

EEG EVIDENCE FOR THE EFFECTIVE PROACTIVE CONTROL OF
EMOTIONAL DISTRACTION

BY

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Abstract

Recent behavioural studies using an emotional flanker task have found that task-irrelevant emotional images are more distracting than neutral images under infrequent, but not frequent, distractor conditions. It has been proposed the effective control of distraction in the high distractor frequency condition may be due to a shift to a proactive control strategy, whereby a potential distraction is anticipated and minimised in advance. However, although it is well established that proactive control is effective at reducing neutral distraction, it is not yet clear whether emotional distraction can be effectively proactively controlled. In this thesis, I used EEG to measure pre-stimulus indices of proactive control in order to determine whether proactive control is responsible for the effective control of emotional and neutral distraction in the high distractor frequency condition, as well as to examine whether proactive control differs according to whether a neutral or emotional distraction is anticipated. In addition to replicating the previous behavioural findings, posterior EEG alpha was found to be tonically suppressed in the high compared to low distractor frequency condition, strongly supporting the hypothesis that proactive control was engaged in the high distractor frequency condition. By contrast, there was no difference in phasic alpha suppression (i.e., the drop in alpha in response to fixation onset) between conditions, indicating that the more effective control of distraction in the high frequency distractor conditions was due to a sustained proactive control strategy, rather than greater trial-by-trial preparation to attend to the target. In addition, no alpha lateralisation was found, indicating the mechanisms by which distraction was proactively controlled did not include the preparatory suppression of expected distractor locations. Finally, tonic alpha did not differ according to the expected distractor valence, but phasic alpha suppression was more pronounced when negative, compared to neutral or positive, distractors were expected, independent of distractor frequency condition. This suggests proactive control was also used to some extent in the low distractor frequency condition, but more importantly also provides initial evidence that the proactive control of negative distraction may be unique. Taken together, my findings provide compelling evidence that emotional distraction can be effectively proactively controlled. Future research is needed to determine the mechanisms by which this occurs, and whether the proactive control of emotional distraction is particularly effortful.

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EEG Evidence for the Effective Proactive Control of Emotional Distraction

When we look out at the world, our visual system is bombarded with visual information. In order to efficiently make sense of our complex visual world our limited-capacity visual system needs to prioritize which visual information is selected for further processing (Desimone & Duncan, 1995; Carrasco, 2011). One factor that influences the prioritization of visual information is the emotional content.

Emotional information preferentially captures attention and receives prioritized processing relative to non-emotional information (Okon-Singer, Lichtenstein-Vidne, & Cohen, 2013; Pouthois, Schettino, & Vuilleumier, 2013). The attentional bias toward emotional stimuli is likely an evolutionary adaptation, as emotional information signals potential threats and rewards, and so is important for promoting adaptive behavioural responses (e.g., approaching a potential mate, or avoiding a predator; LeDoux, 1996). But the prioritized processing of emotional information can also be problematic. For example, attending to an attractive roadside pedestrian over the mundane road ahead may well compromise our survival. Hence, when emotional information is irrelevant to our current goals, it is important to be able to ignore it (Lee & Chao, 2012). However, because emotional information is perceptually prioritized, emotional stimuli can make for particularly potent distractors (Okon-Singer et al., 2013; Pouthois et al., 2013; Yiend, 2010). In this thesis, I explore the cognitive and neural mechanisms that are used to control emotional distractions.

Inhibiting the processing of goal-irrelevant information - in order to prevent distraction - is an essential cognitive ability for both day-to-day functioning and mental well-being (Burgess et al., 2010; Edwards, Barch & Braver, 2010; Lee, & Chao, 2012). Chronic distraction leads to little being achieved. A vulnerability to *emotional* distraction can be particularly debilitating. Indeed, beyond being a frequent nuisance, a deficit in ignoring irrelevant emotional information appears to be an important factor in disorders such as addiction, anxiety and depression (Cisler & Koster, 2010; De Raedt & Koster, 2010; Field & Cox, 2008). Therefore, beyond its theoretical importance, an understanding of how emotional distraction can be effectively controlled has important societal and therapeutic implications as well.

Although the neural processing of emotional information has been increasingly investigated, little is known about how the processing of emotional information is suppressed when necessary. Notably, it is not yet known whether 1) the same control processes that inhibit goal-irrelevant non-emotional information can also effectively inhibit goal-irrelevant

emotional information; and 2) greater cognitive effort (i.e., more cognitive resources) are required to inhibit goal-irrelevant emotional information than goal-irrelevant non-emotional information.

In this thesis, I will present two experiments that investigate the mechanisms by which emotional distraction can be effectively controlled. In Experiment 1, I replicate a recent behavioural finding indicating that emotional images are more distracting than neutral distractors when they not anticipated, but can be as effectively controlled as neutral distractors when they are anticipated (Kranz, 2015). Experiment 2 replicates and extends Experiment 1 by also examining electrophysiological indices of sustained and anticipatory biasing of attention to further our understanding of how emotional distraction can be effectively controlled.

Proactive and Reactive Cognitive Control of Distraction

In order to maintain goal-directed cognition and behaviour in the face of distraction or other types of conflict, *cognitive control* processes must be recruited. Cognitive control is a general term describing mechanisms which comprise the top-down regulation of attention, perceptual processing, and behaviour in order to facilitate our current goals (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Braver, 2012).

According to the Dual Mechanisms of Control framework (DMC), the cognitive control of non-emotional information can be understood as operating within two primary modes, reactive and proactive control (Braver, 2012; Braver, Paxton, Locke & Barch, 2009; Geng, 2014). Reactive control consists of regulatory processes in reaction to deviations from goal-directed cognition, e.g., the disengagement from goal-irrelevant information after distractor onset, enabling a return of focus to goal-relevant information. By contrast, proactive control is a more effective strategy whereby distraction is anticipated and minimised in advance, by preparatory enhancement of target processing and/or preparatory suppression of distractor processing.

The DMC posits that the extent to which reactive and proactive control strategies are used will shift dynamically depending on motivational and task demands, according to a cognitive cost-benefit analysis (Braver, 2007). Specifically, proactive control is metabolically expensive and cognitively taxing because it requires the active maintenance of a current goal. As a result, proactive control is only engaged in conditions where either distractors are predictably frequent and/or there is a high degree of motivation to maintain goal-directed focus (e.g., if there is a reward incentive for good performance; Braver, Gray, & Burgess, 2007; Locke & Braver, 2008; Aron, 2011). By contrast, because reactive control

is less taxing, it can be understood as the default cognitive control strategy, operating in the absence of proactive control.

The DMC framework nicely accounts for widespread behavioural findings showing that task-interference is reduced when distracting task-irrelevant or conflicting information is predictable or when motivation is heightened. In the Stroop task, for instance, interference observed on conflict trials (e.g., reading “RED” in blue ink) is reduced as the proportion of conflict-trials increases (Bugg & Crump, 2012), and when conflict trials are predictively cued (Padmala & Pessoa, 2012), allowing for preparatory cognitive control when upcoming conflict is predictable.

Neuroimaging and psychophysiological evidence also supports predictions made by the DMC (e.g., Braver & Botvinick, 2015; Burgess & Braver, 2010; Chatham, Frank, & Munakata, 2009; Chevalier, Martis, Curran, & Munakata, 2015; Chiew, & Braver, 2013; Jimura, Locke, & Braver, 2010). Behavioural markers of reactive control have been associated with post-conflict increases in pupil dilation (an index of cognitive effort; Chiew & Braver, 2013), and with transient activation of the lateral prefrontal cortex (LPFC) and anterior cingulate cortex (ACC), areas thought to subservise conflict resolution processes. By contrast, behavioural markers of proactive control (e.g., reduced interference following predictive or incentive cues) have been associated with an increase in tonic as well as preparatory pupil dilation (Chiew & Braver, 2013), and sustained activity in the lateral PFC (Burgess, & Braver, 2010; Jimura et al., 2010;), reflecting the ongoing active maintenance of task goals.

Cognitive Control of Emotional Distraction

It is well established that emotional information can capture attention and interfere with task-performance (Yiend, 2010). However, in many studies demonstrating emotional distraction, the emotion has not been *entirely* task irrelevant (e.g., Most, Smith, Cooter, Levy, & Zald, 2007; Carretie, 2014), which may explain greater attentional capture by the emotional than non-emotional content (e.g., an attractive pedestrian *crossing* the road is not entirely goal-irrelevant, and may be expected to capture attention more readily than an entirely irrelevant attractive roadside pedestrian). Because the emotion is not entirely task irrelevant in most studies of emotional distraction, the control of emotional distraction remains poorly understood.

However, several recent experiments from our lab demonstrate that entirely task-irrelevant emotional stimuli are indeed more potent distractors than non-emotional stimuli (Grimshaw, Kranz, Moody, Carmel, & Devue, 2016; Kranz, 2015). These studies use an

irrelevant flanker task adapted from Forster & Lavie (2008a; 2008b) who used it to study distraction from non-emotional stimuli. On each trial, subjects indicate whether a 'K' or an 'N' is presented in a visual search array centred at fixation. On a certain proportion of trials, a distractor image is presented either above or below the central array in a task irrelevant location. Even though distractors share no features with targets and occurred only in task-irrelevant locations, they still disrupted performance on the central task. We adapted this task to use images that were positive (erotic), negative (mutilation) and neutral (people). Importantly, the presentation of distractors was blocked by valence, enabling participants to anticipate what type (i.e., emotional or non-emotional) of distractor would appear.

In Experiment 1, Grimshaw et al. (2016) presented distractor images on 50% of trials. In one condition, distractors were pixel-scrambled versions of the intact images, maintaining the low level visual properties but not semantic content of the originals. In the scrambled condition, there was no difference in distraction produced by emotional and neutral images. However, in the intact condition, an emotional distraction effect was observed – people were slower to respond when the distractors were emotional (either positive or negative) than non-emotional. These findings suggest that task irrelevant emotional content is more distracting than task-irrelevant non-emotional content.

In Experiment 2, the potency of emotional distractors was found to depend on the frequency with which they are presented. Distractor frequency was manipulated between subjects (25% or 75% of trials) in order to promote either reactive or proactive control strategies, respectively. High frequency distractor conditions promote the more taxing proactive control because distractors can be more veridically anticipated (Braver 2012; Augst, Kleinsorge, & Kunde 2014). In the infrequent distractor condition, a typical emotional distraction effect was found: emotional images slowed RT more than neutral images. However, when distractors were frequent, people effectively controlled both neutral and emotional distraction. These findings indicate that, under proactive conditions, emotional distraction *can* be effectively controlled by biasing cognitive processes toward goal-relevant processing.

A follow up study by Kranz (2015) further supports the hypothesis that emotional distractions can be effectively controlled under proactive, but not reactive, conditions. Kranz (2015) provided further insight into the cognitive control of emotional distraction by examining Event Related Potentials (ERPs) time-locked to the onset of the target (plus distractor) display. A proposed index of reactive control, the N2 (Eimer, 1993; Jodo & Kayama, 1992), was observed to be more pronounced under infrequent than frequent

distractor conditions, suggesting reactive control was relied upon more heavily in the low distractor frequency condition than the high distractor frequency condition. This further suggests that effective control in the high frequency condition is achieved through proactive mechanisms.

Together, these findings demonstrate that entirely task-irrelevant emotional distraction can be effectively controlled under frequent distractor conditions. A natural interpretation of this finding is that reactive control is vulnerable to emotional distraction, but proactive control is not. Notwithstanding, the current evidence that proactive control is responsible for the effective control of emotional distraction remains somewhat indirect: proactive control consists of preparatory processes, yet the current evidence for proactive control in the frequent distractor condition is confined to post-stimulus measures, namely response latencies and ERPs. Thus it remains possible that reduced emotional distraction in the frequent distractor condition is caused by stimulus desensitisation and/or enhanced reactive control processes. Moreover, if emotional distraction is indeed proactively controlled, it remains unclear on the current evidence whether the preparatory demands for the effective control of emotional and non-emotional distraction differ. By contrast, *pre-stimulus* indices of proactive control observed in the frequent but not infrequent distractor condition would offer stronger evidence that emotional distraction can be effectively controlled proactively, and would point to the mechanisms involved as well. EEG alpha oscillations in the pre-trial period may provide a useful pre-stimulus index of proactive control.

Tonic and Phasic Alpha

When neural populations in the brain act in synchrony, they produce electrical oscillatory signals which can be recorded from the scalp using EEG. The alpha brain rhythm (8-13 Hz) has been extensively researched (Basar, 2012), and is well established as an inverse index of cortical excitability (Pfurtscheller, Stancak, & Neuper, 1996; Basar, 2012). For example, combined EEG/fMRI studies have observed power in the alpha-band to be negatively correlated to the BOLD signal (e.g., Goldman, Stern, Engel Jr & Cohen, 2002; Laufs et al., 2006), and this has been corroborated by intracranial work with primates, where increased alpha has been associated with decreased spike and firing rates (Becker, Knock, Ritter, & Jirsa, 2015; Haegens, Nácher, Luna, Romo, & Jensen, 2011).

As a natural extension of the inverse relationship to cortical excitability, variations in tonic (i.e., on the scale of seconds to minutes) alpha over posterior scalp (from here on referred to as tonic alpha) has been routinely observed as inversely related to levels of

sustained attention and task-engagement (e.g., Bonnefond et al, 2008; Gevins, Smith, McEvoy, Yu, 1997; Kelly, Gomez-Ramirez, Montesi, & Foxe, 2008), that is, when tonic alpha is high sustained attention and task engagement are poor (Macdonald, Mathan, & Yeung, 2011; O'Connell, Dockree, Robertson, Bellgrove, Foxe, & Kelly, 2009). For example, Hans Berger made the original observation that tonic alpha was reduced when participants were given a mental arithmetic task compared to a no-task baseline (Berger, 1929). More recently, posterior tonic alpha has been correlated with trial-to-trial variations in subjective attentional ratings (Macdonald, Mathan, & Yeung, 2011), and increases in posterior tonic alpha has been observed to predict upcoming errors due to attentional lapses (O'Connell et al, 2009).

Similarly, phasic fluctuations in alpha (i.e., on the scale of sub-seconds to seconds) over sensory cortex has consequences for sensory attention. For example, prestimulus fluctuations in alpha power originating in the visual cortex have been observed to predict visual discrimination of hard-to-detect stimuli, with decreased alpha associated with greater visual sensitivity (e.g., Van Dijk, Schoffelen, Oostenveld, & Jensen, 2008). Importantly, phasic alpha changes can be brought under proactive control. For example, alpha suppression following cues predicting stimulus onset has been associated with heightened target-directed attention, leading to enhanced perceptual processing and better behavioural performance (Klimesch, Doppelmayr, Russegger, Pachinger, & Schwaiger, 1998; Bastiaansen & Brunia, 2001; Bastiaansen, Böcker, Brunia, De Munck, & Spekreijse, 2001; Kerr et al., 2011; Compton, Arnstein, Freedman, Dainer-Best, & Liss).

The top-down control of phasic alpha has increasingly been established as playing an important role in selective attention, implicated in both target-enhancement and distractor suppression processes (that is, mechanisms of proactive control; see Foxe, Simpson, & Ahlfors, 1998; Foxe and Snyder, 2011; Fu, Foxe, Murray, Higgins, Javitt, & Schroeder, 2001; Kelly, Lalor, Reilly, & Foxe, 2006; Rihs, Michel, & Thut, 2007; Romei, Gross, & Thut, 2010; Snyder and Foxe, 2010; Worden, Foxe, Wang, & Simpson 2000). It may at first seem contradictory that phasic alpha is associated with both target facilitation and distractor-suppression. However, these two distinct control processes may be helpfully understood as two sides of the same physiological “functional gating” mechanism.

In contrast to the longstanding interpretation of alpha as an “idling rhythm”, (Berger, 1929; Pfurtscheller et al., 1996), the active inhibition model proposes the more nuanced view that alpha reflects “functional gating” of cortical activity (Foxe & Snyder, 2011; Gregoriou, Paneri, & Sapountzis, 2015; Jensen & Mazaheri, 2010; Klimesch, Sauseng,

&Hanslmayr, 2007; Klimesch, 2012). That is, an increase in alpha power reflects the inhibition (or “gate closing”) of cortical activity, whereas a decrease in alpha reflects release from that inhibition (or “gate opening”; Foxe & Snyder, 2011).

The active inhibition model can perhaps be best understood with reference to the retinotopic organisation of the visual cortex - the processing of the visual field in a corresponding anatomical “map” (e.g., the processing of the left visual field in the right visual cortex and vice versa). According to the active inhibition model, the site-specific modulation of alpha is an important neural mechanism allowing the perceptual prioritization of specific locations in the visual field, by “gating” activity in the corresponding visual cortex (Foxe & Snyder, 2011).

The active inhibition model was developed in accordance with EEG findings in intersensory and visuospatial attention tasks (e.g., Foxe et al., 1998; Fu et al., 2001; Worden et al., 2000; Kelly et al. 2006). In an early representative study, Foxe and colleagues (1998) observed that a cue instructing subjects to attend exclusively to either the visual or auditory modality, in order to detect an imminent target stimulus, both decreased alpha over areas associated with the cued modality, and increased alpha over areas associated with the uncued modality. In more recent visuospatial studies, attention (fronto-parietal) networks have been demonstrated to modulate alpha over the visual cortex in a retinotopic manner, reflecting top-down anticipatory prioritization of visual information (Capotosto, Babiloni, Romani, & Corbetta, 2009; Mathewson et al., 2014). For example, in response to cues to attend left or right for an upcoming lateral target, pre-target posterior alpha power decreases contralaterally, and increases ipsilaterally, to the attended location (e.g., Kelly et al. 2006; Sauseng et al. 2005; Thut, Nietzel, Brandt, & Pascual-Leone, 2006). Moreover, the extent of the alpha lateralisation has been observed to be proportionate to cue validity (Gould, Rushworth, & Nobre, 2011; van Ede, de Lange, & Maris, 2012; Dombrowe & Hilgetag, 2014), and to predict behavioural performance (e.g., Thut et al., 2006). Together these findings indicate that the retinotopic modulation of alpha reflects preparatory biasing of visual cortex excitability, such that target-processing can be facilitated by the suppression of alpha originating in target-processing areas, and distractor-processing can be inhibited by increases in alpha originating in distractor-processing areas.

In sum, tonic alpha provides an established EEG index of sustained attention and task-engagement. On a more transient time-scale (e.g., within a cue-target interval), event-related phasic alpha reflects the anticipatory prioritizing of task-relevant information over task-irrelevant information.

The Current Experiments

Recent studies from our lab have found that irrelevant emotional distractors are more potent than non-emotional distractors under low but not high distractor frequency conditions. A natural hypothesis is that the high distractor frequency condition promotes a strategy shift from reactive to proactive control, where proactive (but not reactive) control is able to effectively control both emotional and non-emotional distraction. However, currently there is only limited, post-stimulus evidence that a shift to proactive control occurs. Because proactive control is characterised by sustained and/or anticipatory biasing of attention, the respective indices of tonic and phasic alpha offer provide more compelling measures to determine whether a shift to proactive control in fact occurs.

Accordingly, the aim of this thesis is to use EEG to test the hypothesis that a shift to proactive control occurs in the high distractor frequency condition, and secondly to determine whether proactive control differs according to the type of anticipated distractor (i.e., emotional or non-emotional). Experiment 1 is a behavioural study conducted to ensure that the previous behavioural findings replicate under slight procedural changes to the irrelevant distractor task, which were made to make the task more amenable to EEG recording in Experiment 2. Of particular note, in our previous studies distractors have been presented directly above or below a central target. However, due to the retinotopic nature of phasic alpha modulation, this previous design poses problems for distinguishing distractor-related increases in alpha from attention and target-related decreases in alpha, because both targets and distractors occur along the midline, and so might produce contradictory effects that cancel each other out. For this reason, distractors were presented laterally in the current experiments. Therefore, any lateralised changes in alpha could be attributed to distractor suppression instead of target enhancement. EEG was recorded in Experiment 2, so I could examine both tonic and phasic alpha in order to determine whether people use proactive control when distractors are frequent, and whether they tailor that control to the type of distractor they expect.

Experiment 1

Experiment 1 is a behavioural study using a slightly modified version of the irrelevant-distractor task used in previous experiments (Grimshaw et al., 2016; Kranz, 2015). The purpose of these task modifications was to make the task more amenable to EEG analysis. Experiment 1 is important in order to first confirm that the task modifications do not abolish the central finding that emotional images are more distracting than non-emotional images when distractors are frequent, but not infrequent.

The Irrelevant Distractor Task.

On each trial, participants indicate whether a briefly presented target appeared in a visual search array that was centred at fixation. On a certain proportion of trials (either 25% or 75%, depending on condition), an entirely task-irrelevant distractor image is presented simultaneously in a peripheral, task irrelevant location. The purpose of this distractor frequency manipulation is to promote reactive and proactive control, respectively. Importantly, distractors are blocked by valence (negative, neutral, positive) enabling participants to anticipate what type of distractor could appear on a given trial. The distraction produced by images of a particular valence is determined by comparing reaction times on distractor trials compared to no-distractor trials within the same valence-block.

Compared to other paradigms that have been used to study emotional distraction (e.g., Barratt & Bundesen, 2012; Fox et al., 2012; Padmala & Pessoa, 2014; Williams, Matthews, & MacLeod, 1996), this paradigm has two important advantages: 1) the distractors are entirely task-irrelevant, so distraction cannot be attributed to the task-relevant attention to emotion; and 2) both emotional and neutral distraction are measured, allowing direct comparison of the mechanisms that support emotional and non-emotional distraction.

Task Modifications.

Two modifications were made to the task so that effects of distractor suppression could be assessed through retinotopic alpha modulation. First, distractors were presented laterally instead of above and below fixation as was done previously. Importantly, the side of the potential distractor location was predictable on each trial, only alternating sides midway between each block. The purpose of lateralising distractors was to identify distractor-related increases in alpha over contralateral cortex in order to index location-based distractor suppression, as well as to avoid conflating distractor-related increases in alpha with concurrent alpha suppression at central occipital electrode sites (either due to heightened task engagement and/or retinotopic target-enhancement). Secondly, for the same reasons, the circular visual array used in previous studies was altered into a central vertical column, increasing the lateral distance between the midline target and the distractor stimuli while also ensuring that targets were not even slightly lateralised.

Each trial began with a fixation cross which alerted the participant to an upcoming target. The fixation-target interval was selected to optimise the measurement of phasic alpha changes in response to fixation-onset. Specifically, the jitter of the fixation-target interval was reduced (so that participants could predict when a target would appear) and the duration was extended (900-1100ms, compared to 416-834ms in previous studies) to allow enough

time for alpha to shift in response to the fixation cue. The purpose of this modified fixation-target interval was to enable participants more accurate anticipation of the target/distractor onset, as well as to provide participants more time to prepare for the target/distractor onset.

Method

Participants

48 participants (24 men; 24 women; 7 left handed) ranging from 18 to 26 years of age ($M = 18.56$, $SD = 1.35$) with normal or corrected-to-normal vision were recruited from the undergraduate psychology pool at Victoria University of Wellington. All participants reported on a screening questionnaire not receiving current treatment for depression or anxiety. Participants were randomly assigned to low or high distractor frequency conditions. They received course credit for their participation, and provided written informed consent prior to participation. This study was approved by the Human Ethics Committee of the School of Psychology, Victoria University of Wellington (Wellington, New Zealand).

Materials

Task Procedure. The irrelevant distraction task was very similar to the task used previously in Kranz (2015) and Grimshaw et al. (2016). Participants discriminated whether a briefly (100ms) presented capitalized target letter was a 'K' or an 'N'. The target letter (font: Arial; font size: 24; colour: white; subtending 0.67° of visual angle) was randomly presented in one of six possible locations arranged in a central column along the vertical midline, where letters were evenly spaced (0.67° visual degrees apart) with the top and bottom letters appearing 1.68° visual degrees directly above and below fixation. Lowercase 'o's (font: Arial; font size: 8; subtending 0.22° of visual angle) appeared in the five non-target positions on each trial. Each trial began with a central fixation cross of a random duration between 900 and 1100ms. Following fixation, the visual letter display was presented for 100ms. Subjects were required to indicate whether the target was an 'N' or a 'K' by pressing '1' or '2' with the index and middle finger of their dominant hand, respectively. Key response mappings were counterbalanced. On a certain proportion of trials (25% and 75% in the low and high distractor frequency conditions, respectively) a lateralised distractor image was presented simultaneously with the visual letter display, randomly in either an upper or lower quadrant, with the centre of the image 7.59° visual angle from fixation.

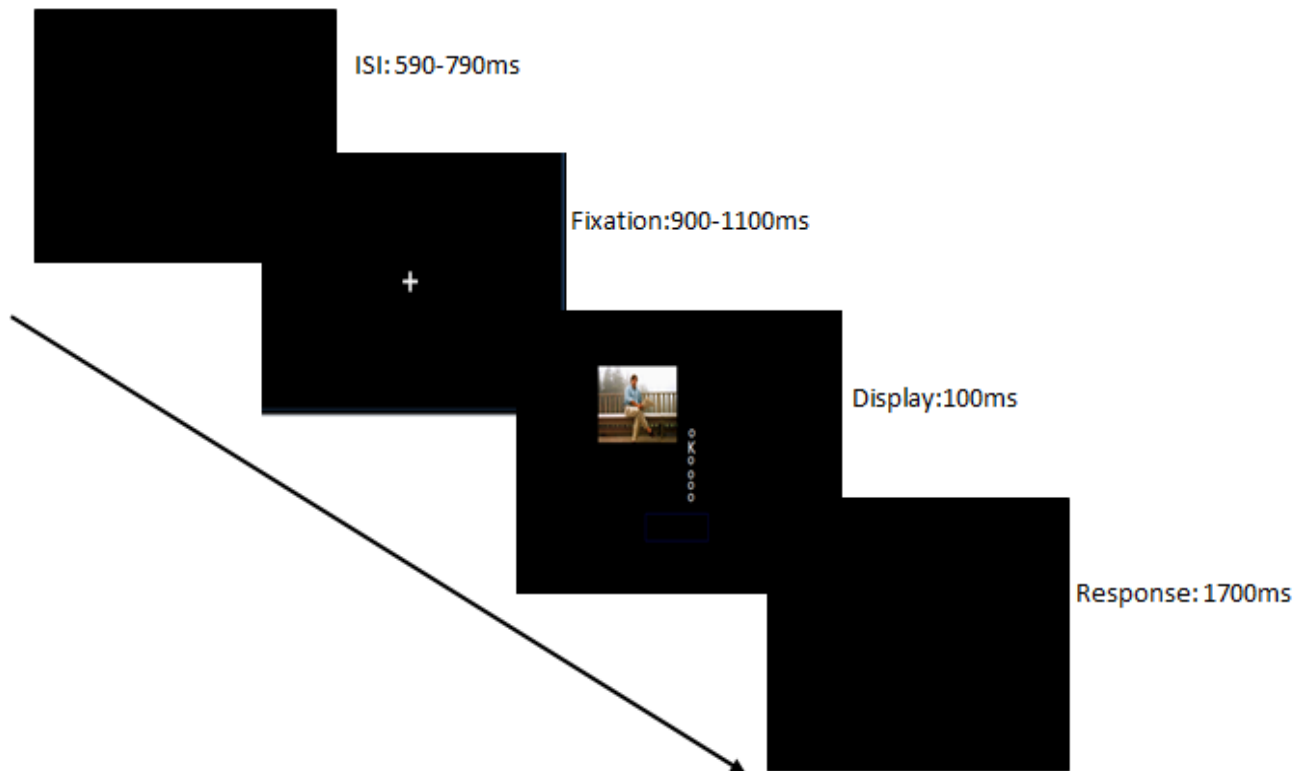


Figure 1: Schematic of the distraction task trial procedure

Note. Figure is for illustrative purposes only; stimuli are not depicted in actual size or ratio used.

Participants received negative auditory feedback (a 100ms ‘beep’) following either an incorrect response or a response slower than the 1700ms response window. A jittered inter-trial-interval was used, ranging between 590ms and 790ms after each response. Trials were blocked by valence (positive, negative and neutral). Specifically, participants completed three valence-blocks, with each valence-block consisting of four equal sub-blocks. Importantly, the side of the potential distractor location alternated between each sub-block (i.e., left, right, left, right; or vice versa), and thus the side of the potential distractor location (although not quadrant) was predictable on each trial. The order of distractor location across sub-blocks was consistent for each valence-block, but was counterbalanced between participants. The order of valence-block was also fully counterbalanced. In total, participants completed twelve sub-blocks of 48 trials each; 192 trials per valence. In addition, subjects completed two initial practice blocks of 48 trials (4 sub-blocks of 12 trials each), with distractor stimuli consisting of pixel-scrambles of the intact images used during the task, and presented at the same distractor frequency as the assigned condition.

Picture Stimuli. The same distractor stimuli were as used as in Grimshaw et al. (2016). Two gender-tailored sets of 36 colour images were taken from the IAPS (Lang et al.,

2008; see Appendix A), selected to have similar average valence and arousal ratings for each gender. Stimuli were 12 neutral pictures (scenes depicting people in daily life activities), 12 negative pictures (body mutilations), and 12 positive pictures (erotic images involving heterosexual couples). Pictures were matched for luminance and contrast with Matlab SHINE toolbox (Willenbockel et al., 2010). Pictures subtended $6.68^\circ \times 6.68^\circ$ of visual angle and were presented in colour.

Procedure and Design

The experiment was programmed and run in E-Prime 2.0 (Schneider, Eschman, & Zuccolotto, 2002). The experiment took approximately 30 minutes to complete. Data were collected in groups of up to four participants per session. Participants were seated in private individual cubicles, separated by dividing walls. Participants completed the experiment on Dell Precision T1700 desktop computers with 24" inch AOC monitors with a vertical refresh rate of 120 Hz and a resolution of 1920 by 1080 pixels. Chin rests were used to maintain an approximate viewing distance of 57 cm throughout the experiment.

The independent variables were distractor frequency (high, low; between subjects), distractor valence (positive, negative, neutral; within subjects), and distractor presence (present, absent; within subjects). The dependent variable of primary interest was response time (RT) on the letter search task, which was used to determine distraction (distractor present RTs - distractor absent RTs within each block). Accuracy was also recorded as a dependent variable, but accuracy levels were expected to be very high due to the ease of the task.

Results

Mean response times (RTs) and overall accuracy rates were calculated for each condition (See Table 1 and Table 2, respectively). One participant was excluded from analyses due to an overall accuracy rate below 80%. For RT measures, only correct responses with an RT longer than 200ms were analysed, ensuring anticipatory responses were not included in the analyses. The exclusion criteria led to the average removal of 3.15% ($SD = 4.50$) of trials per participant. For all analyses, Greenhouse-Geisser corrections were applied when Mauchly's test of sphericity was violated.

Accuracy

As expected, accuracy rates were very high overall ($M = 97.6$ $SD = 2.97$). Accuracy scores (% of correct responses) were analysed in a 2 (distractor frequency: low, high) \times 3 (valence: negative, neutral, positive) \times 2 (distractor presence: present, absent) mixed ANOVA. There were no significant main effects or interactions.

Response Times

Mean RTs were entered in a 3 (valence) x 2 (distractor presence) x 2 (distractor frequency: low, high) mixed ANOVA. A main effect of distractor presence was observed $F(1, 45) = 13.46, p = .001, \eta_p^2 = .23$, showing responses were slower when distractors appeared. Additionally, there was a two-way distractor presence x distractor frequency interaction, $F(1, 46) = 4.76, p = .034, \eta_p^2 = .10$, and a two-way valence x distractor presence interaction, $F(1, 46) = 4.35, p = .016, \eta_p^2 = .09$. Importantly, all effects were qualified by the predicted three-way valence x distractor presence x distractor frequency interaction, $F(1, 46) = 3.82, p = .026, \eta_p^2 = .078$.

To further explore the three-way interaction, a one-way repeated measures ANOVA with valence (positive, neutral, negative) as the within subjects variable and distraction indexes (total distractor present RTs - distractor absent RTs) as the dependent variable was conducted for the low and high distractor frequency conditions separately (see figure 3). ‘Neutral’ was always inserted as the middle variable in analyses, allowing me to examine quadratic relationships to assess in a hypothesis driven manner whether emotional distraction (i.e., both positive and negative) differed from neutral distraction.

In the low distractor frequency condition, there was a significant effect of valence, $F(1,22) = 5.75, p = .006, \eta_p^2 = .20$, and a significant quadratic relationship for valence, $F(1,23) = 10.44, p = .004, \eta_p^2 = .31$. Follow up t-tests found that neutral images were less distracting than both negative images, $t(23) = 2.28, p = .032, d = .41^1$, and positive images, $t(23) = 3.43, p = .002, d = .63$, which did not differ, $t(23) = .85, p = .404, d = .13$. By contrast, in the high distractor frequency condition there was no effect of valence, $F(1.54, 35.52) = 1.68, p = .204, \eta_p^2 = .07$, and no significant quadratic relationship for valence, $F(1,23) = .23, p = .636, \eta_p^2 = .01$. Although effects of valence were not significant, follow up t-tests were conducted to confirm that neutral images were no less distracting than negative, $t(23) = 1.09, p = .286, d = .33$, or positive images, $t(23) = .760, p = .455, d = .15$, which again did not statistically differ, $t(23) = 1.64, p = .115, d = .44$. This indicates that although negative images produced small but significant distraction in the high distractor frequency condition (see Table 1), it did not statistically differ from the non-distraction produced by positive and neutral images, consistent with our previous studies where no differences in distraction between valences were also observed.

¹ For all t-tests in this thesis, Cohen’s d is calculated using the difference between the means, divided by the pooled standard deviation (Dunlap, Cortina, Vaslow, & Burke, 1996).

Table 1

Mean (SD) RTs and distraction indices (ms) for the distraction task, for participants who met the behavioural inclusion criteria, by distractor frequency, valence and distractor presence in Experiment 1.

Condition	Distractor Present	Distractor Absent	Distraction Index	<i>t</i>	<i>d</i>	<i>p</i>
<u>Low Frequency</u>						
Positive	561 (93)	536 (68)	24 (42)	4.2	.31	.000
Neutral	543 (72)	533 (64)	10 (26)	1.9	.15	.037
Negative	559 (93)	529 (66)	29 (34)	2.8	.37	.005
<u>High Frequency</u>						
Positive	539 (66)	538 (68)	1 (26)	.24	.01	.407
Neutral	537 (66)	532 (64)	5 (23)	.59	.08	.282
Negative	550 (69)	536 (57)	14 (32)	2.2	.22	.019

Note. Distraction = RT on distractor-present trials – RT on distractor-absent trials.

Table 2

Mean (SD) accuracy (%) for the distraction task by distractor frequency, distractor presence, and valence in Experiment 1.

	Low Distractor Frequency		High Distractor Frequency	
	Present	Absent	Present	Absent
Valence	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>
Negative	98.08 (2.12)	98.51 (1.45)	97.36 (3.95)	96.62 (4.23)
Neutral	98.09 (2.37)	98.35 (1.47)	97.44 (4.06)	97.30 (3.83)
Positive	97.05 (3.42)	97.99 (1.82)	97.02 (3.68)	97.53 (3.28)

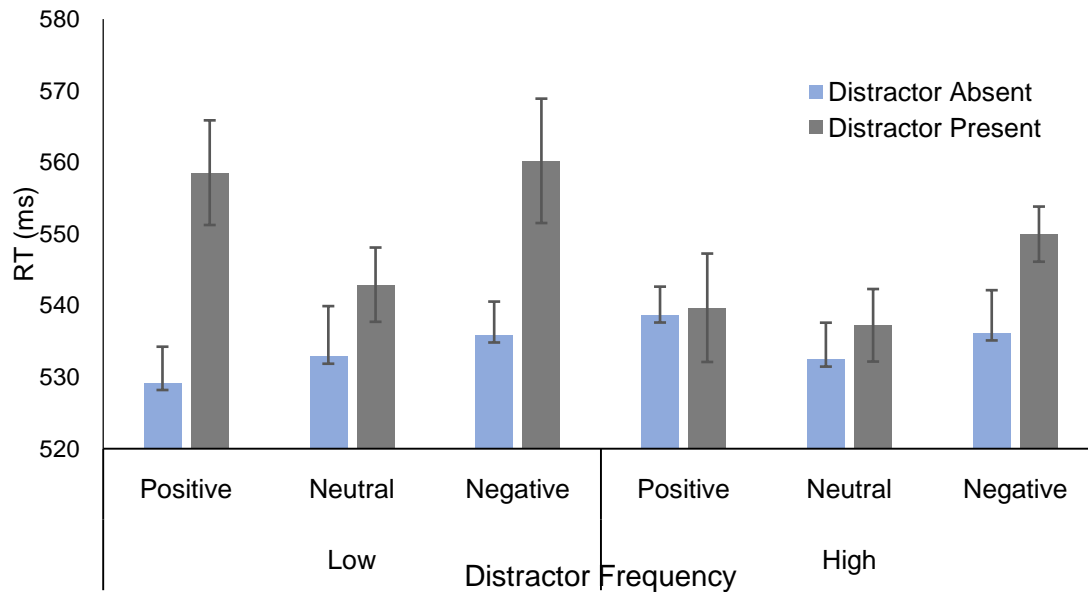


Figure 2. Mean RTs on the distraction task by distractor frequency, valence and distractor presence in Experiment 1.

Note. Errorbars represent standard errors of the mean for within subject comparisons (Morey, 2008)

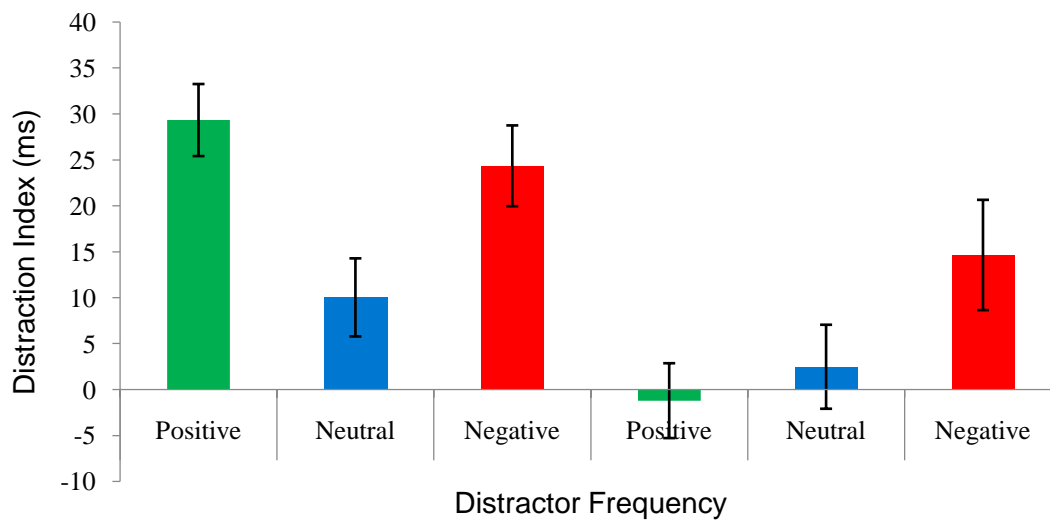


Figure 3. Mean distraction Index (RT on distractor-present trials - RT on distractor-absent trials) by distractor frequency and valence in Experiment 1. Emotional distraction was observed in the low distractor frequency condition but not high distractor frequency condition.

Note. Errorbars represent standard errors of the mean for within subject comparisons (Morey, 2008)

* = $p < .05$

Discussion

As predicted, the results from Experiment 1 replicate recent findings from our lab. Consistent with a shift from reactive to proactive control, entirely task- irrelevant distractors were distracting in the low but not high distractor frequency condition. Importantly, emotional images were more distracting than non-emotional images in the low but not high distractor frequency condition, consistent with the hypothesis that proactive (but not reactive) control can effectively control emotional distraction.

In this study, negative images produced small but significant distraction in the high distractor frequency condition. However it is important to note that the distraction caused by negative images did not differ from the non-distraction caused by positive and neutral distractors. This lack of significant difference in distraction between valences in the high distractor frequency condition is consistent with our previous studies.

Importantly, the successful replication of our previous studies confirm that the central findings outlined above are relatively robust, and are not abolished by the modified task parameters used in Experiment 1. Accordingly, the modified task-design in Experiment 1 was considered appropriate for further investigation with EEG in Experiment 2

Experiment 2

The aim of Experiment 2 is to use EEG to further elucidate the cognitive mechanisms responsible for the effective control of emotional distraction in high but not low distractor frequency conditions in the irrelevant distractor task. It has been proposed previously that a shift towards proactive control in the high distractor frequency condition is responsible for the improved performance. The current experiment tests this hypothesis in a more direct manner than the strictly behavioural methods used in other studies, by examining an electrophysiological index of proactive control. Because proactive control is characterised by the effortful, ongoing maintenance of goal-directed cognition, a shift to proactive control entails an increase in sustained attention and/or anticipatory biasing of attention (Braver, 2012; Braver, 2014). These processes can be indexed by tonic alpha and phasic alpha modulation, respectively.

Changes in tonic alpha (i.e., on the scale of seconds to minutes) have been routinely observed to track the waxing and waning of sustained attention and task-engagement throughout continuous performance tasks(e.g.,Bonnetfond et al, 2008; Gevins et al., 1997; Kelly et al., 2008Macdonald et al., 2011;O'Connell et al., 2009). Across numerous tasks, increased tonic alpha has been found to predict poorer behavioural performance, whereas

lower tonic alpha has been found to predict improved behavioural performance (Gevins et al., 1997; Macdonald et al., 2011; O'Connell et al., 2009).

Phasic alpha (i.e., transient and event-related changes, on the scale of subseconds to seconds) is associated with preparatory prioritization of task-relevant over task-irrelevant visual processing. Phasic alpha suppression is observed over target-processing areas in visual cortex when target onset is predictably imminent, e.g., during the cue-target interval in cued attention tasks (e.g., Romei et al., 2010; Worden et al., 2000). This phasic alpha suppression is thought to reflect preparatory attention directed towards the expected target, and is associated with improved behavioural performance. Conversely, phasic alpha enhancement is observed over distractor-processing areas in visual cortex when the onset of distractor stimuli is predictably imminent (e.g., Kelly et al., 2006; Thut et al., 2006). Phasic alpha enhancement is thought to reflect the preparatory suppression of distractor processing, and has also been associated with improved behavioural performance.

Predictions

Based on the hypothesis that participants rely on proactive control in the high but not low distractor frequency condition, I make several predictions about tonic and phasic alpha during the high compared to low distractor frequency task.

Low distractor frequency condition compared to High distractor frequency condition

First, it is predicted that tonic alpha (i.e., alpha collapsed across pre-fixation and pre-stimulus intervals) will be lower in the high distractor frequency condition, reflecting higher levels of sustained attention, characteristic of proactive control. Secondly, it is predicted that phasic alpha suppression (i.e., the drop in alpha from the pre-fixation to pre-stimulus intervals; in response to presentation of the fixation cross that cues an imminent trial) will be more pronounced in the high distractor frequency condition, indicative of participants' preparation to attend to the target in order to minimise attention capture by anticipated distractor stimuli. Third, it is predicted that pre-stimulus alpha lateralisation (i.e., the measure of lateralised distractor suppression) will be observed in the high, but not low, distractor frequency condition, such that alpha will be greater over the hemisphere that is contralateral than that which is ipsilateral to the expected distractor. In this study, pre-stimulus alpha lateralisation indicates the use of location-based proactive control, i.e., the advance inhibition of anticipated distractor locations.

Emotional compared to non-emotional distractor blocks

Because distractors are blocked by valence in the irrelevant distractor task, participants are able to anticipate the valence of an upcoming distractor. Part of the aim of

this thesis is to establish whether participants tailor their cognitive control to the type of distractor they anticipate. If so, there should be differences in tonic and phasic alpha suppression between emotional and neutral valence-blocks in the high but perhaps not low distractor frequency conditions. Specifically, if *more effortful* proactive control is required to control emotional distraction (because emotional distractors are more potent), then each of the above indices of proactive control should be potentiated in emotional compared to non-emotional valence-blocks in the high, but not low, distractor frequency condition.

EEG Alpha and Wavelet Analysis

Testing the above predictions relies on the use of power in the alpha frequency as a dependent measure. In neuroscience, the EEG alpha power occurring within a given epoch is most commonly measured using the Fast Fourier Transform (FFT). The Fourier Transform decomposes a signal (the EEG data) into a formula consisting of multiple pure sine and cosine terms, of differing frequencies, summed together. The extent to which the pure sine and cosine terms of a given frequency together account for (i.e., can reconstruct) the EEG data provides an estimate of the specific frequency power within the analysed epoch (typically 1-2 seconds; e.g., Grimshaw, Foster, & Corballis, 2014). However, a major limitation of the FFT is that, because pure sine and cosine terms are mathematically infinite, FFT is unable to determine the power of a frequency at any given time within an epoch (Cohen, 2014; Gross, 2014). That is to say, FFT has a temporal resolution only equivalent to the length of the epoch analysed, and thus is unable to provide the time-course of power change in a given frequency within an epoch.

Depending on the measure of interest, sometimes the poor temporal resolution provided by FFT is sufficient, e.g., measuring the hemispheric asymmetry of alpha power over an extended period. However, some measures of interest require a more specific time-course of frequency power. For example, if the research question requires tracking the behaviour of alpha power before, during, and after stimulus presentation, then a single FFT over the trial epoch will be of no help, as it will only provide an estimate of the overall average alpha power within the trial. One way to get around the poor temporal resolution of FFT is to compute multiple FFTs over short (e.g., 1s) contiguous epochs, effectively providing a time-course of a larger epoch by virtue of measuring discrete smaller epochs. However, a more sophisticated and precise method is to use a *time-frequency analysis*, of which I will focus on the most common, wavelet analysis (Cohen, 2014; Gross, 2014).

The advantage of wavelet analysis is that it enables an optimal balance between temporal and frequency resolution (Cohen, 2014; Gross, 2014). A refinement of the FFT,

wavelet analysis computes the extent to which multiple *finite* waves (known as “wavelets”), also of varying frequencies, can account for the EEG data. As opposed to the pure sine waves used in the FFT (which are infinite), wavelets are sine waves tapered to zero, most commonly with a gaussian distribution (i.e., Morlet Wavelets; see fig 4). The individual (or “daughter”) wavelets provide a “template” to compare with the EEG data. The wavelet analysis essentially consists of “sliding” the different daughter wavelets across the EEG data (see figure 5), computing the extent to which each “template” matches the EEG data at different time-points, thus providing an estimate of the time-course of power (μV^2) for different frequency bandwidths (or “layers”; see the example time-frequency plot in figure 6; Cohen, 2014; Gross, 2014). In this thesis, I will use a wavelet analysis to map how alpha power changes across the pre-fixation to pre-stimulus interval.

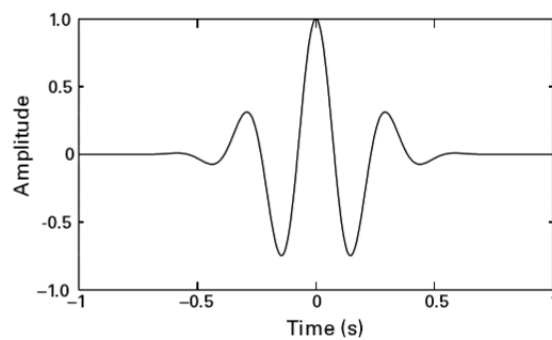


Figure 4. An example of a Morlet Wavelet: a sine wave tapered to zero with a Gaussian Distribution. Image retrieved from (Cohen, 2014).



Figure 5. A schematic representation of the wavelet analysis procedure. An individual wavelet (depicted in blue) is “slid” across the EEG data (depicted in black), yielding comparisons to the EEG data at each time-point. The output of the wavelet-to-EEG data comparison provides an estimate of the power of a specific frequency bandwidth across time (where the frequency bandwidth is dependent on the specific wavelet).

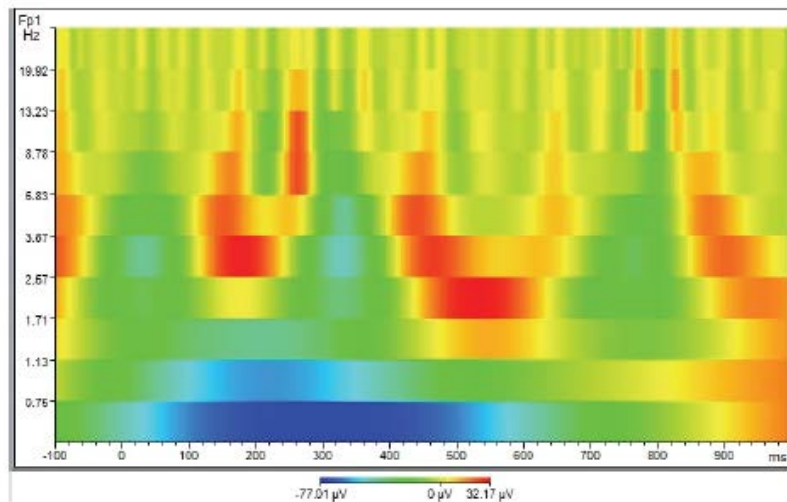


Figure 6. An example of a time-frequency plot resulting from a wavelet analysis. Frequency (Hz) is plotted on the Y-Axis, and time (ms) is plotted on the X-axis. Note the visible stacking of “layers”, corresponding to outputs for a particular frequency bandwidth. The power (μV^2) of each frequency bandwidth is depicted in colour, with blue indicating low power and red indicating greater power. Image retrieved from the BrainvisionAnalyzer Manual.

Method

Participants

60 participants (26 men; 34 women) ranging from 18 to 27 years of age ($M = 21.78$, $SD = 2.87$) with normal or corrected-to-normal vision were recruited from the undergraduate psychology pool at Victoria University of Wellington. All participants reported on a screening questionnaire not receiving current treatment for depression or anxiety. Participants were randomly assigned to low or high distractor frequency conditions. They received course credit for their participation, and provided written informed consent prior to participation. This study was approved by the Human Ethics Committee of the School of Psychology, Victoria University of Wellington (Wellington, New Zealand).

Procedure

Participants took part in the experiment individually. Each session took approximately 100 minutes, including EEG setup. EEG recordings took place in a dimly lit, electrically-shielded room. Participants completed the same distraction task as in Experiment 1. Tasks were completed on a Dell Precision T1600 computer, with a 23” Alienware 2310 LCD monitor running at a vertical refresh rate of 120 Hz. A viewing distance of 57cm was maintained using a chinrest.

EEG Recording

EEG was recorded during the distraction task with a Lycra Quick-Cap (CompumedicsNeuroMedical Supplies) embedded with Ag/AgCl electrodes at 28 scalp sites (FP1, FP2, F7, F3, FZ, F4, F8, FT7, FC3, FC4, FT8, T7, C3, CZ, C4, T8, TP7, CP3, CP4, TP8, P7, P3, PZ, P4, P8, O1, Oz, and O2, according to the modified 10-20 system; American Electroencephalographic Society, 1994). In addition, to detect blinks and eye movements, the electrooculogram (EOG) was recorded from electrodes placed at the outer canthus of each eye (horizontal), and above and below the left eye (vertical). Electrodes were also placed on the mastoid bones behind the right and left ear. The EEG and EOG channels were referenced online to the left mastoid and re-referenced offline to the algebraic average of the left and right mastoids. Impedances were periodically checked throughout the experiment and were kept below 5 k Ω .

The EEG signal was amplified with Professional BrainAmps and digitized at a sampling rate of 500 Hz with Brain-Vision Recorder (Brain Products, Gilching, Germany). Data was filtered online with a highpass filter of 0.02 Hz. Data were analysed using Brain-vision Analyzer 2.0 (Brain Products, Gilching, Germany). Horizontal EOG (HEOG) and Vertical EOG (VEOG) and channels were created by calculating the difference between HEOR and HEOL, and VEOL and VEOU, respectively. Data was filtered with a low cut-off of 0.01, a high cut-off of 30 Hz, and a notch filter at 50 Hz using a zero phaseshift Butterworth filter (12 dB/oct).

EEG analysis

Data was partitioned into 1700ms segments, beginning 400ms before the onset of the fixation cross (i.e., during the ITI) and finishing 1500ms after fixation onset. The purpose of this segment length was to provide 200ms buffer zones at the beginning and end of the segment, in order to avoid contaminating data in the time-windows of interest due to “edge artefacts” produced by the wavelet analysis. Edge artefacts are inherent to wavelet analysis due to the initial and final “sliding” of the wavelets over the EEG data, where only a small proportion of the wavelet overlaps with the EEG data.

Only correct trials were used for analysis. To deal with artefacts from muscle movements, segments with a change in voltage exceeding 100 μ V over posterior electrodes (O1, O2, Oz, Pz, P3, P4, P7, P8) were excluded. In addition, segments containing eye blinks within 200ms of stimulus onset were removed by visual inspection. This rejection criterion lead to an average total rejection of 12.9% ($SD = 8.6\%$) of trials.

Individual alpha frequency

To account for individual differences in the alpha frequency band, the specific frequency band used for statistical alpha power analysis was determined individually (e.g. Başar, 2012; Klimesch, 1999; Pfurtscheller & Lopes Da Silva, 1999). A Fast Fourier Transform was calculated to extract alpha across all segmented epochs, with a frequency resolution of 0.49 Hz. Each participant's individual alpha frequency (IAF) was defined as the frequency with the greatest power in the 8- to 13-Hz range over the parietal ROI (01, 02, 0z; similar to method used in Gould, Rushworth, & Nobre, 2011). The frequency band used for statistical analysis was determined by the wavelet layer with the closest central frequency to each participant's IAF.

Alpha power analysis

Single-trial power (μV^2) was estimated using a Continuous Morlet wavelet transformation, and averaged separately for each valence block in both conditions. The wavelet analysis consisted of 15 log-spaced frequencies, ranging from 5-20 Hz (Delorme & Makeig, 2004). The resulting bandwidth of the layers in the alpha frequency range are as follows: (7.1– 9.5 Hz), (7.7– 10.2 Hz), (8.3–11.0 Hz), (8.9-11.9 Hz), (10.3-13.7 Hz). Mean IAF alpha power was calculated in two-time windows: a 200 ms pre-fixation interval (i.e., during the ITI), and a pre-stimulus time-window 700 – 900 ms following the onset of fixation (i.e., immediately prior to the earliest possible onset of target/distractor stimuli). These two time-windows were used to test the predictions of lower tonic alpha (i.e. collapsed across both time-windows) and greater phasic alpha suppression (a pre- fixation to pre-stimulus decrease) in the high compared to low distractor frequency condition.

Alpha Lateralisation

Using the raw alpha power data from the wavelet analysis, Alpha Lateralisation Indexes (ALIs) for the p7/p8 electrode pair were calculated to determine if alpha power in the 700 - 900 ms pre-stimulus window was lateralised. ALIs were calculated using the double subtraction method outlined in Van der Lubbe & Utzerath (2013). Specifically, the calculation $(\text{Ipsilateral} - \text{Contralateral}) / (\text{Ipsilateral} + \text{Contralateral})$ was determined separately for each sub-block (with a left and right distractor location side, respectively), and the overall average was determined for each valence block per condition. Values of this ALI can vary from -1 to +1, where a negative value indicates greater alpha power over the side contralateral to the potential distractor location (indicating spatial inhibition of the distraction location), and a value of zero signifies the absence of lateralised differences. An

advantage of this double subtraction method is that it controls for baseline shifts in alpha power within and between blocks (Van der Lubbe&Utzerath, 2013).

Results

Behavioural Results

Mean overall accuracy rates and response times (RTs) were calculated for each condition, and used to compute distraction indices (See Table 3). For RT measures, only correct responses with an RT longer than 200ms were analysed, ensuring anticipatory responses were not included in the analyses. The exclusion criteria led to the average removal of 3.15% ($SD = 4.50$) trials per participant. For all analyses, Greenhouse-Geisser corrections were applied when Mauchly's test of sphericity was violated.

Accuracy

As expected, accuracy rates were very high overall ($M = 96.8$ $SD = 3.9$). Accuracy scores (% of correct responses) were analysed in a 2 (distractor frequency: low, high) x 3 (valence: negative, neutral, positive) x 2 (distractor presence: present, absent) mixed ANOVA. There were no significant main effects or significant interactions.

Response Times

RTs were entered in a 3 (valence) x 2 (distractor presence) x 2 (distractor frequency: low, high) mixed ANOVA. A main effect of distractor presence was observed, $F(1, 114) = 8.15$, $p = .006$, $\eta_p^2 = .13$, showing responses were slower when distractors appeared. Additionally, there was a two-way distractor presence x distractor frequency interaction, $F(1.00, 103.11) = 12.43$, $p = .001$, $\eta_p^2 = .02$, and a two-way valence x distractor presence interaction, $F(1.81, 103.11) = 3.47$, $p = .039$, $\eta_p^2 = .06$. Importantly, as in Experiment 1 and previous studies, all effects were qualified by the predicted, although marginal, three-way valence x distractor presence x distractor frequency interaction, $F(1.71, 100.11) = 2.78$, $p = .053$, $\eta_p^2 = .05$. Although marginal, this three-way interaction has now been replicated in this paradigm several times (Grimshaw et al, 2015; Kranz, 2015), and so can relatively safely be considered as genuine rather than spurious. Given that the interaction was predicted, it was followed up to compare distraction under high and low distractor frequency conditions.

As a first step in following up the three-way interaction, distraction indexes (total distractor present RTs - distractor absent RTs) were analyzed in a 3 (valence: positive, neutral, negative) x 2 (distractor frequency: low, high) mixed ANOVA. There was a main effect of both valence, $F(2, 114) = 6.31$, $p = .003$, $\eta_p^2 = .10$, and frequency, $F(1, 57) =$

Table 3

Mean (SD) RTs and distraction indices (ms) for the distraction task, for participants who met the behavioural inclusion criteria, by distractor frequency, valence and distractor presence in Experiment 2.

Condition	Distractor Present	Distractor Absent	Distraction Index	<i>t</i>	<i>d</i>	<i>P</i>
<u>Low Frequency</u>						
Positive	529 (71)	509 (58)	21 (30)	3.7	.31	.000
Neutral	526 (68)	516 (63)	10 (19)	3.0	.15	.003
Negative	539 (89)	522 (77)	17 (34)	2.7	.20	.006
<u>High Frequency</u>						
Positive	525 (82)	526 (78)	-1 (18)	.28	.01	.391
Neutral	532 (80)	531 (78)	1 (19)	3	.01	.442
Negative	527 (81)	529 (81)	-2 (16)	.50	.02	.309

12.43, $p = .001$, $\eta_p^2 = .18$, and a significant distractor frequency x valence interaction $F(2, 114) = 6.85$, $p = .002$, $\eta_p^2 = .11$.

To explore this interaction, a one-way repeated measures ANOVA on distraction indices, with valence (positive, neutral, negative) as the within subjects variable was conducted for the low and high distractor frequency conditions separately. ‘Neutral’ was always inserted as the middle variable in analyses, allowing me to examine quadratic relationships to assess in a hypothesis driven manner whether emotional distraction (i.e., positive and negative) differed from neutral distraction.

In the low distractor frequency group, although there was no significant effect of valence, $F(2, 39.49) = 1.23$, $p = .291$, $\eta_p^2 = .04$, there was a significant quadratic effect of valence, $F(1, 28) = 5.03$, $p = .033$, $\eta_p^2 = .15$, indicating an emotional distraction effect was present, consistent with previous studies. Follow up t-tests found that neutral images were less distracting than positive, $t(28) = 2.30$, $p = .029$, $d = .40$, but not negative images, $t(28) = 1.00$, $p = .324$, $d = .24$, while distraction produced by positive and negative images did not differ, $t(28) = .45$, $p = .659$, $d = .11$. By contrast, in the high distractor frequency condition there was no effect of valence, $F(2, 58) = .13$, $p = .880$, $\eta_p^2 = .004$, and no significant

quadratic effect of valence, $F(1,29) = .24$, $p = .631$, $\eta_p^2 = <.01$, indicating no emotional distraction effect was present, consistent with previous studies.

Finally, paired t-tests compared RTs on distractor trials and no-distractor trials for each valence in the low and high distractor frequency conditions separately, in order to determine the instances where distraction occurred. The results are displayed in Table 3 above.

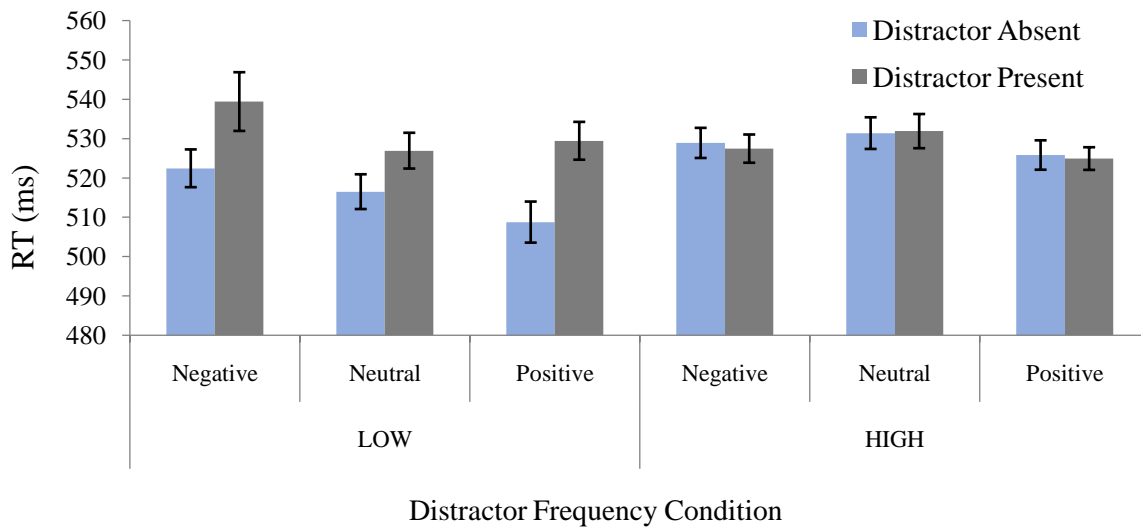


Figure 7. Mean RTs on the distraction task by distractor frequency, valence and distractor presence in Experiment 2.

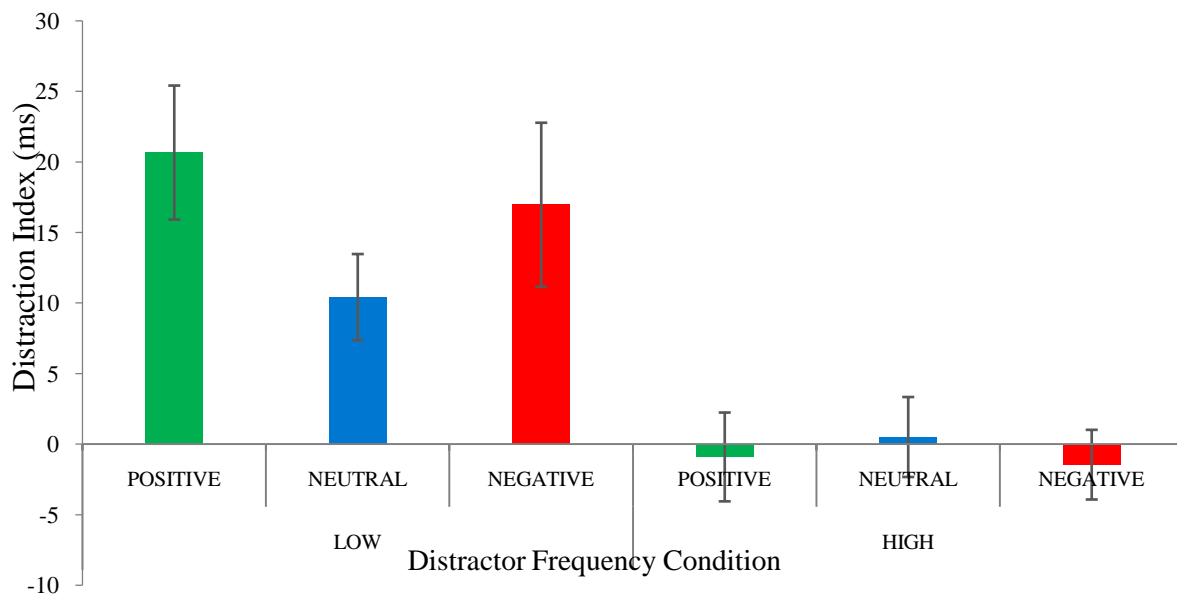


Figure 8. Mean distraction Index (RT on distractor-present trials - RT on distractor-absent trials) by distractor frequency and valence in Experiment 2. Emotional distraction was observed in the low distractor frequency condition but not high distractor frequency condition.

EEG Results

As in the behavioural results, quadratic effects were examined for predicted valence relationships (i.e., valence and valence x distractor frequency effects) in addition to overall effects of valence. Marginal effects were followed up but only if they were predicted or addressed the primary hypotheses. For all analyses, Greenhouse-Geisser corrections were applied when Mauchly's test of sphericity was violated.

Alpha Power

The raw alpha power waveforms for trials in the negative, neutral and positive blocks are presented in Figure 9. Mean alpha power was analysed in a 2 (time-window: pre-fixation, pre-stimulus) x 3 (valence: positive, neutral, negative) x 2 (distractor frequency: low, high) mixed ANOVA. As predicted, a main effect of distractor frequency was observed, $F(1, 55) = 5.12, p = .027, \eta_p^2 = .09$, showing tonic alpha power was suppressed in the high compared to low frequency condition. This finding indicates that participants in the high frequency condition had higher levels of sustained attention and were more engaged in the task than participants in the low distractor frequency condition, characteristic of a shift to proactive control.

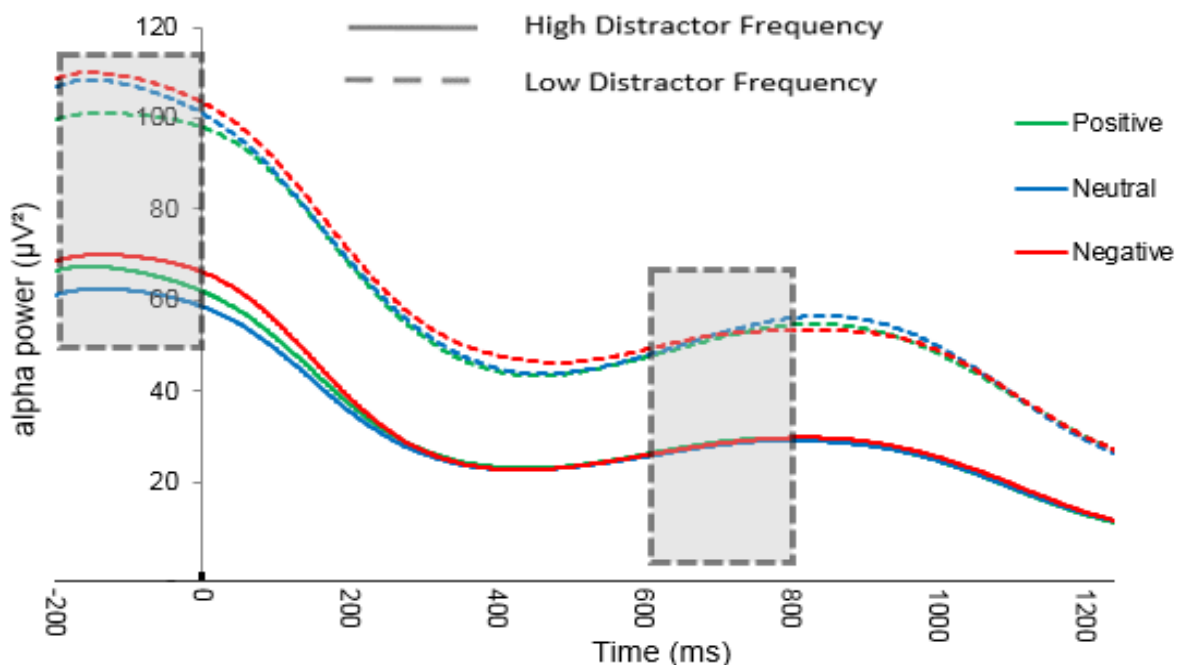


Figure 9. Grand average waveforms of raw IAF alpha power during the low (dashed) and high (undashed) distractor frequency conditions, according to valence-block. Fixation onset occurs at 0 ms. Dashed boxes indicate the pre-fixation (-200 – 0 ms) and pre-stimulus (700 – 900 ms) time-windows used for statistical analysis.

There was also a predicted main effect of time-window, $F(1, 55) = 39.70, p < .001$, $\eta_p^2 = .42$, showing that alpha was suppressed phasically in response to the fixation cue, reflecting preparation to attend to the imminent target.

However, contrary to prediction, there was no time-window x distractor frequency interaction, $F(1, 55) = 1.10, p = .300$, $\eta_p^2 = .02$, indicating that the extent of phasic alpha suppression did not depend on the level of distractor expectancy.

There was no main effect of valence, $F(2, 110) = 1.83, p = .165$, $\eta_p^2 = .03$, indicating that tonic alpha did not differ between emotional and neutral valence-blocks. There was however, a marginally significant valence x time-window interaction, $F(1.69, 92.86) = 2.76, p = .077$, $\eta_p^2 = .05$, indicating that phasic alpha suppression differed according to which type (i.e., valence) of distractor was expected, independent of distractor frequency. Follow up t-tests indicated that phasic alpha suppression (the drop in alpha between the two time-points) was more pronounced during negative ($M = 46.9, SD = 54.5$) than both neutral ($M = 41.7, SD = 54.3$), $t(56) = 2.02, p = .048, d = .10$, and positive ($M = 41.5, SD = 51.4$) valence-blocks, $t(56) = 2.56, p = .013, d = .10$, while phasic alpha suppression did not differ between positive and neutral valence-blocks, $t(56) = .07, p = .946, d < .01$. These findings suggest that participants tailored their cognitive control such that phasic alpha suppression was more prominent when negative compared to either positive or neutral distractors were expected, independent of distractor frequency.

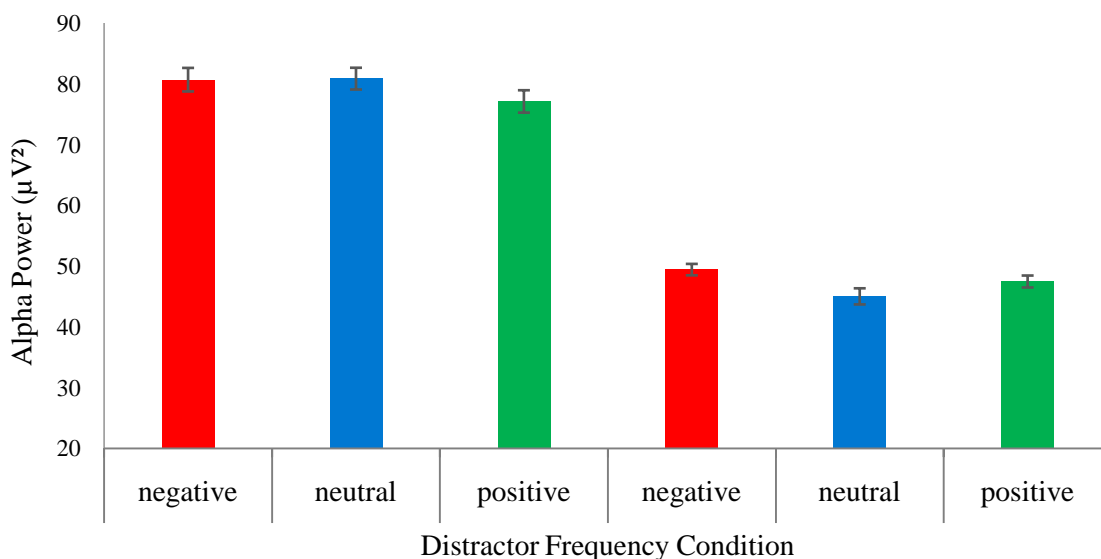


Figure 10. Mean Tonic Alpha Power (the average of alpha power in the pre-fixation and pre-stimulus time-windows) for the low and high distractor frequency conditions, according to valence-block.

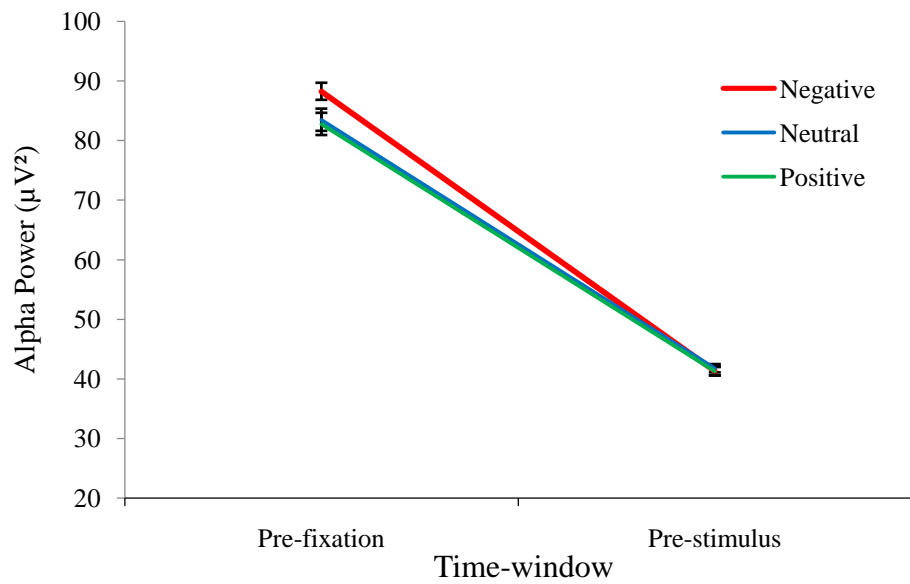


Figure 11. Comparison of mean alpha power during the pre-fixation and pre-stimulus time windows, according to valence-block, collapsed across low and high frequency conditions.

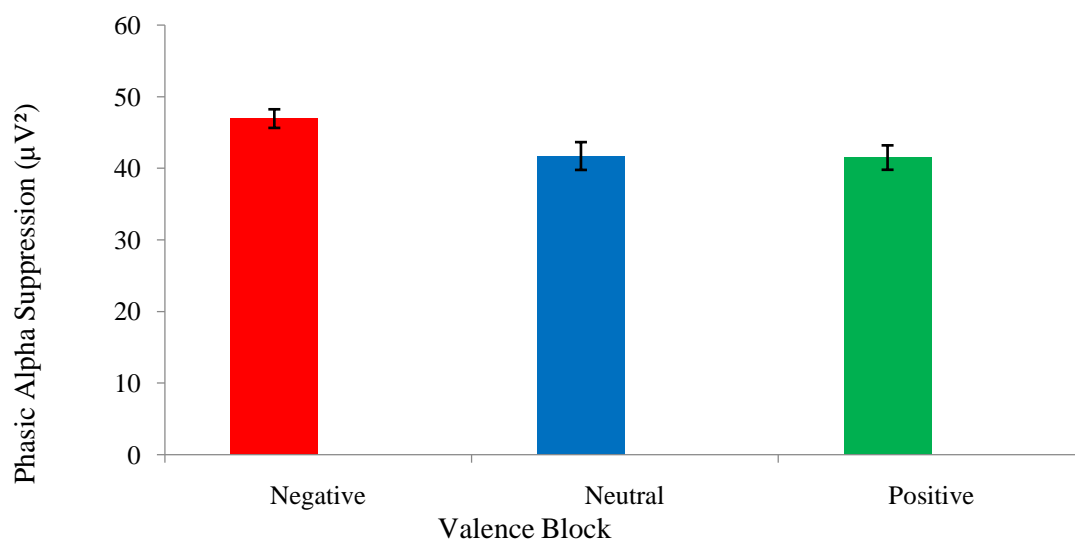


Figure 12. Mean phasic alpha suppression (the drop in alpha in response to fixation onset) according to valence-block, collapsed across the low and high distractor frequency conditions.

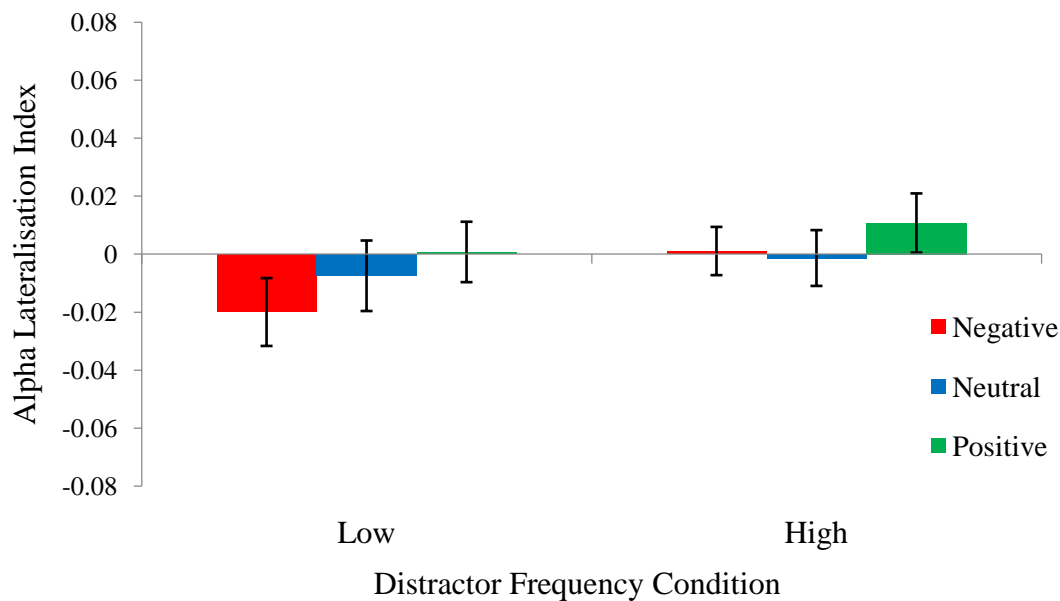


Figure 11. Alpha Lateralisation Indices for the low and high distractor frequency conditions, according to valence-block. Positive values indicate increased alpha power over the hemisphere ipsilateral to the distractor location. No ALI was significantly different from zero.

Alpha Lateralisation

Alpha lateralisation indices (ALIs) can be seen in figure 13. ALIs during the pre-stimulus (700 – 900 ms) time window were analysed in a 3(valence: positive, neutral, negative) x 2 (distractor frequency: low, high) mixed ANOVA. There was no main effect of valence, $F(2, 110) = .81, p = .450, \eta_p^2 = <.01$, or frequency, $F(1, 55) = .24, p = .625, \eta_p^2 = <.01$. There was, however, a marginal valence x distractor-frequency interaction, $F(2, 110) = 2.73, p = .069, \eta_p^2 = .05$. Given its relevance to the hypotheses, this marginal interaction was explored further. Although the interaction shows small differences in alpha lateralisation as a function of valence, t-tests show that none of the valences, in either the high distractor or low distractor condition, produced alpha lateralisation that differed from zero (p values ranged from .125 to .996). Furthermore, the pattern of results are not consistent with any hypothesised effects of distractor suppression. The interaction may therefore not be particularly meaningful. Together these findings indicate alpha power was not lateralised in preparation of distractor onset. The lack of significant pre-stimulus alpha lateralisation indicates that the proactive control mechanism of location-based distractor suppression was not utilized (see also Grimshaw et al., 2016).

Discussion

In Experiment 2, I used EEG to examine the mechanisms by which emotional distraction is effectively controlled. The behavioural results again replicated the previous findings: emotional images were more distracting than non-emotional images in the high but not low distractor conditions. The overall effect of emotion was observed in the quadratic effect of valence in the low distractor frequency condition, although only positive images produced significantly more distraction than non-emotional images. A minor difference was that, whereas previous studies have observed slight distraction in the high distractor frequency condition, in the current experiment no distraction was observed in the high distractor frequency condition at all. In addition, the three-way distractor presence x distractor frequency x valence interaction observed in previous studies was only marginal ($p = .053$) in this study. This may be due to slightly lower levels of distraction in the low distractor frequency condition compared to previous studies, as indicated by visual inspection of previous data. The slightly lower levels of overall distraction in this study may possibly owe to the higher motivational context of an EEG study, compared to strictly behavioural studies. Nevertheless, the typical pattern of behavioural findings observed in previous studies was clearly also present in the current study (see figure 8), justifying use of the paradigm in an EEG study.

The results from analysis showing tonic alpha provide support for the hypothesis that participants in the high distractor frequency condition shift to a proactive control strategy. As predicted, tonic alpha power was significantly reduced in the high compared to low distractor frequency condition, evidenced by lower alpha power sustained across the pre-fixation (-200 – 0 ms) to pre-stimulus (700 – 900 ms) intervals. This finding suggests that the high distractor frequency condition promoted higher levels of sustained attention and ongoing task-engagement, characteristic of the effortful, ongoing maintenance of goal-directed cognition which defines proactive control.

As predicted, alpha was found to be suppressed phasically in response to the onset of the fixation-cross. However, contrary to prediction, the extent of phasic alpha suppression did not differ according to distractor expectancy (as indicated by a nonsignificant time-window x distractor frequency interaction). This indicates that the more effective control of distraction observed in the high compared to low frequency condition relates to tonic alpha suppression instead of (or in addition to) greater phasic alpha suppression.

Contrary to prediction, no main effect of valence was found, indicating tonic alpha did not differ according to whether emotional or neutral distractors were expected. However,

phasic alpha suppression was found to be greater during negative than both positive and neutral valence-blocks, indicating the dynamics of cognitive control were adjusted when negative distractors were expected, such that participants prepared to a greater extent to attend to the target following the onset of the fixation-cross.

Finally, no alpha lateralisation was observed in any condition, indicating the proactive control mechanism of location-based distractor suppression was not implemented, consistent with previous behavioural evidence (Grimshaw et al., 2016). This suggests that other distractor suppression mechanisms may have instead been utilized. Potential mechanisms will be considered in the general discussion.

Together, the electrophysiological evidence supports the hypothesis that a shift to proactive control accounts for the effective control of emotional and non-emotional distraction in the high frequency condition. The shift to proactive control in the high frequency condition is characterised by tonic alpha suppression, but not increased phasic alpha suppression. However, the results also indicate that, independent of distractor frequency, participants tailored cognitive control such that phasic alpha suppression was more pronounced when negative distractors were expected, reflecting greater preparation to attend to the target in response to the onset of the fixation cross. Finally, no alpha lateralisation was observed, suggesting the effective control of emotional and neutral distraction in the high distractor frequency condition is due to mechanisms other than location-based distractor suppression.

General Discussion

Prior studies in our lab (Grimshaw et al., 2016; Kranz, 2016) have demonstrated that task-irrelevant emotional images are more distracting than task-irrelevant non-emotional images under infrequent, but not frequent, distractor conditions. Because high distractor frequency conditions are thought to promote proactive control, these studies suggest that proactive control is able to effectively control emotional distraction. However, the behavioural evidence alone does not provide compelling evidence that proactive control is used in the high distractor frequency condition. The aim of this thesis was to use EEG to measure pre-stimulus indices of proactive control in order to test the hypothesis that the high frequency condition promotes a shift to proactive control, and secondly to determine whether proactive control differs according to the type (i.e., emotional or neutral) of distractor anticipated. Because procedural changes to the irrelevant distractor task were necessary in order to make it more amenable to EEG recording, Experiment 1 was a behavioural study conducted to ensure these changes did not significantly affect the

behavioural outcome. Following justification from Experiment 1, EEG was recorded during Experiment 2.

Behavioural Results

In both experiments task-irrelevant emotional images were found to be more distracting than task-irrelevant non-emotional images in the low but not high frequency conditions. Because the task design was slightly modified from previous experiments, the replication of this central finding indicates that it is robust. Both experiments also replicated the finding that distraction produced by negative and positive images did not significantly differ. This is consistent with evidence that attention capture by positive and negative images does not differ when the images are matched for sufficiently high arousal (Gupta, Hur, & Lavie, 2015; Most, Smith, Cooter, Levy, & Zald, 2007; Vogt, De Houwer, Koster, Van Damme, & Crombez, 2008).

One minor difference between the two current experiments is that overall levels of distraction were slightly reduced in the EEG experiment compared to Experiment 1. One possible explanation for this difference in distraction is the contrasting settings of the behavioural and EEG study. In contrast to the behavioural study, the EEG study was conducted in a particularly novel setting (an electrically shielded chamber), and involved a prolonged setting up period during which one-to-one interactions between experimenter and participant were extensive. Together these factors may have heightened the motivational context of the EEG experiment, facilitating task performance. Indeed, heightened motivation has been shown to improve both proactive and reactive control (Botvinick & Braver, 2015; Hu, Padmala, & Pessoa, 2013). Nevertheless, even though distraction may have been attenuated overall, the pattern of greater emotional than neutral distraction in the low, but not high distractor condition was clearly maintained in Experiment 2.

Tonic Alpha

Tonic alpha power over posterior electrode sites is an established inverse index of sustained attention and task-engagement (Bonnefond et al., 2010; Gevins et al., 1997; Kelly et al., 2008; Macdonald et al., 2011). As predicted, tonic alpha (that is, mean alpha across pre-fixation and pre-stimulus time windows) was suppressed in the high compared to low frequency condition. Because proactive control requires sustained attention in order to maintain goal-directed cognition ahead of anticipated distraction (Braver, 2007; Marini, Demeter, Roberts, Chelazzi, & Woldorff, 2016), this finding strongly indicates that proactive control was prominent in the high distractor frequency condition.

Consistent with tonic alpha suppression as an index of proactive control, neuroimaging and psychophysiological studies have observed similar tonic differences in attention between proactive and reactive control conditions in other paradigms (Burgess & Braver, 2010; Chatham et al., 2009; Chiew & Braver, 2013; Jimura et al., Braver, 2010). For example, Chiew & Braver (2013) found that pupil dilation (an index of cognitive effort) was tonically increased during reward blocks compared to non-reward blocks within an interference task (the A-X Continuous Performance task), accompanied by behavioural markers of proactive control. The similar pattern of tonic alpha suppression observed in the high compared to low distractor frequency condition, together with eliminated behavioural distraction, thus provides compelling evidence that proactive control was engaged.

In the previous studies presenting evidence for the proactive control of emotional distraction, no pre-stimulus measure of proactive control has been included (e.g., Grimshaw et al., 2016; Kleinsorge, 2007, 2009; Kranz 2015; Okon-Singer, Tzelgov, & Henik, 2007; Padmala & Pessoa, 2014). Consequently, because enhanced reactive control processes and/or stimulus desensitisation could potentially account for the observed reductions in emotional distraction in the high distractor frequency condition, it has not been entirely certain that participants actually engaged in proactive control. The current study makes an important contribution to the literature by confirming the presence of a pre-stimulus index of proactive control under conditions where emotional distraction was effectively controlled, thus strongly indicating that proactive control is at least partially responsible for the effective control of emotional distraction.

The strong evidence for the effective proactive control of emotional distraction in the current study also speaks to the broader debate about whether the prioritization of emotional processing is independent of top-down control. The pronounced attention capture by emotional compared to non-emotional stimuli is argued to be driven by an emotion-specific subcortical processing system (Lang, Bradley, & Cuthbert, 1998; LeDoux, 1995; Pourtois, Schettino, & Vuilleumier, 2013; Vuilleumier, 2005). Specifically, emotional information is thought to be detected rapidly by automatic, rudimentary processing in the amygdala (LeDoux, 1995), which is then thought to prioritize the cortical processing of emotional information via feedback pathways to sensory cortices (e.g., Pessoa, 2009; Vuilleumier, 2005).

Some researchers have argued that because the prioritization of emotional information is amygdala-driven, attention capture by emotional information is automatic and independent of top-down control (e.g., Brosch, Pourtois, Sander & Vuilleumier, 2011;

Viviani, 2013; Vuilleumier, 2005). Although this view can explain why emotional distractors are particularly potent in the low frequency condition, it is inconsistent with the current evidence that emotional distraction can be as effectively controlled proactively as non-emotional distraction. The current finding thus lends support to the opposing argument that the prioritization of emotional processing is not entirely independent of top-down control systems (e.g., Berggren, Koster, & Derakshan, 2012; Pessoa, 2005; Pessoa, 2013).

In addition, the current study highlights the methodological value of including a pre-stimulus measure of proactive control; not only for confirming effective proactive control, but also for demonstrating instances of *ineffective* proactive control. For example, inconsistent with the current results, Augst et al. (2014) found no reduction in emotional distraction under conditions thought to be conducive to proactive control (including high distractor frequency, and cuing an upcoming distractor), suggesting that the proactive control of emotional distraction is ineffective (at least under some conditions). However, Augst et al., (2014) used a slightly different paradigm from the current study, where participants had to determine whether the orientation of two bars presented on either side of a central distractor was the same or different. Hence, an alternative explanation for why emotional distraction was not reduced in Augst et al. (2014) is that the task parameters in Augst et al. (2014) did not lead participants to actually engage in proactive control. Ideally, in order to establish whether the proactive control of emotional distraction is ineffective under certain conditions, future research should include a pre-stimulus measure of proactive control (e.g., tonic alpha) in order to demonstrate that proactive control is in fact *attempted*.

Is proactive control in the high distractor frequency condition global or local?

Together with the behavioural results, tonic alpha suppression in the high compared to low distractor frequency condition suggests that a global (i.e., block-wide) proactive control strategy was adopted. Consistent with this interpretation, in other paradigms (e.g., Stroop, flanker) the list-wise manipulation of trial proportion has been found to promote global proactive control, sustained across trials in anticipation of upcoming conflict (Bugg & Crump, 2012). However, local (i.e., trial-by-trial) control effects have also been widely reported in interference paradigms, triggered by the presence of conflict on a preceding trial (Bugg & Crump, 2012). These sequential effects are thought to reflect a reflexive prioritization of task-relevant information in response to a conflict trial (Botvinick et al., 2001; Braver et al., 2007; De Pisapia & Braver, 2006). Thus although both sequential and global effects could be considered proactive control (in that they occur before trial onset),

they vary in the extent to which they imply voluntary or strategic control (Bugg & Crump, 2012).

In order to distinguish between local and global control processes, it is necessary to look at sequential effects. However, because the current study was designed to examine differences at the block-wide level, insufficient trial numbers do not allow me to examine sequential effects adequately. Because any sequential effects will be invariably fewer in the low compared to high distractor frequency condition (due to fewer post-distractors trials), it is possible that cumulative sequential effects contribute to both the reduced distraction and tonic alpha suppression observed in the high distractor frequency condition. Consistent with this possibility, previous trial type has been shown to modulate alpha power during the inter-trial interval within the Stroop task, such that alpha is suppressed following conflict trials, and especially following performance errors (Carp & Compton, 2009; Compton et al., 2011).

The extent to which the proactive control of emotional distraction is local or global has implications for how voluntarily emotional distraction can be effectively controlled, which is of significant clinical importance regarding the therapeutic treatment of disorders characterised by vulnerability to emotional distraction (e.g., anxiety, depression, and addiction). A straightforward next step to examine the extent to which proactive control is global or local in the current paradigm is to increase trial numbers enough to sufficiently examine local effects. In order to avoid introducing fatigue, it is recommended that in addition neutral images, only one of either negative or positive images are initially used, as this will allow for more blocks of the same valence in shorter time.

Phasic Alpha Suppression

It has been shown in other paradigms that cues (predictive or incentive) can prompt proactive control at the onset of a trial (e.g., Beck et al., 2010; Chiew & Braver, 2013; Jimura & Braver, 2009; Padmala & Pessoa, 2014). In the current paradigm, it was considered that in addition to cueing an imminent target, the onset of the fixation-cross may also cue an imminent *distractor* (with 25% and 75% reliability in the low and high distractor frequency condition, respectively). Accordingly, it was predicted that the fixation cross would prompt proactive control in the high frequency condition, and therefore phasic alpha suppression (i.e., the decrease in alpha in response to fixation onset) would be more pronounced in the high than low frequency condition, reflecting heightened preparation to attend to the target, due to greater anticipation of distractors.

Consistent with the onset of fixation acting as a predictive cue, overall phasic alpha suppression was observed (as indicated by a main-effect of time-window), reflecting

increased preparation to attend to the target in response to fixation onset. Contrary to prediction, however, the extent of phasic alpha suppression did not differ according to distractor frequency, as indicated by a non-significant interaction between time-window and distractor frequency condition. This finding suggests that the more effective control of distraction observed in the high compared to low frequency condition is not due to greater fixation-cued preparation to attend to the target, but instead to a more sustained proactive control strategy as indicated by tonically suppressed alpha. It should be noted, however, that direct comparison of phasic suppression between conditions may potentially be misleading due to the baseline (i.e., pre-fixation) differences in tonic alpha.

Notwithstanding, one possible reason why phasic alpha suppression may not differ between conditions is because substantial phasic alpha suppression is needed regardless of distractor expectancy, reflecting preparation to attend to the target necessary to perform well on the visual search task. Future research can examine this possibility by comparing the extent of phasic alpha suppression in a distractor-absent condition (or alternatively, explicitly distractor-absent blocks) to the low and high distractor frequency conditions. If phasic alpha suppression reflects necessary preparation to attend to the target even in the absence of distractor expectancy, then phasic alpha suppression should not differ between the distractor-absent and low or high frequency conditions. Conversely, if the extent of phasic alpha suppression is sensitive to distractor expectancy, then phasic alpha suppression should be less pronounced in the distractor-absent condition than in the low and high distractor frequency conditions, which would suggest that the fixation-cross prompts proactive control of anticipated distractions to some extent in *both* the low and high frequency conditions.

It is also possible that the fixation-cross did not prompt differential proactive control between conditions because the informational value of the fixation “cue” was consistent on every trial. By contrast, in studies where proactive control has been associated with increased cue-related activity, the cues prompting proactive control have been infrequent and more informationally salient (e.g., incentive cues informing participants that the subsequent trial will be rewarded for good performance; Beck et al., 2010; Braver & Botnivick, 2015; Chiew & Braver, 2016; Jimura & Braver, 2009). To examine whether a more informationally salient cue would prompt greater proactive control in the current paradigm, future research could adapt the fixation-cross to explicitly cue the likelihood of a distractor-present or distractor-absent trial occurring on a trial-by-trial basis. For example, the fixation-cross could be presented in red to cue a 75% likelihood of a distractor trial, and

presented in green to cue a 25% likelihood of distractor-present trial. If more informationally salient cuing of an imminent distractor is required to prompt proactive control, then phasic alpha suppression should be more pronounced following high than low likelihood distractor-present (fixation-cross) cues. This may be an effective way to determine if cuing a high likelihood of emotional distractors prompts proactive control in a comparable way to cuing a high likelihood of neutral distractors. An additional advantage of this design is that it would avoid baseline differences in tonic alpha, and thus comparison of phasic alpha suppression between conditions of high and low anticipation of distractors would be more transparent.

What are the Mechanisms of Proactive Control?

Although the finding of tonic alpha suppression strongly supports the hypothesis that proactive control was engaged in the high frequency condition, it does not elucidate which control mechanisms were used. In order to prioritize task-relevant over task-irrelevant information, proactive control relies on preparatory target enhancement and/or distractor suppression (Braver, 2012; Geng 2014).

One specific way by which this can be achieved is enhancing or suppressing attention to the locations where targets and distractors are expected to appear, respectively. At a neural level, this location-based proactive control is thought to be implemented by the retinotopic modulation of alpha, such that alpha is decreased over target processing areas and increased over distractor processing areas (e.g., Jensen & Mazaheri, 2010; Kelly et al., 2006; Thut et al., 2006 Worden et al., 2001). Because it is only possible to discern retinotopic alpha modulation when it is lateralised, the current measures of tonic and phasic alpha are unable to distinguish between alpha relating to location-based target enhancement and alpha relating to goal-maintenance and other mechanisms of target enhancement. In order to examine location-based target enhancement specifically, future research could present the targets laterally in an expected location. If greater location-based target enhancement accounts for the more effective control of distraction in the high compared to low frequency condition, then more alpha suppression should be observed contralateral to the target in the high than low frequency condition.

Because distractors were presented laterally, and on a predictable side for each trial (although the quadrant was predictable), I was able to measure pre-stimulus alpha lateralisation in order to examine whether the specific mechanism of preparatory location-based suppression was used to control distraction. Contrary to prediction, no alpha lateralisation was observed in either condition. This finding therefore indicates that expected

distractor locations were not suppressed in advance, and that other mechanisms are responsible for the effective control of emotional distraction.

The absence of location-based distractor suppression in the current study is consistent with a prior behavioural study from our lab using the irrelevant distractor task (Grimshaw et al., 2016). In that study, an additional ‘combined’ condition was included during which intact images were presented on 25% of trials while scrambled images (of the same stimuli set) were presented on another 50% of trials (i.e., 75% in total). It was expected that, if high distractor frequency promotes the suppression of distractor locations, then both scrambles and intact images should be equally well controlled (because the semantic content of intact images would no longer be processed). Instead, intact images produced just as much distraction as when presented infrequently (i.e., in the low distractor frequency condition), while scrambled images no longer produced any distraction at all. The lack of alpha lateralisation in the current study complements this behavioural finding, and together these findings suggest that, within the irrelevant distractor paradigm, distractor locations are not suppressed in advance.

It should be cautioned however, that the current task differs from the majority of studies in which alpha lateralisation has previously been observed. Alpha lateralisation has typically been observed in cued attention tasks, where the lateral location of the distractor is cued at the beginning of each trial. By contrast, the side (although not quadrant) of the potential distractor location in the current study is consistent across trials and always predictable (only alternating sides mid-way through each block). A recent study found evidence that when a lateral distractor location was consistent block-wide, location-based distractor suppression occurred *in the absence* of alpha lateralisation, but was indicated by reduced distraction and a diminished P1 ERP component (Noonan, Adamian, Pike, Printzlau, Crittenden, & Stokes, 2016). Hence, due to the consistency of distractor location in the current study, it is possible that location-based distractor suppression was implemented by a neural mechanism other than alpha lateralisation.

Notwithstanding, together with Grimshaw et al. (2016) the evidence against location-based distractor suppression suggests that other distractor suppression mechanisms may have instead been utilized. Because all distractor stimuli were in colour and targets were presented in white on a black background, one potential mechanism is the advance feature-based suppression of colour processing (Maunsell & Treue, 2006; Min & Park, 2010; Saenz, Buracas, & Boynton, 2002; Snyder & Foxe, 2010). Preparatory colour suppression has been observed in other paradigms, and has been associated with the advance inhibition of activity

in V4 (a cortical area specialised for colour processing; Min & Park, 2010; Snyder & Foxe, 2010). Future research could test for colour-based suppression in the current paradigm by equally intermixing colour and grey-scale distractor stimuli. If the effective control of both emotional and non-emotional distraction is due in part to preparatory colour suppression, then distraction produced by grey-scale images should be less effectively controlled than distraction produced colour-images (at least relative to the distraction produced by grey-scale and colour stimuli images when presented separately in a low distractor frequency condition).

It is also possible that, rather than (or in addition to) preparatory suppression, distractors are suppressed by enhanced reactive control processes in the high distractor frequency condition: proactive and reactive control mechanisms are not necessarily mutually exclusive. Indeed, they may well be independent and complementary (Geng, 2014; Gonthier, Braver, & Bugg, 2016). A natural next step after this study is to measure the distractor positivity (Pd) ERP component, an established index of the reactive suppression of lateral distractors (Hickey, Di Lollo, & McDonald, 2009; Hilimire, Hickey, & Corballis, 2012). Examining the Pd may allow to simultaneously determine whether distractors are suppressed by either proactive or enhanced reactive control processes. If distractors are proactively suppressed in the high distractor frequency condition, then a smaller Pd component would be expected than in the low distractor frequency condition. Conversely, if distractors are suppressed by enhanced reactive control processes, then a larger Pd would be expected in the high compared to low distractor frequency condition.

Is the Proactive Control of Emotional Distraction More Effortful?

The finding of tonic alpha suppression in the high distractor frequency condition provides compelling evidence that proactive control was effectively used to reduce both neutral and emotional distraction. A secondary goal of this thesis was to determine whether proactive control differs according to whether a distractor is expected to be neutral or emotional. Because distractors were blocked by valence, participants were able to reliably predict what type (i.e., valence) of distractor could potentially appear on any given trial. It was considered that the predictability of distractor valence may lead participants to tailor cognitive control to the type of distractor they expect. Because emotional distractors are particularly potent, it was hypothesised that the proactive control of emotional distraction would be more effortful, and therefore alpha suppression (tonic, phasic, or both) would be more pronounced during emotional compared to neutral distractor blocks within the high

distractor frequency condition (where proactive control was expected to be prominent), but perhaps not low distractor frequency condition.

Contrary to prediction, tonic alpha did not differ between emotional and neutral distractor blocks, indicating there were no sustained differences between the proactive control of emotional and neutral distractors. However, a marginally significant time-window x valence interaction indicated that phasic alpha suppression did vary according to the expected valence of a potential distractor, but independent of distractor frequency condition. Follow up t-tests found that total phasic alpha suppression (i.e., collapsed across conditions) was more pronounced during negative valence-blocks than both neutral and positive valence-blocks.

The more pronounced phasic alpha suppression during negative blocks suggests that proactive control was also adopted to some extent in the low distractor frequency condition, because preparation to attend to the target would not differ according to expected distractor type if only reactive control was used. This is not surprising given that there are considerable individual differences in the tendency and capacity to adopt proactive control (Braver, 2012). Indeed, some degree of proactive control in the low distractor frequency condition is consistent with the slightly reduced distraction observed in Experiment 2, and was possibly promoted by the heightened motivational context of the EEG setting (Padmala & Pessoa, 2014). However, it is not clear why the dynamics of proactive control was different for negative valence-blocks.

Visual inspection of figure 11 (showing alpha in the pre-fixation and pre-stimulus time-windows, collapsed across conditions) clearly indicates that the more pronounced phasic alpha suppression during negative valence-blocks was driven by higher alpha power within the pre-fixation time-window, while pre-stimulus alpha did not differ according to valence-block. This suggests that participants in both conditions disengaged to a greater extent during the inter-trial-interval when negative distractors were expected, and instead relied to a greater extent on fixation-cued preparation to attend to the target. However, because pre-stimulus alpha did not vary, it is not clear whether preparation to attend to the target was more effortful *per se*. One speculative interpretation is that the sustained proactive control of negative distractors was particularly cognitively taxing, leading participants to disengage to a greater extent during inter-trial intervals in order to conserve cognitive resources. Although speculation, this idea is consistent with evidence that taxing cognitive control resources with a concurrent working memory task increases emotional distraction more so than non-emotional distraction (Berggren, Koster and Derakshan, 2012;

Holmes, Mogg, de Fockert, Nielsen and Bradley, 2014). However, although the current study provides initial evidence that the dynamics of proactive control differ according to whether an anticipated distractor is negatively valenced or not, future research is ultimately required to elucidate why the time-course of alpha was different during negative valence-blocks, and whether the proactive control of emotional distraction is more effortful than neutral distraction.

In future research, using pupillometry to measure pupil dilation during the irrelevant distractor task may provide a valuable method to elucidate whether the proactive control of emotional distraction is particularly effortful, as pupil dilation provides a sensitive index of cognitive effort (Chatham et al., 2009; Chiew & Braver, 2013). In addition, instead of blocking by distractor valence, which has the potential to lead to valence-specific cumulative effects (e.g., differential cognitive fatigue) and thereby influence results in a non-transparent way, future research may benefit from instead cueing the valence of a potential distractor within a *mixed* distractor valence block (e.g., a red fixation cross might cue a potential negative distractor). If the proactive control of negative distraction is particularly effortful, then greater pre-stimulus pupil dilation would be expected following the cuing of potential negative distractors, compared to positive or neutral distractors.

Conclusions

The aim of this thesis was to use EEG to measure pre-stimulus indices of proactive control in order to test the hypothesis that the high frequency condition promotes a shift to proactive control, and secondly to determine whether proactive control differs according to whether emotional or neutral distraction is anticipated. Experiment 1 confirmed that slight modifications to the irrelevant distractor task (to make it more amenable to EEG analysis) did not abolish the behavioural finding that emotional distractors are more distracting than non-emotional distractors under low but not high distractor frequency conditions (Grimshaw et al., 2016; Kranz, 2015). The typical pattern of behavioural results was again replicated in Experiment 2, during which EEG was recorded.

Importantly, tonic alpha was suppressed in the high compared to low distractor frequency condition, strongly supporting the hypothesis that proactive control would be prominent in the high distractor frequency condition. This finding makes an important contribution to the literature by, together with the behavioural findings, providing the most compelling evidence yet that emotional distraction can be effectively proactively controlled. The compelling evidence for effective proactive control of emotional distraction also provides strong support for the argument that attention capture by emotional information is

not entirely independent of top-down control (Pessoa, 2009; Pessoa et al., 2002; Pourtois et al., 2013).

In contrast to tonic alpha, phasic alpha suppression (i.e., the drop in alpha in response to fixation onset) did not differ between the high and low distractor frequency conditions, indicating that the more effective control of distraction in the high distractor frequency condition was due to a more sustained proactive control strategy, rather than more fixation-cued preparation to attend to the target. In addition, alpha lateralisation was not observed in either the high or low distractor frequency condition, indicating that proactive control did not rely on preparatory suppression of expected distractor locations.

While tonic alpha did not differ according to whether emotional or neutral distractors were expected, phasic alpha suppression was more pronounced during negative than positive or neutral valence-blocks, independent of distractor frequency condition. The more pronounced phasic alpha suppression during negative-valence blocks provides initial evidence that the dynamics of proactive control differ when negative, compared to positive or neutral, distractors are expected. Future research, however, is required to elucidate why the dynamics of proactive control differ when negative distractors are expected; whether the proactive control of emotional distraction is more effortful than neutral distraction; and which specific mechanisms are used to effectively control emotional distraction. The irrelevant distractor task provides a valuable paradigm for which to conduct this future research. In addition to the theoretical implications, determining the mechanisms underlying the effective proactive control of emotional distraction is important for developing more effective and targeted treatments for disorders characterised by vulnerability to emotional distraction, such as depression, anxiety, and addiction.

References

- Augst, S., Kleinsorge, T., & Kunde, W. (2014). Can we shield ourselves from task disturbance by emotion-laden stimulation? *Cognitive, Affective & Behavioral Neuroscience*, 14(3), 1009–1025. doi:10.3758/s13415-013-0243-x
- Başar, E. (2012). A review of alpha activity in integrative brain function: fundamental physiology, sensory coding, cognition and pathology. *International Journal of Psychophysiology*, 86(1), 1-24.
- Bastiaansen, M. C., & Brunia, C. H. (2001). Anticipatory attention: an event-related desynchronization approach. *International Journal of Psychophysiology*, 43(1), 91-107.
- Bastiaansen, M. C., Böcker, K. B., Brunia, C. H., De Munck, J. C., & Spekreijse, H. (2001). Event-related desynchronization during anticipatory attention for an upcoming stimulus: a comparative EEG/MEG study. *Clinical Neurophysiology*, 112(2), 393-403.
- Beck, D. M., & Lavie, N. (2005). Look here but ignore what you see: Effects of distractors at fixation. *Journal of Experimental Psychology: Human Perception and Performance*, 31(3), 592–607. doi:10.1037/0096-1523.31.3.592
- Beck, S. M., Locke, H. S., Savine, A. C., Jimura, K., & Braver, T. S. (2010). Primary and secondary rewards differentially modulate neural activity dynamics during working memory. *PloS one*, 5(2), 9251
- Becker, R., Knock, S., Ritter, P., & Jirsa, V. (2015). Relating alpha power and phase to population firing and hemodynamic activity using a thalamo-cortical neural mass model. *PLoS Comput Biol*, 11(9), e1004352.
- Berger, H. (1929). Über das elektrenkephalogramm des menschen. *European Archives of Psychiatry and Clinical Neuroscience*, 87(1), 527-570.
- Berggren, N., Koster, E. H. W., & Derakshan, N. (2012). The effect of cognitive load in emotional attention and trait anxiety: An eye movement study. *Journal of Cognitive Psychology*, 24(1), 79–91. doi:10.1080/20445911.2011.618450
- Blagrove, E., & Watson, D. G. (2010). Visual marking and facial affect: Can an emotional face be ignored? *Emotion*, 10(2), 147–168. doi:10.1037/a0017743
- Bonnefond, A., Rohmer, O., Engasser, O., Hoeft, A., Eschenlauer, R., Muzet, A., & Tassi, P. (2008). Effects of age and task complexity on EEG and performance in relation to psychological states. *Journal of Psychophysiology*, 22(2), 100-109. doi: 10.1027/0269-8803.22.2.100

- Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review*, 108(3), 624–652. doi:10.1037//0033-295X.108.3.624
- Botvinick, M., & Braver, T. (2015). Motivation and cognitive control: from behavior to neural mechanism. *Psychology*, 66(1), 83.
- Braver, T. S. (2012). The variable nature of cognitive control: A dual mechanisms framework. *Trends in Cognitive Sciences*, 16(2), 106–113. doi:10.1016/j.tics.2011.12.010
- Braver, T. S., Krug, M. K., Chiew, K. S., Kool, W., Westbrook, J. A., Clement, N. J., . . . Somerville, L. H. (2014). Mechanisms of motivation-cognition interaction: Challenges and opportunities. *Cognitive, Affective & Behavioral Neuroscience*, 14, 443–72. doi:10.3758/s13415-014-0300-0
- Braver, T. S., Paxton, J. L., Locke, H. S., & Barch, D. M. (2009). Flexible neural mechanisms of cognitive control within human prefrontal cortex. *Proceedings of the National Academy of Sciences*, 106(18), 7351–7356. doi:10.1073/pnas.0808187106
- Brosch, T., Pourtois, G., Sander, D., & Vuilleumier, P. (2011). Additive effects of emotional, endogenous, and exogenous attention: Behavioral and electrophysiological evidence. *Neuropsychologia*, 49(7), 1779–1787. doi:10.1016/j.neuropsychologia.2011.02.056
- Burgess, G. C., & Braver, T. S. (2010). Neural mechanisms of interference control in working memory: Effects of interference expectancy and fluid intelligence. *PLoS ONE*, 5(9), 1–11. doi:10.1371/journal.pone.0012861
- Capotosto, P., Babiloni, C., Romani, G. L., & Corbetta, M. (2009). Frontoparietal cortex controls spatial attention through modulation of anticipatory alpha rhythms. *The Journal of Neuroscience*, 29(18), 5863–5872.
- Carp, J., & Compton, R. J. (2009). Alpha power is influenced by performance errors. *Psychophysiology*, 46(2), 336–343. doi:10.1111/j.1469-8986.2008.00773.x
- Carretié, L., Mercado, F., Tapia, M., & Hinojosa, J. A. (2001). Emotion, attention, and the “negativity bias”, studied through event-related potentials. *International Journal of Psychophysiology*, 41(1), 75–85. doi:10.1016/S0167-8760(00)00195-1
- Chao, H. F. (2011). Active inhibition of a distractor word: The distractor precue benefit in the stroopcolor-naming task. *Journal of Experimental Psychology: Human Perception and Performance*, 37(3), 799–812. doi:10.1037/a0022191

- Chatham, C. H., Frank, M. J., & Munakata, Y. (2009). Pupillometric and behavioral markers of a developmental shift in the temporal dynamics of cognitive control. *Proceedings of the National Academy of Sciences*, 106(14), 5529-5533
- Chiew, K. S., & Braver, T. S. (2016). Reward favors the prepared: Incentive and task-informative cues interact to enhance attentional control. *Journal of experimental psychology: human perception and performance*, 42(1), 52.
- Cohen, M. X. (2014). *Analyzing neural time series data: theory and practice*. MIT Press.
- Compton, R. J., Arnstein, D., Freedman, G., Dainer-Best, J., & Liss, A. (2011). Cognitive control in the intertrial interval: evidence from EEG alpha power. *Psychophysiology*, 48(5), 583-590.
- De Pisapia, N., & Braver, T. S. (2006). A model of dual control mechanisms through anterior cingulate and prefrontal cortex interactions. *Neurocomputing*, 69(10), 1322-1326.
- Edwards, B. G., Barch, D. M., & Braver, T. S. (2010). Improving prefrontal cortex function in schizophrenia through focused training of cognitive control. *Frontiers in Human Neuroscience*, 4, 1–12. doi:10.3389/fnhum.2010.00032
- Eimer, M. (1993). Effects of attention and stimulus in a go/nogo task. *Biological Psychology*,
- Forster, S., & Lavie, N. (2008a). Attentional capture by entirely irrelevant distractors, *Visual Cognition*, 16(2-3), 200–214. doi:10.1080/13506280701465049
- Forster, S., & Lavie, N. (2008b). Failures to ignore entirely irrelevant distractors: The role of load. *Journal of Experimental Psychology: Applied*, 14(1), 73–83. doi:10.1037/1076-898X.14.1.73
- Foxe, J. J., Simpson, G. V., & Ahlfors, S. P. (1998). Parieto-occipital ~ 10 Hz activity reflects anticipatory state of visual attention mechanisms. *Neuroreport*, 9(17), 3929-3933.
- Fu, K. M. G., Foxe, J. J., Murray, M. M., Higgins, B. A., Javitt, D. C., & Schroeder, C. E. (2001). Attention-dependent suppression of distracter visual input can be cross-modally cued as indexed by anticipatory parieto-occipital alpha-band oscillations. *Cognitive Brain Research*, 12(1), 145-152.
- Geng, J. J. (2014). Attentional mechanisms of distractor suppression. *Current Directions in Psychological Science*, 23(2), 147-153.

- Gevins, A., Smith, M. E., McEvoy, L., & Yu, D. (1997). High-resolution EEG mapping of cortical activation related to working memory: effects of task difficulty, type of processing, and practice. *Cerebral cortex*, 7(4), 374-385.
- Goldman, R. I., Stern, J. M., Engel Jr, J., & Cohen, M. S. (2002). Simultaneous EEG and fMRI of the alpha rhythm. *Neuroreport*, 13(18), 2487.
- Gonthier, C., Braver, T. S., & Bugg, J. M. (2016). Dissociating proactive and reactive control in the Stroop task. *Memory & cognition*, 1-11.
- Gould, I. C., Rushworth, M. F., & Nobre, A. C. (2011). Indexing the graded allocation of visuospatial attention using anticipatory alpha oscillations. *Journal of Neurophysiology*, 105(3), 1318–1326. doi:10.1152/jn.00653.2010
- Gregoriou, G. G., Paneri, S., & Sapountzis, P. (2015). Oscillatory synchrony as a mechanism of attentional processing. *Brain research*, 1626, 165-182.
- Grimshaw, G. M., Foster, J. J., & Corballis, P. M. (2014). Frontal and parietal EEG asymmetries interact to predict attentional bias to threat. *Brain and Cognition*, 90, 76–86. doi:10.1016/j.bandc.2014.06.008
- Grimshaw, G. M., Kranz, L. S., Moody, R., Carmel, D., Devue, C (2016) Sex and Violence don't Always Win: Effective Proactive Control of Emotional Distraction. Manuscript submitted for publication.
- Gross, J. (2014). Analytical methods and experimental approaches for electrophysiological studies of brain oscillations. *Journal of neuroscience methods*, 228, 57-66.
- Gupta, R., Hur, Y.-J., & Lavie, N. (2015). Distracted by pleasure: Effects of positive versus negative valence on emotional capture under load. *Emotion*. Advance online publication. doi:10.1037/emo0000112
- Haegens S, Nácher V, Luna R, Romo R, Jensen O. (2011) α -Oscillations in the monkey sensorimotor network influence discrimination performance by rhythmical inhibition of neuronal spiking. *Proc Natl AcadSci USA*. 108(48):19377–82. doi: 10.1073/pnas.1117190108. pmid:22084106
- Hickey, C., Di Lollo, V., & McDonald, J. J. (2009). Electrophysiological indices of target and distractor processing in visual search. *Journal of cognitive neuroscience*, 21(4), 760-775.
- Hilimire, M. R., Hickey, C., & Corballis, P. M. (2012). Target resolution in visual search involves the direct suppression of distractors: evidence from electrophysiology. *Psychophysiology*, 49(4), 504-509.

- Holmes, A., Mogg, K., de Fockert, J., Nielsen, M. K., & Bradley, B. P. (2014). Electrophysiological evidence for greater attention to threat when cognitive control resources are depleted. *Cognitive, Affective & Behavioral Neuroscience*, 14(2), 827–835. doi:10.3758/s13415-013-0212-4
- Hu, K., Padmala, S., & Pessoa, L. (2013). Interactions between reward and threat during visual processing. *Neuropsychologia*, 51(9), 1763–1772. doi:10.1016/j.neuropsychologia.2013.05.025
- Jimura, K., & Braver, T. S. (2009). Age-related shifts in brain activity dynamics during task switching. *Cerebral Cortex*, 20(6), 1420–1431. doi: 10.1093/cercor/bhp206
- Jimura, K., Locke, H. S., & Braver, T. S. (2010). Prefrontal cortex mediation of cognitive enhancement in rewarding motivational contexts. *Proceedings of the National Academy of Sciences*, 107(19), 8871–8876.
- Jodo, E., & Kayama, Y. (1992). Relation of a negative ERP component to response inhibition in a go/no-go task. *Electroencephalography and Clinical Neurophysiology*, 82(6), 477–482. doi:10.1016/0013-4694(92)90054-L
- Kelly, S. P., Gomez-Ramirez, M., Montesi, J. L., & Foxe, J. J. (2008). L-theanine and caffeine in combination affect human cognition as evidenced by oscillatory alpha-band activity and attention task performance. *The Journal of nutrition*, 138(8), 1572S–1577S.
- Kelly, S. P., Lalor, E. C., Reilly, R. B., & Foxe, J. J. (2006). Increases in alpha oscillatory power reflect an active retinotopic mechanism for distracter suppression during sustained visuospatial attention. *Journal of neurophysiology*, 95(6), 3844–3851.
- Kerr, C. E., Jones, S. R., Wan, Q., Pritchett, D. L., Wasserman, R. H., Wexler, A., & Littenberg, R. (2011). Effects of mindfulness meditation training on anticipatory alpha modulation in primary somatosensory cortex. *Brain research bulletin*, 85(3), 96–103
- Kleinsorge, T. (2007). Anticipatory modulation of interference induced by unpleasant pictures. *Cognition & Emotion*, 21(2), 404–421. doi:10.1080/02699930600625032
- Kleinsorge, T. (2009). Anticipation selectively enhances interference exerted by pictures of negative valence. *Experimental Psychology*, 56(4), 228–235. doi:10.1027/1618-3169.56.4.228
- Klimesch W (1999) EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. *Brain Res Brain Res Rev* 29:169–195

- Klimesch, W. (2012). Alpha-band oscillations, attention, and controlled access to stored information. *Trends in cognitive sciences*, 16(12), 606-617.
- Klimesch, W., Doppelmayr, M., Russegger, H., Pachinger, T., &Schwaiger, J. (1998). Induced alpha band power changes in the human EEG and attention. *Neuroscience letters*, 244(2), 73-76.
- Klimesch, W., Sauseng, P., &Hanslmayr, S. (2007). EEG alpha oscillations: the inhibition–timing hypothesis. *Brain research reviews*, 53(1), 63-88.
- Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1998). Emotion, motivation, and anxiety: Brain mechanisms and psychophysiology. *Biological psychiatry*, 44(12), 1248-1263.
- Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (2008). International affective picture system (IAPS): Affective ratings of pictures and instruction manual. *Technical reportA-8*
- Laufs, H., Holt, J. L., Elfont, R., Krams, M., Paul, J. S., Krakow, K., & Kleinschmidt, A. (2006). Where the BOLD signal goes when alpha EEG leaves. *Neuroimage*, 31(4), 1408-1418.
- LeDoux, J. E. (1996). *The emotional brain*. New York: Simon & Schuster.
- Lee, Y. C., & Chao, H. F. (2012). The role of active inhibitory control in psychological wellbeing and mindfulness. *Personality and Individual Differences*, 53(5), 618–621. doi:10.1016/j.paid.2012.05.001
- Lichtenstein-Vidne, L., Henik, A., & Safadi, Z. (2012). Task relevance modulates processing of distracting emotional stimuli. *Cognition & Emotion*, 26(1), 42–52. doi:10.1080/02699931.2011.567055
- Locke, H. S., & Braver, T. S. (2008). Motivational influences on cognitive control: Behavior, brain activation, and individual differences. *Cognitive, Affective & Behavioral Neuroscience*, 8(1), 99–112. doi:10.3758/cabn.8.1.99
- Macdonald, J. S. P., Mathan, S., & Yeung, N. (2011). Trial-by-trial variations in subjective attentional state are reflected in ongoing prestimulus EEG alpha oscillations. *Frontiers in Psychology*, 2, 1–16. doi:10.3389/fpsyg.2011.00082
- Marini, F., Demeter, E., Roberts, K. C., Chelazzi, L., &Woldorff, M. G. (2016). Orchestrating Proactive and Reactive Mechanisms for Filtering Distracting Information: Brain-Behavior Relationships Revealed by a Mixed-Design fMRI Study. *The Journal of Neuroscience*, 36(3), 988-1000.
- Mathewson, K. E., Beck, D. M., Ro, T., Maclin, E. L., Low, K. A., Fabiani, M., &Gratton, G. (2014). Dynamics of alpha control: preparatory suppression of posterior alpha

oscillations by frontal modulators revealed with combined EEG and event-related optical signal. *Journal of cognitive neuroscience*, 26(10), 2400-2415.

- Maunsell, J. H., & Treue, S. (2006). Feature-based attention in visual cortex. *Trends in neurosciences*, 29(6), 317-322.
- Min, B. K., & Park, H. J. (2010). Task-related modulation of anterior theta and posterior alpha EEG reflects top-down preparation. *BMC neuroscience*, 11(1), 1.
- Morey, R. D. (2008). Confidence intervals from normalized data: A correction to Cousineau (2005). *reason*, 4(2), 61-64.
- Most, S. B., Smith, S. D., Cooter, A. B., Levy, B. N., & Zald, D. H. (2007). The naked truth: Positive, arousing distractors impair rapid target perception. *Cognition and Emotion*, 21(5), 964-981. doi:10.1080/02699930600959340
- Munneke, J., Van der Stigchel, S., & Theeuwes, J. (2008). Cueing the location of a distractor: An inhibitory mechanism of spatial attention? *Acta Psychologica*, 129(1), 101-107. doi:10.1016/j.actpsy.2008.05.004
- Noonan, M. P., Adamian, N., Pike, A., Printzlau, F., Crittenden, B. M., & Stokes, M. G. (2016). Distinct Mechanisms for Distractor Suppression and Target Facilitation. *The Journal of Neuroscience*, 36(6), 1797-1807.
- O'Connell, R. G., Dockree, P. M., Robertson, I. H., Bellgrove, M. A., Foxe, J. J., & Kelly, S. P. (2009). Uncovering the neural signature of lapsing attention: electrophysiological signals predict errors up to 20 s before they occur. *The Journal of Neuroscience*, 29(26), 8604-8611.
- Okon-Singer, H., Tzelgov, J., & Henik, A. (2007). Distinguishing between automaticity and attention in the processing of emotionally significant stimuli. *Emotion*, 7(1), 147-157. doi:10.1037/1528-3542.7.1.147
- Okon-Singer, H., Tzelgov, J., & Henik, A. (2007). Distinguishing between automaticity and attention in the processing of emotionally significant stimuli. *Emotion*, 7(1), 147-157. doi:10.1037/1528-3542.7.1.147
- Padmala, S., & Pessoa, L. (2011). Reward reduces conflict by enhancing attentional control and biasing visual cortical processing. *Journal of Cognitive Neuroscience*, 23(11), 3419-3432. doi:10.1162/jocn_a_00011
- Padmala, S., & Pessoa, L. (2014). Motivation versus aversive processing during perception. *Emotion*, 14(3), 450-454. doi:10.1037/a0036112
- Pessoa, L. (2009). How do emotion and motivation direct executive control? *Trends in Cognitive Sciences*, 13(4), 160-166. doi:10.1016/j.tics.2009.01.006

- Pessoa, L. (2013). *The cognitive-emotional brain: From interactions to integration*. MIT press.
- Pfurtscheller, G., Stancak, A., & Neuper, C. (1996). Event-related synchronization (ERS) in the alpha band—an electrophysiological correlate of cortical idling: a review. *International journal of psychophysiology*, 24(1), 39-46.
- Pourtois, G., Grandjean, D., Sander, D., & Vuilleumier, P. (2004). Electrophysiological correlates of rapid spatial orienting towards fearful faces. *Cerebral Cortex*, 14(6), 619–633. doi:10.1093/cercor/bhh023
- Pourtois, G., Schettino, A., & Vuilleumier, P. (2013). Brain mechanisms for emotional influences on perception and attention: What is magic and what is not. *Biological Psychology*, 92(3), 492–512. doi:10.1016/j.biopsycho.2012.02.007
- Rihs, T. A., Michel, C. M., & Thut, G. (2007). Mechanisms of selective inhibition in visual spatial attention are indexed by α -band EEG synchronization. *European Journal of Neuroscience*, 25(2), 603-610.
- Romei, V., Gross, J., & Thut, G. (2010). On the role of prestimulus alpha rhythms over occipito-parietal areas in visual input regulation: correlation or causation?. *The Journal of neuroscience*, 30(25), 8692-8697.
- Saenz, M., Buracas, G. T., & Boynton, G. M. (2002). Global effects of feature-based attention in human visual cortex. *Nature neuroscience*, 5(7), 631-632.
- Sauseng, P., Klimesch, W., Freunberger, R., Pecherstorfer, T., Hanslmayr, S., & Doppelmayr, M. (2006). Relevance of EEG alpha and theta oscillations during task switching. *Experimental Brain Research*, 170(3), 295-301.
- Sauseng, P., Klimesch, W., Stadler, W., Schabus, M., Doppelmayr, M., Hanslmayr, S., & Birbaumer, N. (2005). A shift of visual spatial attention is selectively associated with human EEG alpha activity. *European Journal of Neuroscience*, 22(11), 2917-2926.
- Shou, G., Dasari, D., & Ding, L. (2015). Pre-stimulus alpha and post-stimulus N2 foreshadow imminent errors in a single task. *Neuropsychologia*, 77, 346-358.
- Snyder, A. C., & Foxe, J. J. (2010). Anticipatory attentional suppression of visual features indexed by oscillatory alpha-band power increases: a high-density electrical mapping study. *The Journal of Neuroscience*, 30(11), 4024-4032.
- Thut, G., Nietzel, A., Brandt, S. A., & Pascual-Leone, A. (2006). α -Band electroencephalographic activity over occipital cortex indexes visuospatial attention

- bias and predicts visual target detection. *The Journal of Neuroscience*, 26(37), 9494-9502. doi:10.1080/02699930903205698
- Van der Lubbe, R. H., & Utzerath, C. (2013). Lateralized power spectra of the EEG as an index of visuospatial attention. *Advances in cognitive psychology*, 9(4), 184-201.
- Van Dijk, H., Schoffelen, J. M., Oostenveld, R., & Jensen, O. (2008). Prestimulus oscillatory activity in the alpha band predicts visual discrimination ability. *The Journal of Neuroscience*, 28(8), 1816-1823.
- van Ede, F., de Lange, F. P., & Maris, E. (2012). Attentional cues affect accuracy and reaction time via different cognitive and neural processes. *The Journal of Neuroscience*, 32(30), 10408-10412.
- Viviani, R. (2013). Emotion regulation, attention to emotion, and the ventral attentional network. *Frontiers in Human Neuroscience*, 7, 1 – 24.
doi:10.3389/fnhum.2013.00746
- Vogt, J., De Houwer, J., Koster, E. H. W., Van Damme, S., & Crombez, G. (2008). Allocation of spatial attention to emotional stimuli depends upon arousal and not valence. *Emotion*, 8(6), 880-885. doi:10.1037/a0013981
- Vuilleumier, P. (2005). How brains beware: Neural mechanisms of emotional attention. *Trends in Cognitive Sciences*, 9(12), 585–594. doi:10.1016/j.tics.2005.10.011
- Williams, J. M. G., Mathews, A., & MacLeod, C. (1996). The emotional Stroop task and psychopathology. *Psychological bulletin*, 120(1), 3.
- Worden, M. S., Foxe, J. J., Wang, N., & Simpson, G. V. (2000). Anticipatory biasing of visuospatial attention indexed by retinotopically specific-band electroencephalography increases over occipital cortex. *J Neurosci*, 20(RC63), 1-6.
- Yamagishi, N., Callan, D. E., Goda, N., Anderson, S. J., Yoshida, Y., & Kawato, M. (2003). Attentional modulation of oscillatory activity in human visual cortex. *Neuroimage*, 20(1), 98-113.
- Yamagishi, N., Goda, N., Callan, D. E., Anderson, S. J., & Kawato, M. (2005). Attentional shifts towards an expected visual target alter the level of alpha-band oscillatory activity in the human calcarine cortex. *Cognitive Brain Research*, 25(3), 799-809.
- Yiend, J. (2010). The effects of emotion on attention: A review of attentional processing of emotional information. *Cognition & Emotion*, 24(1), 3–47.
doi:10.1080/02699930903205698

Appendix A

IAPs image set for females:

neutral – 2026; 2102; 2221; 2305; 2393; 2397; 2411; 2512; 2593; 2595; 2745.1; 2840;

negative – 3015; 3030; 3059; 3103; 3131; 3140; 3150; 3195; 3550.1; 9253; 9405; 9420;

positive – 4658; 4659; 4660; 4668; 4680; 4690; 4693; 4694; 4695; 4697; 4698; 4800.

IAPs image set for males:

neutral – 2026; 2102; 2104; 2221; 2393; 2397; 2411; 2512; 2593; 2595; 2745.1; 2840;

negative - 3000; 3015; 3053; 3060; 3069; 3071; 3080; 3100; 3120; 3130; 3131; 9410;

positive – 4645; 4650; 4653; 4658; 4660; 4666; 4669; 4680; 4690; 4692; 4693; 4698.