas traditionally known as the frontoparietal attention network. This network is involved in keeping goal-relevant information stored in working memory, and greater activation of this network is associated with responses to task-relevant target stimuli (Iordan, Dolcos, & Dolcos, 2013). The ventral affective network is comprised of the amygdala, and regions of the prefrontal cortex (e.g. medial PFC, ventrolateral PFC) involved in emotion regulation functions through their connections to the amygdala. Greater activation of these affective regions is associated with more distraction and impaired performance in the presence of emotional stimuli, as well as disrupted activation in the dorsal executive network (e.g. Dolcos & McCarthy, 2006). The interaction between these systems can account for individual differences in emotional distractibility (Dolcos, 2009), and longer-term disruptions have even been linked to psychopathology such as depression (Drevets & Raichle, 1998; Mayberg, 1997).

One particularly relevant structure in emotional distraction is the amygdala. The amygdala is a grey matter structure in the medial temporal lobe involved in emotion processing (e.g. Phelps & LeDoux, 2005) and therefore likely plays an important role in emotional distraction effects. The amygdala shows increased activation in response to fearful and other emotional content (e.g. Vuilleumier et al., 2001; Whalen et al., 1998).
and influences attentional and perceptual functions (Armony & LeDoux, 1999; Armony, Servan-Schreiber, Cohen, & LeDoux, 1997; Whalen et al., 1998) through connections with cortical regions (Amaral et al., 2003). The amygdala has extensive feedback connections to visual cortical areas as far back as the primary visual cortex (V1; Amaral et al., 2003) and amygdalar responses influence emotion-specific activation in the extrastriate cortex, which is involved in visual perception (Morris et al., 1998). This influence indicates that once information about the emotional stimulus reaches the amygdala, feedback from the amygdala may enhance representation of an emotional stimulus in sensory processing areas (Armony & LeDoux, 1999; Armony et al., 1997; Whalen et al., 1998). This allows emotional content to pull attention away from neutral target stimuli. In addition, the areas involved in directing attention to relevant stimuli (e.g. dorsolateral PFC) are less active when the stimulus is emotional, suggesting that the amygdala may be enhancing the representations of emotional stimuli the same way that the frontoparietal attention network does for neutral stimuli, and that there is a potentially inhibitory relationship between these regions (Amting, Greening, & Mitchell, 2010; Mitchell & Greening, 2012).

There is some debate as to whether emotional processing occurs automatically or depends on higher-order perceptual and attentional resources. While some theories assume that sensory information must pass through cortical areas before reaching the amygdala (e.g. Pessoa & Adolphs, 2010), it has been suggested that visual emotional content may be able to activate the amygdala through subcortical channels (LeDoux, Sakaguchi, & Reis, 1984; Vuilleumier et al., 2002) involving the superior colliculus and pulvinar (Morris, Öhman, & Dolan, 1999; Morris, de Gelder, Weiskrantz, & Dolan, 2001). The presence of this pathway is supported by Vuilleumier and colleagues (2001) who found that fearful expressions can impact performance on a task even when emotional stimuli are not the targets of attention; however, this theory is controversial (see Pessoa & Adolphs, 2010). These researchers argue that the anatomy for this system is not well mapped-out, there is no evidence that it would be necessary, and there are multiple routes involving the cortex that could account for the speed at which emotion is processed (Pessoa & Adolphs, 2010). Additionally, the existence of a subcortical pathway would suggest a mechanism through which emotion could be encoded independently of attention and awareness;
however, evidence exists that attention does impact emotional processing. For instance, behavioural and functional magnetic resonance imaging (fMRI) evidence exists which suggests that attentional processing load impacts emotional stimulus encoding (e.g. Mitchell et al., 2007; Pessoa, McKenna, Gutierrez, & Ungerleider, 2002), casting doubt on emotional processing as a completely automatic process. It is, however, possible that emotion can be processed automatically, but still influenced by attentional resources (Shafer & Dolcos, 2010). One possibility is that emotional information transmitted through the theoretical subcortical route elicits transient activity in areas such as the amygdala and medial PFC that is then suppressed by attentional mechanisms and therefore not detectable through fMRI (see Mitchell et al., 2007), which reconciles these two positions to some extent. This idea is supported by MEG evidence that the amygdala can distinguish emotional and neutral stimuli within the first 30 milliseconds of stimulus presentation (Luo, Holroyd, Jones, Hendler, & Blair, 2007); however, as stated previously, Pessoa and Adolphs (2010) argue that there may be multiple pathways through the cortex that may account for this.

3 Enhancement Effects

3.1 Enhancement Effects in Unimodal Emotional Paradigms

Despite the many examples previously mentioned of emotion producing distraction effects, it can also enhance task performance in some cases. Enhancement has been demonstrated in stimulus-detection tasks (e.g. Padmala & Pessoa, 2008), visual search paradigms (e.g. Barbot & Carrasco, 2018), and long-term memory tasks (e.g., Bradley, Greenwald, Petry, & Lang, 1992; Christianson, 1992). The emotional valence of these stimuli and subsequent increased arousal might increase their sensory representations as well as improve overall attention and performance. This depends on many factors including the task demands and stimulus timing.
One key factor that influences whether observed effects are distracting or enhancing in nature is whether the emotional content is the task-relevant target or a task-irrelevant stimulus (Blair & Mitchell, 2009). For instance, participants perform better at target detection when target stimuli are paired with electric shocks through classical conditioning (Padmala & Pessoa, 2008). In addition, while an emotional stimulus preceding a neutral target stimulus extends the duration of the attentional blink, the blink is attenuated when the emotional stimulus is the target (e.g. Schwabe et al., 2011). In other words, an emotional stimulus that closely follows a neutral stimulus is more likely to be perceived than if it had also been neutral. Studies comparing neutral, emotional, and highly arousing emotional words demonstrate that this is due to the arousal value of the stimulus to a greater extent than its valence (e.g. Anderson, 2005). There is some evidence, from a lesion study, that this effect depends on proper functioning of the amygdala (specifically the left amygdala; Anderson & Phelps, 2001). Still, other evidence suggests the amygdala may not be crucial for all attentional capture by emotional stimuli when emotional stimuli are task-irrelevant rather than targets (Piech et al., 2011). Therefore, more work is needed to determine what neural structures are necessary for these differing effects to take place.

Although task-irrelevant emotional stimuli are often distracting, even they can sometimes enhance task performance if they are not in direct competition with target stimuli. For example, emotional content leads to faster response times and better performance in visual search paradigms (Barbot & Carrasco, 2018; Becker, 2010; Olatunji, Ciesielski, Armstrong, & Zald, 2011; Phelps, Ling, & Carrasco, 2006), in contrast with basic stimulus perception tasks. Phelps and colleagues (2006) also found that not only does emotion enhance the effect of having attention cued to a target’s location, it also improves contrast sensitivity regardless of attention.

Even in basic perception studies, aspects of the paradigm can be altered to reduce competition between targets and task-irrelevant stimuli. Bocanegra and Zeelenberg (2009) demonstrated that, although task-irrelevant emotional cues impaired identification of targets at short inter-stimulus intervals and with good stimulus visibility, when the inter-stimulus intervals were increased or cue visibilities decreased, they actually
improved performance. Therefore, although arousal and attention are likely increased any time an emotional stimulus is presented, enhancement effects are thought to be observed when competition between task-irrelevant emotional stimuli and target stimuli is low (or when the emotional stimuli are the task targets), since these are the cases in which larger distraction effects cannot cancel out smaller enhancement effects.

3.2 Enhancement Effects in Cross-Modal Emotional Paradigms

One effective way to reduce the competition between stimuli and thereby reduce distraction effects is to present the target stimuli and the task-irrelevant emotional stimuli through different sensory modalities. There has been conflicting evidence regarding whether separate perceptual resources exist for separate sensory modalities (Arnell & Larson, 2002; Duncan et al., 1997) and this is particularly important in the case of emotional stimuli due to their impact on performance. If stimuli presented through different modalities do not directly compete with and inhibit one another as stimuli of the same modality do, then the alerting and arousing aspect of emotional content may produce noticeable enhancement effects.

In addition, there is some evidence that even in neutral paradigms, stimulus perception may be enhanced by simultaneously presenting another stimulus in a different sensory modality, through multisensory integration. For example, a simultaneous sound can improve performance on visual perception tasks (Gleiss & Kayser, 2013; Kayser, Philiastides, & Kayser, 2017; Stein, London, Wilkinson, & Price, 1996), as does somatosensory information for auditory perception tasks (Kayser, Petkov, Augath, & Logothetis, 2005). This effect is thought to be produced by multisensory neurons in the cortex and superior colliculus (Kayser & Logothetis, 2007) with feedback connections to sensory cortical areas. This effect of multisensory integration, in combination with the increased arousing effect of emotion, may contribute to performance enhancement effects in the presence of cross-modal emotional stimuli.
The majority of research on distraction effects has been done using unimodal paradigms (e.g. visual task-irrelevant stimuli during a visual task); however, when studies have examined cross-modal tasks (e.g. auditory task-irrelevant stimuli during a visual task), emotion has produced enhancement effects in several cases. For instance, Max, Widmann, Kotz, Schröger, & Wetzel (2015) had participants categorize visual stimuli while task-irrelevant sounds were played. They found that infrequent “oddball” sounds produced distraction compared to a “standard” (i.e. more frequent) tone, regardless of valence; however, when they directly compared negative and neutral environmental stimuli, they found that negative sounds produced faster responses than neutral sounds. Similarly, Kryklywy & Mitchell (2014) found improved accuracy on a visual localization task when concurrent auditory stimuli were negative in valence. To our knowledge, only one study directly compared the impact of emotion in unimodal and cross-modal paradigms, using a language task. They demonstrated distraction effects when both the targets and task-irrelevant emotional stimuli were visual but enhancement effects when the task-irrelevant stimuli were auditory (Zeelenberg & Bocanegra, 2010).

Despite this evidence that cross-modal emotional tasks produce enhancement effects, some null results and even distraction effects have still been observed (Hjärtström, Sörman, & Ljungberg, 2019; Parmentier, Fraga, Leiva, & Ferré, 2019); however, this is likely not caused by the emotional content itself but by other features of the task. For example, infrequent “oddball” stimuli tend to produce distraction effects, compared to “standard” stimuli (i.e. the stimuli played most frequently throughout the task). Therefore, if emotional stimuli are included as oddballs, this feature may cancel out the enhancement effect produced by the emotional content. Interestingly, Hjärtström and colleagues (2019) also compared the impact of sadness and anger in task-irrelevant stimuli, finding that sadness produces longer response times than anger. Additionally, Parmentier and colleagues (2019) looked specifically at disgusting vs. neutral sounds and found no difference in their effect. These results suggest that stimuli evoking different emotions may produce smaller or larger cross-modal enhancement effects than others and that the impact of different emotions should be further examined.
3.3 Neural Structures Involved in Emotional Enhancement Effects

The enhancement effects of emotional stimuli are likely due, in part, to increased alertness and arousal that promote better attention to target stimuli; therefore, neural structures involved in alertness and arousal may play a key role. The locus coeruleus (LC) is a structure in the pons of the brainstem that is involved in arousal and is the main source of norepinephrine in the brain (Dahlström and Fuxe, 1964; Moore and Bloom, 1979). The LC has been associated with the sleep-waking cycle, for instance, firing quickly during waking and more slowly or undetectably during different phases of sleep (Aston-Jones and Bloom, 1981). Within waking states, it has also been linked to arousal levels, varying from drowsiness to focused attention to distractibility and anxiety (Aston-Jones & Cohen, 2005). LC activation is frequently accompanied by autonomic responses, as a result of input from the nucleus paragigantocellularis which also sends signals to spinal sympathetic areas (Aston-Jones, Rajkowski, Kubiak, Valentino, & Shipley, 1996). LC neurons show increased activity in response to intense, conspicuous stimuli, and stimuli made salient through other means, including stimuli with emotional significance, and stimuli that are made emotional through conditioning (e.g. Aston-Jones et al., 1996; Rasmussen & Jacobs, 1986), as well as stressors and noxious stimuli (Aston-Jones et al., 1996). Any stimuli that produce a behavioural orienting response and disrupt ongoing behaviour tend to strongly activate the LC (Aston-Jones & Bloom, 1981). It appears equally responsive to stimuli of all sensory modalities (Aston-Jones et al., 1996). Activation latency in the LC is also associated with behavioural response times (Aston-Jones, Chiang, & Alexinsky, 1991).

The LC exhibits either phasic or tonic firing patterns which show different associations with emotional distraction and task performance. In general, phasic activity occurs in response to goal-relevant stimuli (Aston-Jones & Cohen, 2005) and may occur in response to emotionally salient stimuli as well (Aston-Jones et al., 1996). High phasic activity along with moderate tonic activity is related to focus and better task performance (Aston-Jones, Rajkowski, & Cohen, 1999). Meanwhile, low phasic activity and high tonic activity is associated with distractibility and reactivity to task-irrelevant stimuli, and
is thought to represent a state of behavioural flexibility (Aston-Jones et al., 1999). It is possible that the orbitofrontal cortex (OFC) and the anterior cingulate cortex (ACC) might play a role in determining which LC firing pattern occurs. The OFC, which plays an important role in reward processing, and the ACC, which is involved in processing negative feedback, including monetary loss and social exclusion, both send strong projections to the LC (Aston-Jones & Cohen, 2005).

The LC has connections to many areas of the brain including the cerebral cortex, hippocampus, thalamus, midbrain, brainstem, cerebellum, and spinal cord (e.g. Foote, Bloom, & Aston-Jones, 1983); however, it shows especially dense connections with the prefrontal and parietal areas, and sends norepinephrine signals to these regions (Aston-Jones & Cohen, 2005; Galvao-Carmona et al., 2014). As mentioned previously, these are regions that play an important role in directing attention to task-relevant target stimuli, and are involved in producing an “alerting” effect. There is also some evidence that the LC has connectivity to the salience network, which includes the ACC and anterior insula and is involved in “switching” activation from the default mode network to the frontoparietal attention network (Menon & Uddin, 2010; Uddin, 2015). Interestingly, the ACC and insula also receive input from the amygdala (e.g. Vogt & Pandya, 1987; Uddin, 2015) and are implicated in emotion processing and regulation (e.g. Bush, Luu, & Posner, 2000; De Martino, Kalisch, Rees, & Dolan, 2009; Dolan, 2002). The ACC in particular is thought to be involved in resolving attentional conflict produced by salient emotional stimuli by regulating amygdala activity (e.g. Etkin, Egner, Peraza, Kandel, & Hirsch, 2006). Finally, these regions, along with the OFC, have been shown through functional MRI to be involved in attentional capture by emotional content (Schwabe et al., 2011). Although these structures likely play a role in the effect of emotion on task performance, more research is needed to determine their impact.

Signals from these attentional networks are thought to enhance the neural representation of target stimuli (Desimone & Duncan, 1995; Reynolds et al., 1999), increase awareness of those stimuli (Lumer & Rees, 1999; Sumner, Tsai, Yu, & Nachev, 2006), and improve task performance by sending feedback signals to cortical areas involved in sensory perception (e.g. Greening, Finger, & Mitchell, 2011; Mitchell & Greening, 2012;
Mitchell et al., 2009). Therefore, increased activity of the LC, produced by highly arousing emotional stimuli, may enhance task performance through LC norepinephrine signals to attentional regions of the cortex, which then project back to sensory regions involved in the perception of target stimuli.

4 Factors Affecting Emotional Distraction and Enhancement Effects

We have previously discussed the task paradigms that are likely to elicit emotional distraction and enhancement effects and the neural structures that may be involved in producing them; however, many factors can influence whether these effects occur and to what extent. In this section, we will discuss several key factors that may modulate emotional distraction and enhancement effects.

4.1 Perceptual and Working Memory Load

In designing a task to elicit distraction effects, it is important to consider the demands of the task, what resources are being consumed, and how this might impact the effect of emotional stimuli. For instance, even in non-emotional paradigms, factors such as perceptual and cognitive load can lead to increased or decreased distraction, depending on the type of load (Lavie, 1995).

Recently, researchers have applied these findings to emotional tasks, demonstrating a double dissociation of the effects of perceptual and working memory loads. While high perceptual load produces reduced distraction effects, high working memory load increases distraction effects (Tavares, Logie, & Mitchell, 2016). According to Lavie’s load theory of selective attention (Lavie, 2000; Lavie, Hirst, de Fockert, & Viding, 2004), tasks with high perceptual load may consume processing resources, which prevents task-irrelevant stimuli from being processed. On the other hand, suppressing distraction by task-irrelevant stimuli may require cognitive resources which get depleted by high
working memory load, leading to greater distraction effects (e.g. De Fockert et al., 2001; Lavie, 2000; Lavie et al., 2004; San Miguel, Corral, & Escera, 2008). This theory is supported by event-related potential data (e.g. Zhang, Chen, Yuan, Zhang, & He, 2006) and fMRI data showing reduced activation of the amygdala and medial PFC in the presence of higher perceptual processing load (Mitchell et al., 2007; Munka & Berti, 2006).

4.2 Cognitive Control

As stated above, although encoding of emotional stimuli may be less susceptible to attentional processing than that of neutral stimuli, it is unlikely to be purely automatic and is likely influenced by cortical processes as well. Cognitive control is one factor that may vary depending on the task demands and between participants, and could therefore be a potential source of variance in emotional distraction studies. Many studies have demonstrated reduced emotional distraction effects as a result of increased cognitive control. This is true for both negatively- and positively-valenced emotional stimuli (Straub, Kiesel, & Dignath, 2019). Modulating cognitive control can be achieved by increasing the task difficulty (Grützmann, Riesel, Kaufmann, Kathmann, & Heinzel, 2019), including rewards (Walsh, Carmel, & Grimshaw, 2019) or providing information about the nature of the emotional stimulus (Kennedy, Newman, & Most, 2018). Additionally, promoting proactive, rather than reactive control by displaying task-irrelevant stimuli more frequently also reduces distraction effects (Grimshaw, Kranz, Carmel, Moody, & Devue, 2018), and increasing the frequency of negatively-valenced stimuli is more effective than cueing the valence (Schmidts, Foerster, Kleinsorge, & Kunde, 2020).

4.3 Timing of Stimulus Presentation

Most studies examining the impact of emotional stimuli present short emotional stimuli before and/or after the target stimuli; however, there may be several advantages to using
longer task-irrelevant stimuli and presenting the target stimuli while the task-irrelevant stimulus is present. First, in the case of auditory task-irrelevant stimuli, it may take longer for the emotional valence to become apparent and therefore for performance effects to occur. In addition, distraction and enhancement may show different time course effects such that they appear only when the target stimuli and task-irrelevant stimuli are presented very close in time, or only at later timepoints. Many studies using sequential presentations have shown that distraction effects typically occur in the first few hundred milliseconds following task-irrelevant stimulus onset (e.g. Broadbent & Broadbent, 1987; Raymond et al., 1992); however, it is not clear how timing impacts distraction when targets are presented during a longer task-irrelevant stimulus presentation. Enhancement effects may only emerge when the onset difference between the task-irrelevant stimuli and target stimuli are greater and there is less competition between them, as demonstrated in a previous unimodal study (Bocanegra & Zeelenberg, 2009). On the other hand, one study using a dual-task paradigm demonstrated that a rapid sensory facilitation may precede a slower attentional bias to emotional information (Bekhtereva, Craddock, Gundlach, & Müller, 2019), indicating that enhancement effects might appear earlier than distraction effects. Overall, the temporal dynamics of emotional distraction has not been explored using continuous task-irrelevant stimuli, and much remains unknown about the time course of emotional enhancement effects and how distraction and enhancement interact over time.

4.4 Positive vs. Negative Emotional Valence

More studies have examined the effect of negative emotional stimuli than positive emotional stimuli, and they may produce different effects in some cases. Although positive stimuli typically impact task performance similarly to negative stimuli (e.g. Grimshaw et al., 2018; Gupta, Hur, & Lavie, 2016; Mitchell et al., 2008; Most et al., 2007), in some cases, positive stimuli did not have an impact on performance (e.g. Cohen-Gilbert & Thomas, 2013; Kryklywy & Mitchell, 2014). Additionally, distraction by positive stimuli does not always appear to be reduced by perceptual load manipulations (Gupta et al., 2016) or pre-cueing of image valence (Most et al., 2007). On
the other hand, increasing the frequency of task-irrelevant stimuli seems to reduce distraction for both positive and negative stimuli (Grimshaw et al., 2018). Since the impact of negative emotional stimuli has been better established, comparing negative and neutral stimuli may be an ideal starting point for studies examining emotional distraction and enhancement; however, in time it will be important to extend these findings by examining positive stimuli as well.

5 Current Study

As described above, emotional content can produce either distraction or enhancement effects, and many different variables seem to impact which effect will occur and how large the effect will be. One important factor is the sensory modality through which the stimuli are presented. The current study aimed to examine the effect that the sensory modality of the target task and task-irrelevant stimuli had on performance. It did so by directly comparing the impact of emotional stimuli in unimodal and cross-modal paradigms. In the majority of unimodal paradigms, the target stimuli and task-irrelevant emotional stimuli are directly competing throughout the sensory processing pathway. In cross-modal paradigms, on the other hand, there is less direct competition. As a result, by including cross-modal blocks, we hoped to examine the effects of emotional content when distraction effects were reduced. To our knowledge, only one previous study has directly compared the effects of emotion in unimodal and cross-modal paradigms, by presenting negative and neutral words through the visual and auditory modalities (Zeelenberg & Bocanegra, 2010). We aimed to extend these results to image and sound stimuli, which are relevant to many real-world emotional contexts. Because the impact of negative stimuli has been more thoroughly examined, we chose to focus on comparing negative and neutral stimuli in the current study; however, it will be important to explore the impact of positive stimuli in cross-modal paradigms in future research as well.

We hypothesized that unimodal paradigms produce distraction effects wherein emotional stimuli compete with neutral task stimuli for representation, outweighing any enhancement effects of emotion. On the other hand, cross-modal paradigms likely
produce greatly reduced distraction effects and maybe even enhancement effects due to minimal direct competition between targets and task-irrelevant stimuli. We aimed to generalize this effect to tasks presented through non-visual modalities by presenting negative and neutral images and sounds during an auditory detection task.

The current study also aimed to explore the time course effects of emotional distraction and enhancement by presenting targets at three different timepoints (0ms, 2000ms, and 4000ms following task-irrelevant stimulus onset) while the task-irrelevant stimuli were presented continuously. Two different target contrasts were used in each of the current experiments, to avoid ceiling effects for the easier contrast and a reduction in emotional distraction effects for the more difficult contrast, as a result of higher perceptual load (e.g. Lavie, 1995). To avoid increased cognitive control, negative and neutral stimuli were presented with equal frequency, and stimuli were presented randomly; however, individual differences in attentional control and emotion regulation ability may have influenced the effect of emotional stimuli (Goldsmith, 2018; Peers & Lawrence, 2009).
Chapter 2

6 Experiment 1: Visual Target Stimuli

6.1 Methods

6.1.1 Participants

Fifty healthy adult participants between the ages of 18 and 45 (Mage = 24.92 years, SD = 6.73 years, 64% female) completed the study. Participants were recruited via the Western OurBrainsCAN Research Registry, social media advertisements, flyers around the Western campus or elsewhere in London, and emails to previous participants who expressed interest in being contacted. Participants were eligible if they were between the ages of 18 and 45 and reported having no vision and hearing difficulties, colour blindness, physical health conditions, recent head trauma or current Axis 1 disorders with the exception of substance abuse disorders. All participants provided written informed consent. Each person received $15 per hour (a full session lasted 2 hours). Participants were informed that they could end their participation at any time throughout the study. This procedure was approved by the University of Western Ontario Health Sciences Research Ethics Board.

6.1.2 Procedure

Upon arriving for the study visit, participants completed 12 blocks of a visual detection task and 2 stimulus-rating tasks. All computerized tasks were completed using a Lenovo Legion Y520 laptop and Sony MDR ZX110 On-Ear headphones. The initial brightness was set to the highest setting and the sound to 70% volume; at this level the volume of the sounds ranged from 66.8dB to 74.6dB SPL. Participants were allowed to adjust the lighting and sound levels for comfort (n = 9). The Extech Sound Level Meter was used to assess the volume of the task-irrelevant sounds.
6.1.3 Visual Detection Task

The visual detection task required participants to indicate on which side of the screen a symbol appeared on each trial. The symbol was a Gabor patch, a sinusoidal grating of vertical lines within a Gaussian envelope. Participants were asked to click either the “1” or “2” key on the keypad to indicate “left” or “right” respectively. Two intensity contrast levels were used, corresponding to 12% and 25% deviation from the background intensity. Based on previous pilot data (Pierzchajlo & Mitchell, unpublished data), the largest effect of emotional valence in a similar experimental task occurs when accuracy is close to 75%, therefore the contrast levels selected were those that produced accuracy close to this level. Two different contrast levels were used due to the risk of ceiling effects and because high perceptual load (i.e. a more difficult task) has been shown to minimize emotional distraction effects (Mitchell et al., 2007; Tavares et al., 2016). While participants completed the task, they were also presented with images and sounds. These stimuli were presented for 6 seconds each, during which 3 Gabor patches were displayed at 0ms, 2000ms and 4000ms following stimulus onset. Three Gabor-patch onset times were used due to evidence that distraction-related effects to emotional visual stimuli are highest in the first 500ms following stimulus onset (e.g. Bocanegra & Zeelenberg, 2009); however, it is possible that emotional auditory stimuli need more processing time for their content to be perceived. Due to the dynamic nature of the stimuli, a percept of the object producing the sound may be formed over time rather than immediately at the onset, the way it might for a visual stimulus. The trials were broken up into blocks based on the modality and contrast level. The order of the blocks was counterbalanced across participants, always alternating modality every block and contrast every 2 blocks. The image and sound stimuli were selected from the International Affective Picture Stimulus database (IAPS; Lang, Öhman, & Vaitl, 1988) and the International Affective Digitized Sounds database (IADS; Bradley & Lang, 1999) based on their valence ratings, which ranged from 1-9 (with lower scores indicating negatively valenced stimuli and higher scores indicating positive stimuli). For the experiment, negative stimuli were selected from those with a rating below 4, and neutral stimuli from those with ratings between 4 and 6 in valence. Sounds were rated as more emotionally arousing than images regardless of the valence; however, the difference scores between ordered neutral and negative
stimuli were not significantly different between images and sounds. Low-level physical properties of the visual stimuli were compared via wavelet analysis as per Krusemark and Li (2011). Negative and neutral visual stimuli did not differ on low-level perceptual characteristics of luminance values (t(38) = 0.17; p = 0.87) or spatial frequency in any energy band (all p’s > 0.05 uncorrected). Negative and neutral auditory stimuli were selected so that they did not differ significantly on root-mean-squared amplitude, onset amplitude, mean harmonicity, spectral centroid or spectral entropy (all p’s > 0.05 uncorrected). These tasks were preceded by an introduction block, an image practice block and a sound practice block, which used different stimuli than the task itself. The layout and timings of the task can be found in Figure 1.

**Figure 1.** The visual detection task. Participants were instructed to click “1” or “2” on the keypad to indicate if the Gabor patch appeared on the left or right side of the screen, respectively (Photograph from Gallice, 2009).
6.1.4 Rating Tasks

Following the visual detection task, each participant completed an image rating task and a sound rating task. During the rating tasks, participants were shown each stimulus again and asked to rate them on the parameters of valence, arousal, and dominance. The layout and timings of the tasks can be found in Figure 2.

![Diagram of the visual and auditory rating tasks]

**Figure 2.** The visual and auditory rating tasks. Participants were asked to provide ratings for each previously shown stimulus, on the dimensions of valence, arousal, and dominance.

6.1.5 Data Analyses

We excluded outlier trials for each participant if response times were less than 200ms or greater than 3 standard deviations above the mean for that participant in that trial type (e.g. image, negative, 25% contrast, timing 1). Next, we found the total number of correct responses for each participant for each trial type. Four participants were excluded for
having no correct responses for one or more trial types. Two additional participants were excluded because their accuracy levels were more than 3 standard deviations above or below the mean for one or more trial types. This left 44 participants for the main analyses.

A 4-way repeated measures analysis of variance (ANOVA) was performed using the within-subjects factors of modality (image, sound), valence (negative, neutral), contrast (easy, difficult) and trial timing (1, 2, 3). As in prior work (Mitchell et al., 2008; Tavares et al., 2016), the primary outcome of interest was response time, though accuracy was also examined as a secondary outcome measure. We were particularly interested in the interaction between valence and modality. Greenhouse-Geisser adjusted degrees of freedom were used when the assumption of sphericity was violated.

6.2 Results

6.2.1 Response Time Data Analysis

We conducted a 2 (Modality: image, sound) x 2 (Valence: negative, neutral) x 2 (Contrast: 25%, 12%) x 3 (Trial timing: 0ms, 2000ms, 4000ms) repeated measures ANOVA using response times as the outcome of interest. All p-values for follow-up contrasts are Bonferroni-adjusted. The analysis revealed main effects of modality (F(1,43)=70.53, p<.001), emotional valence (F(1,43)=8.49, p=.006), target contrast (F(1,43)=123.82, p<.001), and trial timing (F(1.08,46.48)=185.72, p<.001). These effects were qualified by significant interactions.

Because our primary objective was to determine the impact of valence on target processing, we first examined any interactions involving valence. We predicted that emotional content would be more distracting on unimodal (image) trials. In line with this prediction, a significant modality x valence interaction emerged (F(1,43)=12.57, p=.001; Figure 3); response times were significantly slower in the presence of negative relative to neutral visual stimuli (t(43)=3.50, p=.002), but not auditory stimuli (t(43)=-0.55, p=1.00). We also predicted that the effects of task-irrelevant auditory and visual stimuli would
show different time courses. An interaction between valence and trial timing (F(1.24, 53.30)=3.84, p=.047) showed that negative stimuli produced significantly longer response times than neutral stimuli at timepoint 1 (t(43)=2.70, p=.03); however, there was no significant difference at timepoint 2 (t(43)=1.76, p=.26) or timepoint 3 (t(43)=1.30, p=.60). There was no significant modality x valence x trial timing interaction.

![Graph showing response time differences](image)

**Figure 3.** A significant modality x valence interaction was observed (F(1, 43)=12.57, p=.001). In the unimodal condition only (i.e. visual task-irrelevant stimuli during a visual task), response times were slower during negative trials than neutral trials (t(43)=3.50, p=.002).

We also found significant modality x contrast (F(1,43)=18.96, p<.001), modality x timing (F(1.09,46.89)=128.13, p<.001) and contrast x timing (F(1.15,49.36)=23.70, p<.001) interactions. These were qualified by a significant modality x contrast x timing interaction (F(1.10,47.11)=22.14, p<.001; Figure 4). To better characterize this interaction, three 2 x 2 ANOVAs were performed examining the interaction between modality and contrast at each timepoint. The modality x contrast interaction was only
significant for timepoint 1 (F(1,43)=23.49, p<.001), not timepoint 2 (F(1,43)=2.44, p=.13) or timepoint 3 (F(1,43)=.15, p=.70). At timepoint 1, response times were longer during the difficult contrast for both images and sounds; however, this was more pronounced for images (t(43)=−6.84, p<.001) than sounds (t(43)=−6.26, p<.001).

Figure 4. A significant modality x contrast x timing interaction was observed (F(1.10,47.11)=22.14, p<.001). At timepoint 1, for the unimodal condition (i.e. visual task-irrelevant stimuli during a visual task), response times were longer during the difficult contrast (t(43)=−6.84, p<.001). This was also true in the cross-modal condition (i.e. auditory task-irrelevant stimuli during a visual task), but to a lesser extent (t(43)=−6.26, p<.001).

6.2.2 Accuracy Data Analysis

We then conducted a second repeated measures ANOVA using the proportion of correct responses to total valid responses as the dependent variable. This also revealed main effects of modality (F(1,43)=48.51, p<.001), emotional valence (F(1,43)=8.29, p=.006),
target contrast (F(1,43)=47.74, p<.001), and trial timing (F(1.05,44.97)=58.07, p<.001). These effects were qualified by significant interactions.

Again, we predicted that emotional content would be more distracting on unimodal (image) trials. In line with this prediction, a significant modality x valence interaction emerged (F(1,43)=9.92, p=.003). This was qualified by a modality x valence x trial timing interaction (F(1.47,63.07)=5.04, p=.017; Figure 5). Follow-up analyses revealed that the modality x valence interaction was significant only at the first trial timing (F(1,43)=11.36, p=.002). It was non-significant at timepoint 2 (F(1,43)=1.88, p=.18) and timepoint 3 (F(1,43)=.16, p=.69). At timepoint 1, negative stimuli produced lower accuracy than neutral stimuli only for images (t(43)=−3.30, p=.004) but not for sounds (t(43)=.73, p=.94).

Figure 5. A significant modality x valence x timing interaction was observed (F(1.47, 63.07)=5.04, p=.017). At timepoint 1, in the unimodal condition only (i.e. visual task-irrelevant stimuli during a visual task), accuracy was lower during negative trials than neutral trials (t(43)=−3.30, p=.004).
Two-way interactions were also found between modality and contrast (F(1,43)=23.47, p<.001), modality and trial timing (F(1,05,44.98)=50.59, p<.001) and contrast and trial timing (F(1,25,53.79)=34.67, p<.001). These were qualified by a modality x contrast x trial timing interaction (F(1,27,54.41)=30.69, p<.001; Figure 6). Follow-up analyses revealed that the modality x contrast interaction was only significant at timepoint 1 (F(1,43)=36.77, p<.001) but not timepoint 2 (F(1,43)=3.65, p=.06) or timepoint 3 (F(1,43)=.84, p=.37). At timepoint 1, accuracy was higher for the easier contrast on both image and sound trials; however, this was more pronounced for image trials (t(43)=7.08, p<.001) than sound trials (t(43)=3.31, p=.004).

Figure 6. A significant modality x contrast x timing interaction was observed (F(1,27,54.41)=30.69, p<.001). At timepoint 1, for the unimodal condition (i.e. visual task-irrelevant stimuli during a visual task), accuracy was lower during the difficult contrast (t(43)=7.08, p<.001). This was also true in the cross-modal condition (i.e. auditory task-irrelevant stimuli during a visual task), but to a lesser extent (t(43)=3.31, p=.004).
6.2.3  Rating Task Data Analysis

Participant ratings on valence and arousal dimensions were examined using 2 (modality) x 2 (valence) ANOVAs. The valence rating analysis showed no effect of modality (F(1,76)=.17, p=.68), a significant effect of valence (F(1,76)=319.72, p<.001), and a significant modality x valence interaction (F(1,76)=9.67, p=.003). Follow-up analyses revealed that negative images were rated as more negative than negative sounds (t(38)=2.47, p=.018), but there was no difference between neutral stimuli (t(38)=1.92, p=0.63). The arousal rating analysis demonstrated significant main effects of modality (F(1,76)=10.98, p=.001) and valence (F(1,76)=206.56, p<.001) and a modality x valence interaction (F(1,76)=9.81, p=.002). Follow-up analyses revealed that neutral sounds were more arousing than neutral images (t(38)=4.65, p<.001), but there was no difference for negative stimuli (t(38)=.13, p=.90). Overall, these results demonstrated that participants rated negative and neutral images as more different than negative and neutral sounds, despite there being no difference in the standardized ratings collected for these stimuli.
Chapter 3

7 Experiment 2: Auditory Target Stimuli

7.1 Methods

7.1.1 Participants

Thirty-eight healthy adult participants between the ages of 18 and 43 (M<sub>age</sub> = 24.89 years, SD = 6.60 years, 74% female) participated in the study. Recruitment methods, exclusion criteria, and reimbursement were the same as for Study 1. Participants were informed that they could end their participation at any time throughout the study. This procedure was approved by the University of Western Ontario Health Sciences Research Ethics Board.

7.1.2 Procedure

All procedures were the same as in Study 1, except the target stimuli were auditory. The task-irrelevant stimuli could be either visual or auditory.

7.1.3 Auditory Detection Task

The goal in producing this task was to create an auditory detection task that mirrored the visual detection task from Study 1 as closely as possible. During the task, white noise was played through the headphones at a volume of approximately 73.3dB throughout each trial. The task required participants to indicate on which side they heard a brief period of amplitude modulation, used to mimic the sinusoidal intensity fluctuations of the Gabor patch in the visual discrimination task. The amplitude modulation was produced by using the function “randomGauss” in Praat (Boersma & Weenink, 2019) with a mean of zero and a standard deviation of 0.1+p(sin(14πx/0.1)), where p is the percentage of modulation divided by 1000 and x is the timepoint. Participants were asked to click either the “1” or “2” key on the keypad to indicate “left” or “right” respectively. Two modulation depths were used, fluctuating 90% and 80% from the background intensity.
these difficulties were determined by having 6 pilot participants perform the neutral unimodal auditory task with different modulations and selecting those with accuracy levels most similar to the accuracy levels in the neutral unimodal visual task of Study 1.

While participants completed the task, they were also presented with images and sounds. These stimuli were presented for 6 seconds each, during which 3 sound modulations were played. The image and sound stimuli were the same as those used in Study 1. These detection tasks were preceded by an introduction block, an image practice block and a sound practice block, which used different stimuli than the task itself. The layout and timings of the task can be found in Figure 7.

**Figure 7. The auditory detection task. Participants were instructed to click “1” or “2” on the keypad to indicate if the white noise modulation was presented on the left or right side, respectively.**
7.1.4 Rating Tasks

Rating tasks were the same as in Study 1. The layout and timings of the tasks can be found in Figure 2.

7.1.5 Data Analyses

We excluded participant outliers in the same way described for Study 1. Three participants were excluded because their accuracy levels were more than 3 standard deviations above or below the mean for one or more trial types. This left 35 participants for the main analyses. Main analyses were the same as those performed in Study 1.

7.2 Results

7.2.1 Response Time Data Analysis

We conducted a 2 (Modality: image, sound) x 2 (Valence: negative, neutral) x 2 (Contrast: 90%, 80%) x 3 (Trial timing: 0ms, 2000ms, 4000ms) repeated measures ANOVA using response times as the outcome of interest. All p-values for follow-up contrasts are Bonferroni-adjusted. The analysis revealed main effects of modality (F(1,43)=9.99, p=.003), emotional valence (F(1,43)=8.76, p=.006), and trial timing (F(1.19,40.43)=71.25, p<.001). These effects were qualified by significant interactions.

Because our primary objective was to determine the impact of valence on target processing, we first examined any interactions involving valence. We predicted that emotional content would be more distracting on unimodal (sound) trials; however, no significant interaction was observed to support this prediction. We also predicted that the effects of task-irrelevant auditory and visual stimuli would show different time courses. An interaction between valence and trial timing (F(2,68)=16.92, p<.001) supported this prediction. This was qualified by a modality x valence x trial timing interaction (F(2,68)=10.07, p<.001; Figure 8). Follow-up analyses revealed that the modality x valence interaction was significant at timepoint 1 (F(1,34)=11.76, p=.002) and timepoint
3 (F(1,34)=9.75, p=.004). It was non-significant at timepoint 2 (F(1,34)=2.89, p=.10). At timepoint 1, negative stimuli produced shorter response times than neutral stimuli only for sounds (t(34)=-4.11, p<.001) but not for images (t(34)=-.38, p=1.00). At timepoint 3, negative stimuli produced longer response times than neutral stimuli only for sounds (t(34)=4.62, p<.001) but not for images (t(34)=1.26, p=.43).

Figure 8. A significant modality x valence x timing interaction was observed (F(2, 68)=10.07, p<.001). At timepoint 1, in the unimodal condition only (i.e. auditory task-irrelevant stimuli during an auditory task), response times were faster during negative trials than neutral trials (t(34)=-4.11, p<.001). In contrast, at timepoint 3, in the unimodal condition only, response times were slower during negative trials than neutral trials (t(34)=4.62, p<.001).

We found a significant modality x contrast interaction (F(1,34)=5.16, p=.03; Figure 9); the more difficult contrast produced longer response times for sounds (t(34)=-3.02, p=.01) but there was no difference for images (t(34)=-.54, p=1.00). We also found a modality x trial timing (F(1.29,43.88)=20.98, p<.001) interaction; however, as noted above, this was qualified by a 3-way interaction involving valence (described above).
Figure 9. A significant modality x contrast interaction was observed ($F(1,34)=5.16$, $p=.03$). In the unimodal condition only (i.e. auditory task-irrelevant stimuli during an auditory task), response times were slower for the more difficult contrast ($t(34)=-3.02$, $p=.01$).

7.2.2 Accuracy Data Analysis

We then conducted a second repeated measures ANOVA using the proportion of correct responses to total valid responses as the dependent variable. This also revealed main effects of modality ($F(1,34)=58.53$, $p<.001$), emotional valence ($F(1,34)=66.08$, $p<.001$), and target contrast ($F(1,34)=13.41$, $p=.001$). These effects were qualified by significant interactions.

Again, we predicted that emotional content would be more distracting on unimodal (sound) trials. In line with this prediction, a significant modality x valence interaction emerged ($F(1,34)=14.17$, $p=.001$). We also predicted that the effects of task-irrelevant auditory and visual stimuli would show different time courses. An interaction between valence and trial timing ($F(2,68)=50.14$, $p<.001$) supported this prediction. These were
qualified by a modality x valence x trial timing interaction (F(2,68)=51.53, p<.001; Figure 10). Follow-up analyses revealed that the modality x valence interaction was significant at timepoint 1 (F(1,34)=21.96, p<.001), timepoint 2 (F(1,34)=18.59, p<.001), and timepoint 3 (F(1,34)=63.17, p<.001). At timepoint 1, negative sound trials showed greater accuracy than neutral sound trials (t(34)=5.08, p<.001); there was no difference for image trials (t(34)=1.34, p=.38). At timepoint 2, negative stimuli produced lower accuracy than neutral stimuli for both modalities; however, this was more pronounced for sounds (t(34)=7.85, p<.001) than for images (t(34)=2.59, p=.03). At timepoint 3, negative sounds produced lower accuracy than neutral sounds (t(34)=9.82, p<.001); however there was no difference for image trials (t(34)=.74, p=.93).

Figure 10. A significant modality x valence x timing interaction was observed (F(2, 68)=51.53, p<.001). At timepoint 1, in the unimodal condition only (i.e. auditory task-irrelevant stimuli during an auditory task), accuracy was higher during negative trials than neutral trials (t(34)=5.08, p<.001). At timepoint 2, negative stimuli produced lower accuracy than neutral stimuli in the unimodal condition (t(34)=7.85, p<.001) and, to a lesser extent, in the cross-modal condition (i.e. visual task-irrelevant stimuli during an auditory task; t(34)=2.59, p=.03). At timepoint 3, in the unimodal condition only, accuracy was lower for negative trials than neutral trials (t(34)=9.82, p<.001).
We found a significant modality x contrast interaction (F(1,34)=27.75, p<.001; Figure 11); accuracy was lower for the difficult contrast for sound stimuli (t(34)=5.88, p<.001), however there was no difference for image stimuli (t(34)=-.45, p=1.00). We also found a modality x trial timing interaction (F(1.47,49.91)=18.77, p<.001); however, as noted above, this was qualified by a 3-way interaction involving valence (described above).

![Figure 11](image)

Figure 11. A significant modality x contrast interaction was observed (F(1,34)=27.75, p<.001). In the unimodal condition only (i.e. auditory task-irrelevant stimuli during an auditory task), accuracy was lower for the more difficult contrast (t(34)=5.88, p<.001).

### 7.2.3 Rating Task Data Analysis

Participant ratings were very similar to those obtained in Study 1. Participant ratings on valence and arousal dimensions were examined using 2 (modality) x 2 (valence) ANOVAs. The valence rating analysis showed no effect of modality (F(1,76)=.28, p=.60), a significant effect of valence (F(1,76)=301.36, p<.001), and a significant modality x valence interaction (F(1,76)=15.83, p<.001). Follow-up analyses revealed that
negative images were rated as more negative than negative sounds (t(38)=2.42, p=.021), but neutral images were rated as less negative than neutral sounds (t(38)=-3.22, p=.003). The arousal rating analysis demonstrated significant main effects of modality (F(1,76)=4.13, p=.046) and valence (F(1,76)=192.78, p<.001) and a modality x valence interaction (F(1,76)=6.38, p=.014). Follow-up analyses revealed that neutral sounds were more arousing than neutral images (t(38)=3.74, p=.001), but there was no difference for negative stimuli (t(38)=-.31, p=.76). Overall, these results demonstrated that participants rated negative and neutral images as more different than negative and neutral sounds, despite there being no difference in the standardized ratings collected for these stimuli.
Chapter 4

8 Discussion

A large body of research has established that emotional stimuli have an impact on how humans perform on perceptual and cognitive tasks (e.g. Mitchell et al., 2009; Mathewson et al., 2008). One key factor that determines this impact may be the sensory modality through which the target stimuli and task-irrelevant stimuli are presented (e.g. Duncan et al., 1997; Zeelenberg & Bocanegra, 2010). This study is the first to directly compare the impact of emotional content on task performance in unimodal and cross-modal blocks, using realistic images and sounds. It is also the first to establish the time courses of these effects by presenting targets at different timepoints throughout a continuous task-irrelevant stimulus. Finally, this research extends previous findings by using both a visual and auditory task to demonstrate that emotional stimuli impact performance regardless of the task modality. Extrapolating from previous findings involving emotional stimuli (Mitchell et al., 2008; Zeelenberg & Bocanegra, 2010) and literature concerning the impact of cross-modal paradigms on vision (Duncan et al., 1997), we expected to observe distraction effects in the unimodal blocks and greatly reduced distraction effects or even enhancement effects in the cross-modal blocks. In line with predictions, Study 1 demonstrated that visual emotional task-irrelevant stimuli during a visual task produced distraction effects leading to slower response times and lower accuracy. This was particularly true when the targets and task-irrelevant stimuli were presented simultaneously; however, no distraction effects were observed in the cross-modal condition. Study 2 demonstrated that auditory emotional task-irrelevant stimuli during an auditory task also produced distraction effects, but only at the later target presentations. When the targets and task-irrelevant stimuli were presented simultaneously, we actually observed enhancement effects leading to faster response times and higher accuracy. Again, no effects were observed in the cross-modal condition.

That visual task-irrelevant stimuli during a visual task compete with neutral target stimuli for processing resources, and frequently produce distraction effects is in accordance with previous studies (e.g. Mathewson et al., 2008; Most et al., 2005). This distraction is thought to occur due to emotional stimuli having privileged access to processing...
resources, allowing them to be processed at the expense of neutral target stimuli (e.g. Anderson & Phelps, 2001; LeDoux & Phelps, 2008; Vuilleumier, 2005). The fact that a distraction effect occurred when targets and task-irrelevant stimuli were presented simultaneously is supported by some previous research (e.g. Vuilleumier et al., 2001); however, attentional blink studies examining the time course of distraction effects have demonstrated that they are greatest between 200ms and 500ms following task-irrelevant stimulus onset, and are actually absent when the target and task-irrelevant stimulus are presented very close in time (i.e. within the first 200ms; e.g. Broadbent & Broadbent, 1987; Raymond et al., 1992). Although there are many differences between the setup of the current study and attentional blink paradigms, such as task-irrelevant stimuli in the current study being presented for much longer, it is not entirely clear why the largest distraction effects in the current study were at timepoint 1. Distraction effects may simply be greater when stimulus presentation is simultaneous than when it is sequential.

Alternatively, this difference may arise due to target stimuli and task-irrelevant stimuli being presented in different locations, which would require diverting attention from the central task-irrelevant stimulus to the peripheral target; since it takes time to refocus attention on the target, this could explain why distraction effects are observed despite target presentation being within the first 200ms of task-irrelevant stimulus presentation. In support of this, the N2pc, a neural index of covert attention, is typically observed between 200ms and 300ms following stimulus onset (e.g. Hickey, Van Zoest, & Theeuwes, 2010). In contrast, according to MacLeod (1991), the closer the target and task-irrelevant stimulus are spatially, the greater the interference; however, studies would need to further examine spatial location and simultaneous vs. sequential stimulus presentation, in order to fully understand how these effects impact distraction. Finally, since target timings were spaced out by two seconds each, it is difficult to know if distraction effects might have been even greater had the first target presentation been slightly delayed. Overall, it is important to note that because the current studies used longer continuous task-irrelevant stimuli (6 seconds vs. approximately 15ms to 100ms in other studies; Most et al., 2005; Raymond et al., 1992), the timing manipulation is not directly comparable to other findings examining the stimulus onset asynchronies of briefly presented sequential stimuli.
Although we did not observe any enhancement effects in the cross-modal condition, we did find that distraction was greatly reduced, which is supported by previous studies (e.g. Arrighi et al., 2011; Duncan et al., 1997). Although emotional stimuli often compete with target stimuli for perceptual resources, this competition may be greatly reduced when task-irrelevant emotional stimuli are presented through a different modality (e.g. Zeelenberg & Bocanegra, 2010). Combined with the increased alertness and arousal produced by emotional content, this may explain why several studies have previously observed enhancement effects in the presence of emotional stimuli in cross-modal paradigms (e.g. Kryklywy & Mitchell, 2014; Max et al., 2015; Zeelenberg & Bocanegra, 2010). It is not clear why this enhancement was not observed in the current study. It is possible that the emotional content was not arousing enough compared to the neutral content to elicit this effect; based on stimulus ratings, participants did not find the negative and neutral auditory stimuli to be as different as the visual stimuli in terms of valence and arousal, even though the standardized ratings suggested they were. At later timepoints, this could be due to the fact that task-irrelevant stimuli were presented for 6 seconds, as opposed to previous studies which have used short presentations and shown stimuli sequentially (e.g. Ciesielski et al., 2010; MacLeod et al., 2017; Most et al., 2005); this may have introduced greater distraction, preventing enhancement effects from being observed. Finally, perhaps this sort of basic perception task still produces too much competition between stimuli, particularly at timepoint 1 when distraction is greatest, and enhancement effects would be better observed if the task was more separate from the task-irrelevant stimuli, such as in the case of a working memory or visual search task (e.g. Kryklywy & Mitchell, 2014; Phelps et al., 2006). This is plausible given that presenting targets and task-irrelevant stimuli through different sensory modalities appears to reduce but not completely eliminate distraction effects (e.g. Duncan et al., 1997). This remaining distraction is likely due to inhibition of sensory cortical regions that occurs, not only within, but also across sensory modalities (e.g. Mozolic et al., 2008). Any of these factors, or a combination, may be responsible for the lack of emotional enhancement effects observed.

In Study 2, we also observed a lack of distraction or enhancement effects in the cross-modal condition, likely for the same reasons as in Study 1. The exception to this was that
at timepoint 2 negative images produced lower accuracy than neutral images. This might indicate that images distract from auditory tasks slightly more than sounds do from visual tasks; however, further research would need to be done to confirm this. Different effects were observed in the unimodal condition of Study 2. Although task-irrelevant emotional content generally disrupted task performance, this effect was not consistent over time. Surprisingly, in Study 2, emotional sounds seemed to produce an enhancement effect at timepoint 1 and a distraction effect at the later timepoints. This may have arisen due to differences in the properties of the onset of negative and neutral sounds. Although sounds were matched overall on low-level perceptual features, some factor may have differed within the first few hundred milliseconds during which the first target presentation and response took place. Additionally, it is possible that the valence information of the auditory stimuli only became apparent after some time, resulting in distraction effects only at the later timepoints. Alternatively, this may simply be due to time course differences in distraction and enhancement effects. There is some evidence from studies examining event-related potentials that attentional capture by an emotional stimulus takes place several hundred milliseconds sooner than attentional deployment to that stimulus at the expense of target detection (Bekhtereva et al., 2019); however, if this was the cause of the time course effects, it is not clear why this was only observed in the auditory experiment and only on the unimodal trials. This uncertainty could be resolved by matching the onsets of the auditory stimuli more closely, as well as using dynamic visual stimuli (i.e. videos) rather than images to determine whether this reduces the distraction effect observed at the first timepoint.

Interestingly, we also observed a main effect of modality for the response time and accuracy analyses of both studies. Unimodal blocks produced longer response times and lower accuracy overall, likely resulting from competition being greater during unimodal blocks, regardless of emotional valence. These effects were also qualified by modality x timing interactions. In Study 1, unimodal blocks produced longer response times than cross-modal blocks at timepoint 1 only, with timepoint 3 actually showing a slight opposite effect. In addition, unimodal blocks produced lower accuracy at all timepoints but this was also most pronounced at timepoint 1. The fact that these differences were largest at timepoint 1 may be evidence of multisensory integration producing an even
greater advantage on cross-modal blocks when the targets and task-irrelevant stimuli are presented simultaneously. In Study 2, unimodal blocks produced longer response times at timepoints 2 and 3, and lower accuracy at all timepoints, particularly timepoint 2 followed by timepoint 3. The absence of a larger difference between unimodal and cross-modal blocks at timepoint 1 could possibly indicate that multisensory integration is more effective when targets are visual and task-irrelevant stimuli are auditory than when targets are auditory and task-irrelevant stimuli are visual.

8.1 Limitations and Future Directions

One limitation to this study was that, although stimuli were selected to best match valence and arousal ratings, participant ratings indicate some differences. Specifically, the negative and neutral sound stimuli were rated as more similar in both valence and arousal than the image stimuli. This discrepancy might have partially contributed to enhancement effects not being observed in Study 1 or the sound stimuli in Study 2 producing a mixture of distraction and enhancement effects at the different timepoints. For example, in Study 1, it is possible that cross-modal enhancement effects would have required more emotional or more arousing stimuli; however, this is not completely responsible for the pattern of findings as it would not explain why cross-modal enhancement effects were also not observed in Study 2, when task-irrelevant stimuli were visual. In addition, in Study 2, it is possible that the dynamic nature of the auditory task-irrelevant stimuli made their valence difficult to discern right away, and that the emotional sounds being less negative than the emotional images may have added to this, explaining the lack of distraction effects. On top of this, the neutral sounds being more arousing than neutral images could have caused a carry-over effect such that participants had a higher level of arousal throughout the study and were therefore more prone to enhancement effects; however, if this were the case, we would also expect to observe enhancement during the cross-modal blocks in Study 1. The two contrast levels also produced a somewhat unexpected finding; it was predicted that a more difficult contrast would produce the same effect as a higher perceptual load, potentially reducing emotional distraction effects. Instead, distraction effects in both the visual and auditory
studies were greater for the more difficult contrast level. These results suggest that the contrast level of the target stimuli does not produce the same effect as a higher perceptual load in the task. Other studies have also produced this same result whereby a more difficult task produced more emotional distraction (D'Andrea-Penna, Frank, Heatherton, & Tse, 2017).

Another limitation is that our use of heterogeneous negative emotional stimuli may have been a source of variance. The various stimuli used in the current studies may have elicited emotions ranging from fear to sadness to disgust. As previously noted, these different emotions may not be equivalent in terms of their impact on task performance. For instance, sadness has been shown to produce longer response times than anger (Hjärtström et al., 2019), and the effect of disgust may not even differ from that of neutral stimuli (Parmentier et al., 2019). Future work in this area should examine these emotions separately to more accurately determine their impact on task performance.

This study will lay the groundwork for fMRI studies delineating the neurocognitive signatures associated with emotional enhancement of performance vs. emotional distraction. Future goals should be to identify how key neural networks interact to produce these effects, by having participants perform the task during fMRI or by conducting a study on participants with brain injury. Particular regions of interest include the amygdala for its role in processing emotional content, the pulvinar and superior colliculus for their possible role in bringing information about emotional stimuli to the amygdala, and the locus coeruleus, dorsolateral PFC and lateral parietal cortex for their role in directing attention to task-relevant stimuli, as well as visual and auditory sensory cortical areas.

In addition, future research in this area should examine how various factors that affected emotional distraction effects in previous studies might impact the emotional distraction and enhancement effects observed in the presence of continuous task-irrelevant stimuli, and the time courses of those effects. First of all, studies should use a different manipulation of perceptual load to determine whether higher perceptual load will reduce emotional distraction in this context and what impact it has on enhancement. Secondly,
since time course effects were demonstrated and appeared different for auditory than visual stimuli, it would be beneficial to stagger target timings to determine more precise time courses for emotional distraction and enhancement effects in these different modalities. Additionally, it would be beneficial to examine whether positive emotional stimuli produce the same effects as negative stimuli in cross-modal paradigms and over time. Future studies should also extend the current findings to different emotions and task demands (e.g. visual search or working memory tasks). Finally, it would be beneficial to study these effects in clinical populations, particularly in people with high anxiety, since some research has found clinical levels of anxiety to affect emotional distraction (Hallion, Tolin, & Diefenbach, 2019).

8.2 Conclusions

In conclusion, several neurocognitive processes involved in perception, emotion, and cognition interact to determine what impact task-irrelevant emotional stimuli will have on task performance (e.g. Amaral et al., 2003; Armony & LeDoux, 1999; Mitchell & Greening, 2012). Sensory modality may be one important factor. Understanding the effects of emotional content in each sensory modality is necessary in order to integrate findings from the various sensory modalities to determine how real-world emotional situations affect perception. The current study examined the impact that the sensory modalities of target stimuli and task-irrelevant stimuli have on determining how emotional content will affect task performance. This was the first study to use realistic images and sounds to directly compare the impact of emotional content in unimodal and cross-modal blocks. It also extended previous findings by examining the time courses of these effects throughout a continuous task-irrelevant stimulus, and by extending these findings to an auditory perception task. We established that emotional stimuli generally produce distraction effects in unimodal but not cross-modal paradigms; however, these effects are not consistent across all timepoints throughout the continuous emotional stimulus and more work is needed to further examine the time courses of emotional distraction and enhancement effects. Additionally, future research is needed to determine how other factors interact with sensory modality to produce these effects and what neural
processes are responsible for emotional distraction and enhancement. Overall, the current research is the next step towards understanding human behaviour and performance in emotional situations. It also lays the groundwork for imaging studies examining the interaction between attentional and emotional systems in the brain, research which likely has widespread applications for emotion regulation and emotional disorders.
References


Piech, R. M., McHugo, M., Smith, S. D., Dukic, M. S., Van Der Meer, J., Abou-Khalil, B., ... & Zald, D. H. (2011). Attentional capture by emotional stimuli is preserved in
patients with amygdala lesions. *Neuropsychologia, 49*(12), 3314-3319. doi:10.1016/j.neuropsychologia.2011.08.004


Appendices

Appendix A. Research Ethics and Approval Number

Date: 30 April 2019

To Dr. Derek Mitchell

Project ID: 113655

Study Title: Emotional distraction, focus, and control

Application Type: HSREB Initial Application

Review Type: Delegated

Full Board Reporting Date: May 21, 2019

Date Approval Issued: 30 Apr/2019

REB Approval Expiry Date: 30 Apr/2020

Dear Dr. Derek Mitchell

The Western University Health Science Research Ethics Board (HSREB) has reviewed and approved the above mentioned study as described in the WSREB application form, as of the HSREB Initial Approval Date noted above. This research study is to be conducted by the investigator noted above. All other required institutional approvals must also be obtained prior to the conduct of the study.

Documents Approved:

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<td>17 Apr 2019</td>
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No deviations from, or changes to, the protocol or WSREB application should be initiated without prior written approval of an appropriate amendment form Western HSREB, except when necessary to eliminate immediate hazards to study participants or when the change(s) involves only administrative or logistical aspects of the trial.

REB members involved in the research project do not participate in the review, discussion or decision.

The Western University HSREB operates in compliance with, and is constituted in accordance with, the requirements of the TriCouncil Policy Statement: Ethical
Conduct for Research Involving Humans (TCPS 2); the International Conference on Harmonisation Good Clinical Practice Consolidated Guidelines (ICH GCP); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. The HSREB is registered with the U.S. Department of Health & Human Services under the OHRP registration number IRB-000003940.

Please do not hesitate to contact us if you have any questions.

Sincerely,

Karen Copeland, Ethics Officer on behalf of Dr. Joseph Gilbert, HSREB Chair

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).
Appendix B. Research Ethics and Approval Number (Study 2 Amendment)

Date: 13 June 2019
To: Dr. Derek Mitchell
Project ID: 113655
Study Title: Emotional distraction, focus, and control
Reference Number/ID: n/a
Application Type: HSREB Amendment Form
Review Type: Delegated
Full Board Reporting Date: July 2, 2019
Date Approval Issued: 13 Jun 2019
REB Approval Expiry Date: 30 Apr 2020

Dear Dr. Derek Mitchell,

The Western University Health Sciences Research Ethics Board (HSREB) has reviewed and approved the WREM application form for the amendment, as of the date noted above.

Documents Approved:

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<td>Emotional distraction, focus, and control– Consent (imaging)</td>
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REB members involved in the research project do not participate in the review, discussion or decision.

The Western University HSREB operates in compliance with, and is constituted in accordance with, the requirements of the TriCouncil Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); the International Conference on Harmonisation Good Clinical Practice Consolidated Guideline (ICH GCP), Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

Please do not hesitate to contact us if you have any questions.

Sincerely,

Karen Gopaul, Ethics Officer on behalf of Dr. Philip Jones, HSREB Vice-Chair

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).
Curriculum Vitae
Emma K. Stewart

Education

*University of Western Ontario, London, Ontario* (September 2018-present)
- Master of Science
- Neuroscience
- CGPA 3.90/4.00

*McGill University, Montreal, Quebec* (September 2013-May 2017)
- Bachelor of Science in Biological, Biomedical and Life Sciences
- First Class Honours in Psychology
- Distinction, CGPA 3.82/4.00

Awards

*University of Western Ontario*
- Ontario Graduate Scholarship, $15 000 (May 2020).

*McGill University*
- Science Undergraduate Research Award, $5600 (Summer 2017).
- Tomlinson Engagement Award for Mentoring (Intro Abnormal Psychology 2), $300 (Winter 2017).
- Tomlinson Engagement Award for Mentoring (Social Psychology), $300 (Fall 2016).
- Natural Sciences and Engineering Research Council of Canada (NSERC) Experience Award (InteraXon), $4500 (Summer 2016).
- Dean’s Honour List, 2014/15 academic year (April 2015).

Relevant Work Experience

- Western Graduate Teaching Assistant, Physiology of the Senses (Fall 2018, 2019).
Research Experience

- *Master’s Student*, Emotional Cognition Lab, Dr. Derek Mitchell, University of Western Ontario (September 2018-present).
- *Paid Lab Coordinator*, Translational Research in Affect and Cognition (TRAC) Lab, Dr. Anna Weinberg, McGill University (September 2017-April 2018).
- *Summer Project Coordinator*, Translational Research in Affect and Cognition (TRAC) Lab, Dr. Anna Weinberg, McGill University (May 2017-August 2017).
- *Honours Research Assistant*, Translational Research in Affect and Cognition (TRAC) Lab, Dr. Anna Weinberg, McGill University (September 2016-April 2017).
- *Paid Research Assistant*, Raz Lab, Dr. Amir Raz, McGill University (September 2016-April 2017).
- *Scientific Affairs Summer Intern*, InteraXon Inc. (Summer 2016).
- *Paid Research Assistant*, Social Cognition and Social Intelligence Lab, Dr. Mark Baldwin, McGill University (May 2016).
- *Honours Research Assistant*, Social Cognition and Social Intelligence Lab, Dr. Mark Baldwin, McGill University (September 2015-April 2016).

Publications


Poster Presentations


Attentional Bias. Poster presented at the McGill Psychology Undergraduate Research Day, Montreal, QC.

