THE EFFECT OF PSYCHOLOGICAL STRESS ON AUDITORY PERCEPTION

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Abstract

Psychological stress appears to precede instances of auditory hallucinations in those vulnerable to them. This suggests that psychological stress acts on the auditory perceptual system in such a way as to encourage the generation of false percepts. This thesis investigated the impact of psychological stress on the perception of emotionally neutral sounds with the aim of identifying a potential mechanism to explain the influence of stress on the occurrence of auditory hallucinations. Two interconnected hypotheses, arising from the theory that stress reduces attentional control and therefore the ability to inhibit distracting information, were tested. An auditory signal detection task was created to test whether stress would reduce the ability of the auditory-perceptual mechanism to accurately detect signals. Instead of reducing discrimination ability, stress was found to bias responding towards reporting a signal in highly anxious individuals. A number of passive oddball tasks were designed to test the hypothesis that stress would increase the distraction caused by emotionally neutral sounds. Once again this hypothesis was largely refuted, with stress appearing to reduce, rather than increase, the impact of distracting auditory information on task performance. On the basis of these findings a revised model of how stress may encourage auditory hallucinations was proposed. This model suggests that, through a strengthening of selective attention, stress may mal-adaptively bias auditory perception towards misinterpreting internal signals as external. Further research proposals, designed to test the predictions of this model, are suggested.

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Declaration

This thesis contains original work, completed by the author. No part of this work has been submitted for a degree at any other university. Selected aspects of this research have been presented at conferences or published in peer-reviewed journals, as detailed below.

The data reported in Chapter 2 has been published as

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These data were also presented by the author at British Psychology Society: Cognitive Section conference (Glasgow, August 2012) as '*The effect of psychological stress and expectation on auditory perception: A signal detection analysis'*.

The crossmodal experiment reported in Chapter 3 has been accepted for publication as

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The data from Chapter 3 was also presented by the author at the Royal College of Psychiatrists International Congress (Edinburgh, July 2013) as '*Psychological stress improves selective attention to emotionally neutral auditory stimuli'*.

Chapter 1: General Introduction

Overview

It is increasingly being acknowledged that the burden of mental health disorders represent a huge concern for modern societies (Gustavsson, et al., 2012; W.H.O, 2012). Within mental health, psychotic disorders such as schizophrenia represent one of the greatest challenges for health professionals because of the severity of the disorder and its (relatively) high prevalence. Psychotic disorders involve wide-ranging deficits in perception and mental functioning, which impact to such an extent that the sufferer's experience of reality is impaired. Their lifetime prevalence sits at around 1 in every 200 people (Goldner, et al., 2002). One of the major issues surrounding the understanding of psychotic disorders is the complexity of the condition from a clinical perspective. Different patients can experience differing combinations of symptoms with differing severities. This heterogeneity in psychotic symptomatology suggests either that there is not a unitary disease process underlying psychosis, or that the manifestation of the disease varies significantly depending on the context in which it develops. Given this complexity it is often suggested that psychosis should be addressed by focussing on the processes behind individual symptoms of the disorder, rather than on the condition as a whole (e.g. Tosato & Lasalvia, 2009).

The symptoms associated with psychosis are generally classed as either positive (those not experienced by healthy individuals) or negative (an absence of functioning that is present in the healthy). This thesis focuses on auditory hallucinations (AH), which are a common positive symptom of psychosis. AH tend to be episodic in nature. In particular it has been noted that periods of psychological stress appear to precede periods of auditory hallucinations in those who are vulnerable to them (Slade, 1972). This strongly suggests that psychological stress plays a significant role in the generation of AH. Despite this, no specific mechanism has been constructed to detail how psychological stress acts to encourage AH. The primary aim of the current thesis is to address this gap in scientific knowledge by attempting to identify how psychological stress acts on the auditory perceptual mechanism, and how this process may encourage AH.

What is psychological stress?

In material science, stress is the response of a material to exceptional demands (stressors) that threaten the structural integrity of the material. Biological entities are naturally vulnerable to physical stressors in much the same way as inanimate materials. However, the ability of living organisms to engage in active evaluation of their environment makes them uniquely vulnerable to a different class of stressor. Such stressors arise from changes in the environment that signal potential or ongoing threat, or which reignite memories of past threats. Although these psychological stressors will often accompany a physical stressor, the response to them is independent of any physical stress response, since the reaction to psychological stressors relies on an evaluation of the environment. For example a shaving cut will produce a physical stress response, involving haemostasis to reduce blood loss, inflammation to protect against bacterial infection and the formation of scar tissue around the wound. It will also create a psychological stress response, potentially involving the mental consequence of any attendant pain, self admonishment and trepidation regarding having to continue shaving. Psychological stress can therefore be defined as the response of an organism to changes in its environment which directly or indirectly threaten the wellbeing of the organism. This definition encompasses such complex emotions as fear, tension, anxiety and distress.

From a biological perspective, the stress response is driven by activity in two interrelated neurological systems that are distinguished by both their neuroanatomical location and the temporal dynamics of their activation (Gunnar & Quevedo, 2007). The sympathetic adrenomedullary (SAM) system (Frankenhaeuser., 1986) instigates neurochemical changes which take effect within a matter of seconds of a stressor's appearance. Noradrenaline is release by the brain stem into the spinal column to allow quick reactive motor actions. Concurrently the SAM system also provokes the release of noradrenaline from the Locus Coeruleus (LC) into brain areas such as the prefrontal cortex, hippocampus and thalamus. This neurochemical release allows the LC to mediate the level of arousal and the functioning of attentional networks during stress (Benarroch., 2009). The fast-acting SAM system therefore allows an organism to make a rapid responses to environmental threats. In contrast the hypothalamic-pituitary-adrenocortical system (HPA: Stratakis & Chrousos, 1995) acts much slower, increasing the release of cortisol from the adrenal cortex during acute stress, an action which does not take full effect until around 30 minutes after the initial experience of the stressor. Consequently the impact of the HPA system is slower but more sustained (de Kloet, et al ., 1996) supporting more general adaptive processes in response to threat.

Although the activation of both the HPA and SAM systems is directly controlled by the hypothalamus, it is also mediated by three other inter-related neurological systems: the amygdala, the hippocampus and cortico-limbic loops encompassing areas of the medial prefontal cortex (Gunnar & Quevedo, 2007). It is not entirely clear in what way these three systems mediate the stress response, however their input is most likely an extension of their more general functions. The hippocampus is involved in learning and recalling the contextual information surrounding emotional events, the amygdala is involved in assigning emotional significance to events and regulating behavioural and physiological responses, while the prefrontal cortex (PFC) controls higher order functions such a decision making and executive control (McEwan & Gianaros, 2011). Along with mediating the HPA and SAM systems, these three systems also project to further brain areas in order to co-ordinate the stress response. Notably the amygdala communicates with the ventral striatum, which co-ordinates motivated behaviour (Levita, et al., 2012), and with the anterior insula, which supports interoceptive awareness (Craig., 2009) amongst a range of other functions.

At a neurochemical level, alongside the noradrenline released by the LC, the production of both dopamine and serotonin is also increased during stress (Joels & Baram, 2009). Dopamine is transferred to the PFC via the mesolimbic and mesocortical pathways, both of which can be activated by the amygdala. The release of dopamine into the PFC serves to impair the PFC's ability to inhibit subcortical activity, further strengthening the control that subcortical areas have over behaviour during stress (Arnsten., 2009).

Auditory Hallucinations

A hallucination is an involuntary perception in the absence of concordant sensory information. Although hallucinations can occur in any sensory modality, in psychosis they are most frequent in the auditory modality, often taking the form of verbal utterances (‘hearing voices’). AH are one of the defining symptoms of schizophrenia, being present in around 70% of schizophrenic patients at one time or another (Slade & Bentall, 1988). They are also present to a much lesser extent in healthy (non-psychotic) individuals (Choong, et al., 2007). A notable characteristic of hallucinated voices is that they tend to be context-relevant; discussing ongoing events with reference to the self (Leudar, et al., 1997). This phenomenological observation has inspired the theory that AH may arise from a failure to correctly monitor inner speech (Bentall, 1990). More specifically it is proposed that AH derive from a mismatch between internally generated speech and a predictive signal (the corollary discharge) which is sent from frontal brain areas to warn the auditory cortex of the sensory consequences of inner speech. Where this predictive signal fails it is thought that the brain may process inner speech as if it were from an external source (Ford & Mathalon, 2005; Heinks-Maldonado, et al., 2007). Although such ‘inner speech’ theories have generated much academic interest, they are problematic because they fail to explain the breadth of the phenomenology of AH. For example many voice hearers also experience a significant level of AH that do not involve any verbal content (Nayani & David, 1996). It is difficult to see how such non-verbal AH could result from misattributions of inner speech. Likewise the content of some psychotic verbal hallucinations seem to fit better with the idea that they result from the misperception of intrusive memories, rather than inner speech (see Jones, 2010 for a review). It can therefore be concluded that any model of AH which focuses on one specific cognitive process (such as inner speech) will only be able to explain a proportion of auditory hallucinations, and that multiple versions of such models would therefore be required to provide a comprehensive account of AH (Jones, 2010).

Given the range of content that can be hallucinated, a more fruitful path to understanding AH lies in identifying more general perceptual mechanisms that might explain the occurrence of AH, regardless of their specific content. Taking this approach some theories concerning AH focus their explanations on the deficits in auditory perceptual processing apparent in those who suffer from AH (e.g. Behrendt, 2006; Nazimek, et al., 2012; Waters, Allen, et al., 2012). Although they differ in detail, these auditory-perceptual theories agree that AH are in essence caused by dysfunctions in the mechanism dedicated to processing sound. Hallucinatory experiences are therefore proposed to be generated from erroneous activations within the early sensory areas of the brain (Shergill, et al., 2000; Woodruff, et al., 1997).

The assertion that deficits in auditory processing contribute to the generation of AH arises from varied experimental evidence demonstrating abnormal auditory processing in hallucinating populations. For example Gavrilescu et al (2010) found that individuals with schizophrenia who suffer from AH show reduced functional connectivity between the primary and secondary auditory cortices across both hemispheres, when compared to both clinical and non-clinical controls. Individuals with psychosis also tend to have significant problems with low level auditory processing, as evidenced by their reduced performance on a variety of basic auditory perceptual tasks when compared to controls (C. S. R. Li, et al., 2002; McKay, et al., 2000; Vercammen, et al., 2008). However performance on such tasks does not reliably distinguish between psychotic individuals with and without AH, expect for tasks involving affective auditory information (Rossell & Boundy, 2005). Another strand of evidence supporting the view that AH arise from deficits in the perceptual process comes from findings that AH (when they occur) appear to utilise the same neural resources required for auditory perception. For example the primary auditory cortex has been found to activate during periods when patients are hallucinating (e.g. Dierks, et al., 1999) although this finding has not always been replicated (see Allen et al (2008) for a review). Likewise the neural response to actual verbal input is found to be reduced during periods when participants are experiencing hallucinations (Ford, et al., 2009; Woodruff, et al., 1997) again suggesting that the two processes share neuronal resources. Finally studies of dichotic listening have shown that psychotic individuals exhibit a reduced right ear advantage (REA) for dichotic speech stimuli, with this impaired ability to report right ear stimuli being related to levels of hallucinatory experience (Hugdahl, et al., 2012). As the REA is a measure of the lateralisation of speech processing, the finding of reduced REA in those who hallucinate can be interpreted as evidence that elevated endogenous activity in (left-hemisphere) speech processing areas disturbs the processing of actual speech sounds in such individuals. An alternative explanation however might be that this reduced REA simply reflects a less left-lateralized organisation of speech processing in those who hallucinate.

Existing evidence therefore seem to point towards aberrant activity within early auditory perceptual areas being the initial generator of AH, although the exact processes which cause this aberrant activity are not well defined. The most likely explanation for the varied content of AH is that they result from a combination of internal signals, arising from different sources, which are misattributed as being externally generated due to the presence of this aberrant auditory cortical activity. Thus the subgroup of AH that take the form of context-relevant conversational speech could indeed be the result of misattributed inner speech, but only in the context of a more general dysfunction within the auditory-perceptual mechanism. Likewise some AH might quite plausibly arise from intrusive thoughts (e.g. traumatic memories) which are misattributed as coming from an external source (Morrison & Baker, 2000). Additionally the perceptual process itself may contribute signals which can provide the content for AH. For example it has been proposed that sensory analysis occurs in the context of predictive inference (Friston, 2003). This process of predictive inference relies on the brain holding, and constantly updating, representations of the external world from which it is able to generate predictions relating to future sensory input. These signals of predicted future input are generated in the prefrontal cortex before being sent to lower levels of perceptual hierarchy where they are compared to afferent sensory information (Brunia, 1999; Friston, 2003). Differences between actual and expected input generate a ‘prediction error’ signal, which is propagated back up the hierarchy, thus enabling models of the external world to be updated where necessary. There is much research to suggest that this process of predictive inference may be disrupted in psychotic individuals. For example those suffering from psychosis appear to elicit a reduced prediction error signal from early auditory areas (see Umbricht & Krljes, 2005 for a review) as indexed via the Mismatch Negativity (MMN) event-related potential (Winkler, 2007). This suggests that discrepancies from prediction are not fully processed in psychotic individuals, and therefore that sensory information does not adequately modulate the influence of (erroneous) predictive signals in such individuals. This deficit may allow signals of expected sensory input to recruit endogenous activity existing in the auditory cortex (Hunter, et al., 2006) causing them to be misperceived as actual sensations even in the absence of any genuine, concordant external stimulation (Behrendt, 2006; Nazimek, et al., 2012).

Psychological stress and auditory hallucinations

Even in the absence of a definitive model of auditory hallucinations, it has long been acknowledged that psychological stress is intimately linked to the development of positive symptoms such as AH. Recent theories of psychosis converge on the idea that the condition develops when environmental stressors, which occur during the period when the brain is undergoing maturation, trigger a pre-existing biological vulnerability to psychosis that is present in a minority of people (Garety, et al., 2007). These environmental stressors act on the vulnerable individual in such a way as to induce anomalous perceptual experiences. The resultant anomalous percepts then become expressed as positive symptoms (and maintained as such) due to the presence of cognitive biases within the affected individual (Garety, et al., 2001).

The specific environmental factors that have been linked with the risk of psychosis include childhood trauma, migration, social isolation, urban living and drug abuse (van Os, et al., 2010). These relate to the placement of psychological stress onto the individual, either moderate amounts over a long period (e.g. social isolation) or large amounts over relatively short periods (e.g. childhood abuse). Although not necessarily stressful in itself, drug abuse can be considered an environmental stressor as it can have a chemical effect on the neural mechanism responsible for responding to stressful stimuli (e.g. Adinoff, et al., 2005). These environmental stressors not only trigger anomalous percepts, they also contribute to the presence of the cognitive biases which affect how the anomalous experiences are interpreted. For example unusually frequent exposure to early life stress is likely to lead to an individual developing an anxious personality (Heim & Nemeroff 2001). Highly anxious individuals are more likely to interpret ambiguous information as threatening (Mathews, et al., 1997) and are therefore more likely to assign a sinister or upsetting interpretation to the appearance of an anomalous percept (Garety, et al., 2001). This causes the anomalous percepts to become problematic, explaining why highly anxiety is associated with increased risk of developing psychosis among those individuals who are biologically vulnerable to the condition (Jobe & Harrow, 2010).

Of specific relevance to the current thesis is the observation that along with facilitating the initial development of positive symptoms, psychological stress also appears to have a ‘state effect’ on such symptoms. Periods of psychological stress appear to trigger individual occurrences of positive symptoms in those vulnerable to them. Evidence from experience sampling (Delespaul, et al., 2002; Verdoux, et al., 2003) and retrospective (Johns, et al., 2002; Nayani & David, 1996; Slade, 1972) self-report techniques support the assertion that AH may be triggered by stressful situations. Likewise physiological studies have associated heightened stress responses with periods where schizophrenic patients are suffering from positive symptoms (Dawson, et al., 1994; Dawson, et al., 2010). These findings have recently been supported by a longitudinal study which found that the level of stressful life events experienced by psychotic individuals predicted the change in the level of positive symptoms they suffered (Docherty, et al., 2009). Indeed the relationship between stress and AH is such that cognitive behavioural treatments used ostensibly to treat anxiety disorders have been found to also improve positive symptoms of schizophrenia (Dudley, et al., 2005). The impact of stress on AH even appears to extend to non-psychiatric populations who hallucinate (Johns, et al., 2002).

The apparent causal, or at least facilitating, role of psychological stress in the generation of AH potentially provides an explanation as to their episodic nature (Garety, et al., 2007). Furthermore as the experience of AH is likely in itself to be stressful for psychotic individuals (Mawson, et al., 2010) this may cause a 'vicious circle' effect where the stress caused by the initial appearance of hallucinatory content serves to prolong the experience of hallucination (Nuechterlein & Dawson, 1984). This might explain the finding that sustained periods of hallucination are more common in psychotic than non-psychotic hallucinators (Daalman, et al., 2010). Psychological stress is likely therefore not only to instigate the appearance of AH, but also to promote the maintenance of the hallucinatory experience.

The phenomenological link between psychological stress and the appearance of positive psychotic symptoms is mirrored by neurobiological evidence showing that psychological stress affects neural networks that are known to be dysfunctional in psychosis. For example schizophrenic individuals demonstrate reduced grey matter volume (compared to unaffected relatives) in the dorsolateral PFC (Cannon, et al., 2002). As chronic stress causes a loss of dendritic spines within the dorsolateral PFC, exposure to stress may well exacerbate pre-existing neurological weaknesses in those vulnerable to schizophrenia (Arnsten., 2011). Likewise reduced hippocampal volume (Velakoulis, et al., 2006) and activation (Goghari, et al., 2010) is associated with psychosis, and the hippocampus is also vulnerable to the effects of chronic stress (McEwan & Gianaros, 2011). These lines of evidence suggest possible neurological bases for the cognitive-behavioural impact that stress has on positive psychotic symptoms. Perhaps the strongest neurological link between stress and psychosis vulnerability appears when the behaviour of the neurotransmitter dopamine is considered. Many neurobiological theories of psychosis suggest that dopamine dysregulation plays a key role in the condition, triggering positively symptoms (e.g. Howes & Kapur, 2009). More recently it has been posited that this dopaminergic dysregulation may be triggered by reduced hippocampal responsiveness to glutamate in those at risk of psychosis, a deficiency which produces a disinhibitory effect on striatal dopamine activity (Stone et al., 2010). Acute stress increases the release of dopamine in the striatum (Abercrombie et al., 1989), while chronic stress negatively affects the functioning of the hippocampus through synaptic loss and dendritic shortening (McEwan & Gianaros, 2011). It therefore seems plausible that the direct and indirect effects of stress on the dopaminergic system may be responsible for the impact that stress has on psychotic symptomatology.

Despite the role that psychological stress plays in the generation and maintenance of hallucinations, a specific cognitive model of how stress might serve to encourage AH has not been proposed (Freeman & Garety, 2003, p. 940). If it is accepted (as discussed above) that AH are primarily caused by dysfunctions within the auditory-perceptual mechanism it remains to be identified in what way stress impacts on this mechanism in order to make the perception of hallucinatory sounds more likely. It has been proposed that stress might lower the 'threshold for perceptualization' (Beck & Rector, 2003, p. 592) or increase the level of aberrant neuronal activation (Waters, Allen, et al., 2012, p. 689). Such proposals are vague in terms of the exact cognitive mechanism involved, and also lack concerted empirical support. The current thesis therefore seeks to identify the mechanism by which psychological stress may encourage the generation of auditory hallucinations. This will be achieved by examining how stress affects auditory perception, given the role that dysfunctions in basic auditory perceptual processing appear to play in the generation of AH. This represents an important topic for research as it could serve to improve our understanding of the processes behind auditory hallucinations. Highlighting how stress affects auditory perception will not only inform as to how stress might encourage AH, it will also suggest which cognitive-perceptual functions are involved in the generation of AH. Furthermore as AH severity is related to poor outcome in psychotic populations (Berman, et al., 2010; Cheung, et al., 1997; Fialko, et al., 2006; Simms, et al., 2007) an understanding of the role stress plays in the expression of AH may facilitate the development of treatments for reducing the impact of the symptom on the wellbeing of sufferers.

Psychological stress and auditory perception

As AH are assumed to evolve from dysfunctions within the early auditory processing areas, any examination of how stress generates AH should focus on identifying the effect of stress on basic auditory perception. Before discussing what is currently known about the effect of psychological stress on perception, it is worth considering what types of auditory stimuli are relevant to the discussion of AH. More specifically a distinction has to be made between the perception of emotionally valenced and emotionally neutral auditory stimuli. Although AH in psychotic populations often involve verbal material that is unpleasant (Daalman, et al., 2010; Honig, et al., 1998) a significant proportion of psychotic hallucinations (Leudar, et al., 1997; Nayani & David, 1996) and the majority of non-clinical AH (Daalman, et al., 2010) are neutral in content. It is plausible therefore to assume that whatever mechanism underlies the stress effect on AH must not require the (misperceived) signals themselves to have any emotional content. Stimuli containing emotional content are subject to preferential processing in comparison to neutral stimuli (e.g. Hodsoll, et al., 2011; Huang, et al., 2008; Schupp, et al., 2003; Tamietto & de Gelder, 2010) a process which may be accentuated during periods of stress (Oei, et al., 2012). The perception of emotionally valenced stimuli therefore presumably evokes additional processes not required when neutral stimuli are perceived. As these processes are unlikely to be relevant during instances where stress generates AH (because AH often contain emotionally neutral content) it was decided to restrict this thesis to an examination of the impact of stress on the perception of emotionally neutral sounds.

Attentional Control Theory

How does stress affect perceptual processing? One possible answer is provided by Attentional control theory (ACT: Eysenck & Derakshan, 2011; Eysenck, et al., 2007). It has been proposed that there are two opposing attentional systems (Corbetta & Shulman, 2002). The goal-directed system is involved in allocating and maintaining attention toward a particular focus in light of current goals, knowledge or expectation. In contrast the stimulus-driven system is involved in identifying stimuli in the environment which have salient sensory features, and re-orientating goal-directed attention towards them (Corbetta & Shulman, 2002). For example reading a book requires goal-directed attention to be directed towards the words on the page. A fire-alarm will distract from reading a book because the sensory characteristics of the alarm are capable of stimulating stimulus-driven attention. This occurs despite goal-directed attention being focussed away from the location (and modality) of the alarm. ACT suggests that anxiety affects cognitive performance by reducing (top-down) cognitive control over attention. This has the effect of altering the balance between the two attentional systems such that the 'bottom-up', stimulus-driven system is enhanced at the expense of the 'top-down', goal-directed system (Eysenck, et al., 2007)[1]. More specifically anxiety is proposed to reduce inhibitory control over task-irrelevant information, thus making distracting stimuli (which activate the stimulus-driven system) more likely to interfere with task performance (ibid p344). This reduction in inhibitory control is proposed to be most noticeable for threat-related distracters, explaining the well replicated effect that anxious individuals are more susceptible to distraction from threatening stimuli (Bar-Haim, et al., 2007). However increased distraction from emotionally neutral task-irrelevant stimuli in more anxious individuals is also predicted by ACT (Eysenck, et al., 2007, p. 345).

Attentional control theory is primarily framed as relating to individual differences in (trait) anxiety. In contrast the effect of stress on hallucination proneness that the current project is concerned with is a state effect (i.e. it is changes in the level of stress *within* the individual that alters their vulnerability to hallucinations). Nevertheless ACT posits that the effect on attentional control will be the same regardless of whether stress in manipulated between or within individuals (Eysenck, et al., 2007, p. 336). Indeed, although the majority of evidence cited in favour of ACT relies on between-participant manipulations of trait anxiety (i.e. comparisons between groups of highly anxious and less anxious participants) studies involving manipulations of the state of stress within participants are also cited as evidence in support of the theory (Eysenck, et al., 2007).

Why might ACT be useful in helping to understand the role of stress in encouraging AH? Firstly psychotic individuals who hallucinate have been found to perform worse in tasks requiring intentional inhibition when compared to those who do not hallucinate (Waters, et al., 2003). For example psychotic patients with hallucinations are less able to suppress irrelevant material existing in working memory than patients without hallucinations (Soriano, et al., 2009). The stress-induced disruption in the ability to inhibit distracting stimuli predicted by ACT may therefore play a substantive role in the generation of AH, as it would act to exploit a pre-existing weakness in hallucination-prone individuals. Secondly when the predictions of ACT are applied to auditory perception they suggest plausible mechanisms that could explain the effect of stress on AH. In terms of auditory perception ACT predicts that stress should

[1] The stimulus-driven system can be considered to work in a 'bottom-up' fashion because its activation is controlled on stimulus features. The goal-directed system works in a 'top-down' fashion because its activation is controlled by internal brain states that precede the perception.

a. disrupt goal-directed processing of emotionally neutral auditory stimuli

b. increase the processing of emotionally neutral auditory signals that attract stimulus-driven attention

If these predictions are considered in the context of the problems in source monitoring that psychotic individuals experience (Waters, Woodward, et al., 2012)[2] and the deficits in auditory processing that hallucination-prone individuals exhibit (Gavrilescu, et al., 2010; McKay, et al., 2000; Vercammen, et al., 2008) then two, non-mutually exclusive theories of how stress might generate AH can be proposed:

1. The disruption in goal-directed processing predicted to occur under stress might reduce the ability of hallucinating individuals to accurately distinguish between external and internal auditory signals, causing the two to become confused.

2. The enhancement of stimulus-driven attention under stress might over-generalise in hallucinating individuals such that the increased processing of signals outside the focus of goal-directed attention might apply to internal auditory signals as well as external sounds. Such an effect would serve to enhance the perceptual impact of internal signals during stress. This enhancement would potentially make internal auditory signals more likely to be perceived as emanating from an external source, since their perceptual impact would more closely resemble that which would normally be generated by external sounds. For example a spontaneous auditory memory signal may be more likely to attract the stimulus-driven attention system when that system is enhanced under stress. This may make it more likely that the memory signal is mistaken for a genuine sound, especially in those individuals who experience source monitoring deficits.

Given the promise that ACT has for explaining the effect of stress on hallucination-proneness, it is worth reviewing what is currently known about the effect of stress on the perception of emotionally neutral sounds. This knowledge can reveal to what extent ACT accurately predicts the performance of the auditory perceptual system (i.e. it can be used to test the validity of predictions a. and b. above).

Does stress disrupt the inhibition of distracting, emotionally neutral auditory signals?

[2] Source monitoring is the ability to accurately identify the source of a signal.

Although there are a number of studies that have tested whether anxiety or stress disrupts the inhibition of emotional neutral distracters (Derakshan & Eysenck, 2009, pp. 171-173; Eysenck, et al., 2007, pp. 344-346) these studies have almost always utilised visual stimuli as distracters. Their findings are nevertheless largely in favour of the predictions of ACT. For example both Moser et al (2012) and Pacheco-Unguetti et al (2011) found that highly anxious individuals are more susceptible to distraction by emotionally neutral visual stimuli than less anxious individuals. In contrast some studies have found that highly anxious individuals are only more susceptible to distracting visual information when that information is threat related (Eysenck & Byrne, 1992).

As regards auditory perception, the functioning of the stimulus driven attention system is often assessed using passive auditory oddball paradigms. In these paradigms sounds are presented in an oddball pattern such that a otherwise constant stream of ‘standard’ sounds are interrupted by occasional ‘deviant’ sounds that differ from the standard on some physical characteristic (i.e. pitch). In passive oddball tasks the change in stimulation represented by the deviant is irrelevant to the participant’s task. The deviant stimuli therefore represents (when compared to the standard stimuli) a salient environmental stimulus which is capable of distracting attention away from ongoing goal-directed processing. The consequence of this design is that differences in response characteristics between trials involving the deviant stimuli and those involving the standard stimuli can be taken as an index of stimulus-driven attention. The appearance of the deviant (in comparison to the standard) induces both an increased neural response (the MMN signal[3]) and decreased behavioural performance, due to the distraction that it causes to ongoing task-dedicated processing (Escera, et al., 1998). Studies using such passive oddball paradigms have found, in agreement with the predictions of ACT, that the auditory MMN signal is enhanced during periods of psychological stress (Cornwell, et al., 2007; Dominguez-Borras, et al., 2008a; Dominguez-Borras, et al., 2009; Elling, et al., 2011). It has also been found that the MMN is larger in highly anxious compared to less anxious individuals (Hogan, et al., 2007). In contrast Simoens et al (2007) found that a stress manipulation had little effect on MMN, and even decreased its amplitude for one type of deviant stimuli.

Although the aforementioned neurophysiological evidence generally appears to support the prediction that stimulus-driven auditory attention is enhanced during stress, this interpretation rests on the assumption that neuroimaging markers of neural activation reflect greater levels of cognitive-

[3] As already discussed, the MMN signal can also taken an index of the prediction error signal, as it represents the additional processing performed on the (unexpected) deviant stimulus, when compared to that dedicated to the expected standard stimulus.

perceptual processing, and therefore greater activation of the stimulus driven attentional system. In contrast behavioural effects of stress on stimulus-driven attention (e.g. increased reaction time in the presence of distraction under stress) represent a more direct demonstration of the predictions of ACT. Unfortunately there is a scarcity of behavioural evidence showing that emotionally neutral auditory distracters are processed more under stress. Recently however, one set of studies have demonstrated a behavioural effect of stress on the distraction caused by emotionally neutral auditory stimuli. Dominguez-Borras et al (2008b; 2009) used a crossmodal oddball paradigm where a train of auditory stimuli arranged in an oddball pattern acted as distracters to an ongoing visual task. They found that the behavioural distraction (measured via reaction time to the visual task) caused by the appearance of deviant sounds was greater during negative emotional conditions than during an emotionally neutral control condition.

A further set of studies that appear to support the view that stress makes individuals more sensitive to auditory distraction are those showing that states of fear and anxiety increase a participant's response to individual unexpected stimuli (known as 'startle stimuli'). This effect has been demonstrated both behaviourally (Grillon, 2008) and in terms of the amplitude of event related potentials (ERPs) that are generated within the auditory cortices (Scaife, et al., 2006). Indeed this neurophysiological effect is still evident even when the unexpected auditory stimuli are barely above threshold and unable in themselves to evoke an electromyographic startle response (Al-Abduljawad, et al., 2008). However unlike oddball paradigms, these 'startle' studies do not include a condition showing the effect of the stressor on the response to an expected (non-startle) stimulus. It cannot therefore be ascertained whether or not the enhanced response under stress found in such paradigms is restricted to stimuli that are salient, or whether it might generalise to all sensory stimuli, including those that are not salient enough to attract stimulus-driven attention. This is an important caveat because there is evidence that stress may enhance the processing of auditory stimulus that would not normally be considered the targets of stimulus-driven attention. For example Bass et al (2006) found that the brainstem ERPs generated by regular, predictable auditory stimuli were greater during periods when the participant was threatened with potential electric shocks. This suggests that an increased response to auditory stimuli under stress might not be restricted to those stimuli that attract stimulus-driven attention.

Does stress disrupt goal-directed auditory processing?

The second prediction relating to auditory perception that can be extracted from ACT is that goal-directed auditory processing should be disrupted during stressful conditions. Although a substantial amount of behavioural evidence exists to support the theory that stress disrupts goal-directed attention, these studies have tended to utilise goal-directed tasks that test either advanced cognitive functions such as reading comprehension (e.g. Calvo & Eysenck, 1996) or perceptual-motor functions (e.g. Ansari & Derakshan, 2011). For the purposes of assessing the impact of stress on perception, such studies are potentially problematic because the cognitive functions being tested are not purely perceptual. It is not therefore possible to assess whether any decreased performance during stress found in such studies is due to an effect (of stress) on perceptual performance, or on a different non-perceptual function (e.g. working memory) that is also required for the task. Likewise although disruption to task-processing is inherent in the studies detailed in the previous section (showing increased distractibility to auditory stimuli under stress), these studies have also rarely utilised purely perceptual goal-directed tasks, and where they have used perceptual tasks they have tended to involve visual perception (e.g. Pacheco-Unguetti, et al., 2010; Pacheco-Unguetti, et al., 2011). In addition ACT predicts that reduced goal-directed task performance under stress should occur even in the absence of distracting stimuli (Eysenck, et al., 2007, p. 338) an assertion that is not tested by the studies quoted in the previous section.

There are very few studies specifically looking at the impact of stress on goal-directed auditory perceptual processing. Alexanderov et al (2007) found that threat of monetary loss produced an increased amplitude of an auditory N100 ERP generated in response to the standard tones in an active auditory oddball paradigm (i.e. one where the participant is required to attend to the oddball stimuli). Tartar et al (2012) also found an increase in the amplitude of ERP responses to attended tones when they were presented after viewing negative images, compared to when they followed neutral images. These results suggest that stress does not reduce the processing of auditory information, at least when no distracting stimuli are present. In fact they suggest the opposite, that goal-directed processing of auditory information is increased under stress. Behaviourally, the finding that sounds are rated as louder during stressful conditions (Asutay & Vastfjaill, 2012; Siegel & Stefanucci, 2011) may also be interpreted as suggesting that goal-directed attention is enhanced rather than disrupted during stress. Alternatively, as mentioned in the previous section, stress has been found to enhance the neural processing of stimuli that would not normally be the focus of either goal-directed or stimulus-driven attention (Baas, et al., 2006). Together these results make it possible to argue that stress may evoke a hyper-responsiveness to all auditory stimuli, regardless of the focus of attention. This conclusion is supported by the finding that stress increases the intensity threshold at which the auditory stapedial reflex occurs (Fehmwolfsdorf, et al., 1993) with the result that louder sounds are required to evoke this protective middle-ear mechanism during stress. This effect presumably results in stress inducing an increased level of sensory input towards the auditory system[4] and may therefore represent a mechanism by which stress could cause hyper-responsivity to all auditory stimuli. It may also explain why chronic stress is detrimental to human hearing (Hasson, et al., 2011) as extended periods of increased sensory input, induced by chronic stress, may cause long-term damage to the inner ear mechanism.

The finding that stress appears to enhance the processing of task-relevant auditory stimuli conflicts with the predictions of ACT. In contrast Elling et al (2011) found that ERPs relating to stimulus-driven and goal-directed attention were altered during a stress manipulation in a manner consistent with ACT. Elling et al asked participants to perform a selective attention task which required that they attend to a stream of auditory oddball stimuli presented in one ear while ignoring another stream presented in the other ear. They found that the application of a stressor caused a reduction in the amplitude of event-related potentials (ERPs) associated with goal-directed attention (i.e. in response to the attended stream) while concurrently enhancing those associated with stimulus-driven attention (i.e. the ERPs generated in response to the unattended stream). Indeed a (relative) prioritisation of stimulus-driven processing under stress has also been demonstrated within the same stimulus. For example recent evidence from the visual system suggests that stress potentiates ERPs associated with early sensory detection, while also inhibiting later ERPs associated with task-related processing of the same stimulus (Shackman, et al., 2011). These findings suggest that goal-directed perceptual processing may indeed be disrupted during stress, but perhaps only when distracting stimuli are present. Unfortunately during these studies measures of task performance were either not taken (Elling, et al., 2011) or did not demonstrate increased distraction during stress conditions (Shackman, et al., 2011). It is not therefore clear to what extent this ERP data genuinely reflect modulations of attention under stress, as there is no behavioural evidence to confirm whether the participant's goal-directed attention was disrupted.

Summary of evidence concerning the impact of stress on auditory perception

ACT predicts that stress should disrupt goal-directed processing, while enhancing the response to stimuli that attract stimulus-driven attention. There is much evidence to support this theory, but very little of it relates to auditory perception. There are a number of studies which appear to show that stress enhances the response to emotionally neutral auditory signals that are outside the focus of stimulus-driven attention, although most of this evidence involves neurological rather than

[4] The stapedial reflex acts to reduce the intensity of the auditory signal that is passed to the cochlea

behavioural markers of attention. The assertion that stress should disrupt goal-directed auditory-perceptual processing has not been tested extensively. There are no studies we are aware of which test auditory perceptual performance under stress in the absence of distracters, and only one showing reduced goal-directed auditory processing in the presence of distracting stimuli (Elling, et al., 2011). In contrast, there is neurological evidence which appears to suggest that stress may increase the processing of task-relevant auditory stimuli, at least when no competing stimuli are present. In general it seems reasonable to conclude that the current research literature does not yet provide sufficient evidence that the predictions of ACT extend to the perception of emotionally neutral auditory stimuli.

Project aims and objectives

Phenomenological evidence from clinical populations suggests that periods of psychological stress are associated with an increased likelihood of experiencing auditory hallucinations in those already vulnerable to them. A potential explanation for this effect is provided by attentional control theory (ACT: Eysenck, et al., 2007). As ACT proposes that stress serves to enhance stimulus-driven attention at the expense of goal-directed attention, stress may encourage hallucinations by either:

1. Disrupting goal-directed auditory processing to the extent that the ability to distinguish between external and internal auditory signals is reduced in hallucinating individuals.

2. Enhancing stimulus-driven attention to such an extent that the auditory system in hallucinating individuals begins to pick up internal signals as if they were external.

As AH often contain non-emotional content **Error! Reference source not found.** it was assumed that they are best studied in relation to the perception of emotionally neutral sounds. This assumption is made because the perception of emotionally relevant sounds is likely to engage additional auditory-perceptual processes (e.g. threat detection) which are not instigated when neutral sounds are heard, and are therefore not necessary for the generation of AH. Although ACT may provide an explanation for the effect of stress on auditory hallucinations, it is not clear from the current research literature whether ACT is applicable to the processing of emotionally neutral auditory stimuli. In general there is a lack of behavioural evidence concerning the effect of stress on auditory perception, and there has been no attempt to study this topic in relation to its potential relevance to auditory hallucinations. The aim of this thesis was therefore to assess the effect of psychological stress on the perception of emotionally neutral auditory stimuli in order to gain insight into how stress might act to encourage the generation of auditory hallucinations. The specific objectives of the research were:

1) To improve the understanding of the impact of stress on human auditory perception of emotionally neutral stimuli

2) To test whether the predictions of ACT extend to the processing of emotionally neutral auditory stimuli.

3) To identify a cognitive mechanism that might explain the effect of stress on hallucination-proneness.

These objectives were addressed by examining experimentally the effect of psychological stress on the perception of emotionally neutral auditory stimuli, with an emphasis on testing the predictions of ACT. These experiments were conducted on healthy volunteers, rather than those with psychosis. In addition to the ethical and practical issues that surround the use of psychotic participants in behavioural research, the use of healthy participants was considered advantageous because it allows the project to inform the understanding of the impact of stress on healthy auditory perception. This in turn allows the results of the research to contribute to models of general cognitive processing, in line with the objectives detailed above. As AH can occur in non-psychotic populations, including those without any medical diagnosis (Choong, et al., 2007; Sommer, et al., 2010) psychotic AH can be considered, at least to some extent, to be the severe end of a continuum of human experience. Therefore although healthy individuals do not exhibit the same neural and behavioural abnormalities as those with psychosis, the study of healthy auditory perception should still be relevant to the understanding of AH. Furthermore, as there is evidence that stress and anxiety also have a facilitatory influence on non-psychotic auditory hallucinations (Johns, et al., 2002; Paulik, et al., 2006) it is likely that the mechanism by which stress encourages hallucination-proneness is similar between psychotic and non-psychotic populations.

Self-report measures relating to positive schizotypy were administered to all participants during the project. These psychometric measures allowed an assessment as to whether any behavioural effects found might be accentuated in those healthy individuals who exhibit personality traits associated with positive symptoms of psychosis (e.g. hallucinations and delusions). This in turn can inform the discussion as to the relevance of any effect found in healthy individuals to the generation of AH in psychotic populations.

Method of manipulating psychological stress

Although the exact method of instigating a state of stress in participants was varied slightly between the different studies in the thesis, the basic methodology remained constant. Stress was manipulated through the sporadic presentation of aversive (vs. neutral) images between experimental trials[5]. This manipulation of image valence was expected to instigate a variation in psychological stress within participants during the auditory task, with this stress relating to the anticipation of future aversive images and the reaction to the exposure to prior aversive images. This assumption was based on evidence that the anticipation of aversive images evokes activation in similar brain areas to those activated during anticipation of physical pain (Simmons, et al., 2004) and that this activation is greater in highly anxious individuals (Levita, et al., 2012; Simmons, et al., 2006) and can be attenuated by anxiolytic drugs (Aupperle, et al., 2011; Simmons, et al., 2009). Also supporting the assumption that this manipulation will induce stress in participants is the demonstration by previous studies that behavioural effects can be induced by exposure to aversive images that are separated in time from the task under investigation (Pacheco-Unguetti, et al., 2010; Pereira, et al., 2006). The exact details of the stress manipulation, as applied in each study, are detailed in the relevant method sections.

As mentioned previously, the majority of evidence quoted in favour of ACT tends to involve trait manipulations of anxiety rather than manipulations of the state of stress within participants (Eysenck, et al., 2007). Given this, self-report measures of anxiety were administered in each study in addition to the systematic manipulation of stress. This allowed the predictions of ACT to also be tested by identifying whether individual differences in anxiety predict auditory perceptual performance. The inclusion of self-report measures of anxiety is also of relevance as regards understanding the effect of stress on AH, since information processing biases associated with trait anxiety are considered an important factor in the development and maintenance of positive psychotic symptoms (Garety, et al., 2001). Highly anxious individuals are at greater risk of developing psychosis (Jobe & Harrow, 2010; Turnbull & Bebbington, 2001) and are more likely to suffer from AH among non-clinical populations (Allen, et al., 2005; Paulik, et al., 2006). As anxiety appears to contribute to the development of auditory hallucinations it was of interest to see how individual differences in anxiety affect auditory perceptual performance, particularly when viewed in combination with changes in (situational) psychological stress. The inclusion of a self-report measure

[5] The possibility of using aversive auditory stimuli to evoke psychological stress was rejected because it was thought that it may lead to participants (either consciously or unconsciously) gating their auditory sensory mechanism in the stress condition in order to avoid the full impact of the unpleasant sounds when they occurred. This would serve to reduce auditory processing in the stress condition independent of any emotional effect engendered by the stress manipulation (Armony & Dolan, 2001).

of anxiety therefore allows an assessment of how individual differences might combine with environmental factors to cause auditory hallucinations.

Thesis Outline

Chapter 2 describes a signal detection study designed to test the predictions of ACT while also providing a mathematical description of how stress alters the ability to detect auditory signals.

Chapter 3 describes a study involving the application of two passive oddball paradigms to test more directly the consequence of stress on the performance of the stimulus-driven attention system.

Chapter 4 describes two further passive oddball paradigms designed to assess the parameters of the effects found during the study described in Chapter 3.

Chapter 5 contains a summary of the experimental findings detailed in the previous 3 chapters, along with a discussion as to their implications regarding the understanding of auditory perception and auditory hallucinations.

Chapter 2: Signal Detection Study

Introduction

Attentional Control Theory (ACT: Eysenck, et al., 2007) suggests that stress disrupts goal-directed attention. In Chapter 1 it was hypothesised that this disruption of goal-directed attention might lead to a decreased ability to distinguish internal and external signals, thus explaining how psychological stress might encourage auditory hallucinations (AH) in those vulnerable to them. A direct way of testing this theory is to examine the effect of psychological stress on the ability to detect auditory signals. This can be achieved experimentally by implementing an auditory signal detection task, where participants are required to make forced-choice judgements relating to the presence of a particular signal under ambiguous sensory conditions. As a signal detection task requires goal-directed attention, the addition of a stress manipulation to such a task allows the aforementioned hypothesis regarding the impact of stress on goal-directed auditory attention to be tested.

In signal detection tasks participants are exposed both to trials where the signal is present (signal trials) and where the signal is absent (noise trials). A participant's responses during such a task can therefore be classified into one of four categories, relating to correct and incorrect responses to both the signal and noise trials (Figure 1.). Signal detection paradigms can be considered directly relevant to the study of hallucinations, as the occurrence of a false positive during such a task can be considered analogous to a hallucination in that it reflects the perception of a signal in the absence of concordant external sensory information. The validity of this assumption is supported by studies showing that the level of false positives experienced during both auditory and visual signal detection tasks correlates with self-report measures of the tendency to experience hallucinations (Feelgood & Rantzen, 1994; Jakes & Hemsley, 1986; Merckelbach & van de Ven, 2001). The signal detection task most commonly used to test theories surrounding AH involves presenting an auditory masking stimulus (normally white noise) with the to-be-detected signal on signal trials, and on its own during noise trials (e.g. Barkus, et al., 2007; Vercammen & Aleman, 2010; Vercammen, et al., 2008).

		Response	
		Yes	No
Signal	Present	True Positive (Hit)	False Negative (Miss)
	Absent	False Positive (False Alarm)	True Negative (Correct Rejection)

Figure 1. Classification of possible responses during a signal detection task. Hit rate is equal to the proportion of signal trials in which a signal was detected (True Positive/[True Positive + False negative]). False positive rate equates to the proportion of noise trials in which a signal was reported (False Positives / [False Positives + True Negatives])

Signal detection theory

While a measure of the number of false positive errors made might be considered the primary measure of interest as regards hallucination proneness, it is important to note that as false positives can only occur during noise trials (i.e. when the signal is not present) false positive rate does not provide a complete representation of perceptual performance. Instead signal detection theory (Green & Swets 1966) can be applied to the analysis of data from signal detection tasks in order to provide a more comprehensive picture of perceptual performance. Signal detection theory (SDT) uses both the hit rate (H: relating to the proportion of signal trials where a signal was detected) and false positive rate (F: relating to the proportion of noise trials where a signal was erroneously detected) to calculate two parameters that describe signal detection performance. These parameters are sensitivity and response bias. Sensitivity relates to the ability of a system (in this case a participant's auditory-perceptual mechanism) to distinguish signal from noise[6] while response bias represents the bias a system has for responding a certain way, independent of its sensitivity (Stanislaw & Todorov 1999). In the context of auditory perception, response bias reveals whether an individual has a bias towards reporting a signal as being present or absent over and above their particular ability to distinguish signal from noise. A more detailed description of the concepts of sensitivity and response bias is contained in Appendix 1.

Auditory Hallucinations in a signal detection framework

As previously discussed, hallucination-proneness is associated with an increase in false positive responding during signal detection tasks, reflecting the intuitive association between a false positive response and hallucinations. In terms of understanding the cognitive mechanism behind AH it is of interest to identify whether the increased level of false positives generated by hallucination-prone

[6] This definition of sensitivity is different from that commonly used in medical diagnostics, where 'sensitivity' equates to the hit rate as defined in SDT.

individuals is due to a decrease in auditory-perceptual sensitivity (more errors in general) or a more liberal response bias (i.e. a bias towards reporting a signal). Bentall & Slade (1985) addressed this question by comparing the auditory signal detection performance of students who scored high and low on a self-report measure of hallucination-proneness. They found that while there was no difference in sensitivity between the two groups, highly hallucination-prone individuals exhibited a bias towards reporting a signal being present when compared to low hallucination-prone individuals. They also found a similar difference between hallucinating and non-hallucinating schizophrenic patients (Bentall & Slade, 1985). Later studies on healthy individuals (Barkus, et al., 2007; Rankin & O'Carroll, 1995) have also found support for the view that (self-reported) hallucination proneness relates to a response bias toward perceiving a signal within ambiguous sensory stimuli, rather than a deficit in sensitivity. In contrast, a couple of Taiwanese studies suggest that the difference in signal detection performance between schizophrenic/schizotypal individuals and non-schizotypal control individuals is due to decreased sensitivity in the experimental group, rather than differences in response bias (C. S. R. Li, et al., 2002; C. S. R. Li, et al., 2003). More recently, Vercammen et al (2008) compared hallucinating and non-hallucinating schizophrenic patients with healthy controls on an auditory signal detection task. They found that both sets of patients had lower sensitivity than controls. Interestingly however they also found that hallucinating patients had higher sensitivity than non-hallucinating patients, suggesting that while psychotic individuals have a general deficit in auditory sensitivity, this isn’t the deciding factor in hallucinatory experience. While they did not find any difference in response bias between groups, with each group displaying a liberal response bias (i.e. a bias towards reporting a signal) they did find that only the hallucinating group’s response bias significantly differed from the neutral point (the point at which responding is completely unbiased). Vercammen et al interpreted these results as suggesting that AH may be due to the presence of a liberal response bias in the context of a more general sensitivity deficit (Vercammen, et al., 2008). Thus proneness to auditory hallucinations may be caused by coexisting abnormalities in both auditory-perceptual sensitivity and response bias.

Psychological stress and signal detection

As ACT proposes that stress disrupts goal-directed attention, one would predict that stress should reduce the ability of the auditory perceptual mechanism to distinguish signal from noise trials. Thus on the basis of ACT it would be predicted that stress would lower signal detection sensitivity. This reduction in sensitivity would have the consequence of increasing false positive rate. This prediction therefore coincides with the hypothesis presented in Chapter 1; that the disruption of goal-directed attention during stress might encourage AH by reducing the ability of the perceptual system to accurately identify external signals. This hypothesis is as yet unsupported as there do not appear to be any existing signal detection studies where a systematic manipulation of psychological stress levels within participants has been administered. A number of studies have however compared signal detection performance between different sets of participants, split based on their scores on psychometric or clinical measures of anxiety. The majority of these studies have involved tasks where the participant is required to make an emotional judgement (e.g. the detection of threat) rather than a perceptual judgement (e.g. the detection of the presence of signals). Such studies have tended to find that more anxious participants show a more liberal response bias toward interpreting ambiguous stimuli as threatening (Frenkel, et al., 2009; Manguno-Mire, et al., 2005; Winton, et al., 1995)[7]. A few studies have however compared the performance of groups differing in anxiety on the detection of stimuli. Windmann & Kruger (1998) tested healthy controls and panic disorder patients on a visual lexical decision task (which requires participants to distinguish words from non-words). They found that both groups displayed lower sensitivity and a more liberal response bias (i.e. more likely to report a word as being present) when the stimuli were threat related. They also found that response bias was more liberal in panic disorder patients compared to controls for the neutral words. Using 'jumbled' and unedited pictures of animals, Becker & Rinck (2004) found that spider-phobic participants had a more liberal response bias than non-phobic controls when asked to identify whether an image contained an animal, but only when the animals present were threat-related (i.e. spiders and beetles). Finally Pollock et al (2006) compared the auditory signal detection performance of groups of participants who varied in 'anxiety sensitivity'. The groups did not differ in performance when asked to detect a neutral tone in white noise. However the high anxiety group was found to have a more liberal response bias when detecting a normal heartbeat in white noise, and lower sensitivity (but no difference in response bias) when detecting an abnormal heartbeat from white noise. The response bias toward hearing a normal heartbeat in participants with heightened anxious sensitivity was interpreted as being a product of such individuals being predisposed to attend and fear internal sensations such as heartbeats (Pollock, et al., 2006). However this conclusion doesn't explain why this response bias should disappear when the heartbeats were abnormal (and therefore presumably even more threatening). Unfortunately Pollock et al did not measure how threatening each group found each type of stimulus, so it is difficult to interpret how differences in threat perception might have contributed to relative

[7] Interestingly many of these studies seem to suggest that anxious participants actually have a smaller response bias (i.e. closer to the neutral point) than non-anxious participants, with the differences found being due to non-anxious participants being overly conservative in their response to emotionally negative stimuli (e.g. Frenkel, et al., 2009; Manguno-Mire, et al., 2005)

performance of the two groups.

Aside from the potential issues surrounding interpreting how performance differences due to between-participant (i.e. trait) manipulations of anxiety might be relevant to the (within-participant) effect that psychological stress has on AH, an additional issue with these signal detection studies is that they have used threat-related stimuli. As discussed in Chapter 1, considering the range of content found in psychotic AH, studies investigating the detection of threat related stimuli may not be particularly useful in understanding the processes behind the generation of AH. Moreover as psychological stress appears to precede bouts of hallucination, it seems likely that the origin of the stressor will often be independent of the sensory information that is being misperceived, in contrast to the above studies where it is the signals themselves which are threat related. Although the aforementioned studies appear to show that participants display reduced sensitivity and a more liberal response bias in response to threat related stimuli, this may not therefore have much relevance to the current research questions. The aforementioned studies did however also include tasks requiring the detection of emotionally neutral stimuli. All three studies failed to find any differences in sensitivity between highly anxious and less anxious participants during the presentation of emotionally neutral stimuli. These studies do not therefore provide any support for the hypothesis, inspired by ACT, that psychological stress will reduce sensitivity during the perception of emotionally neutral sounds. Windmann & Kruger (1998) did however find that anxious participants demonstrated a more liberal response bias than less anxious participants when attempting to detect emotionally neutral visual stimuli. Might the state of stress also evoke a more liberal response bias within participants during the detection of emotionally neutral stimuli? Such an effect would, like the hypothesised reduction in sensitivity, cause an increase in false positive rate under stress. It could therefore also act as a potential explanation for the effect of stress on hallucination-proneness. Furthermore there is a theoretical basis for believing that periods of stress may instigate a liberal response bias. As psychological stress is the response to perceived threat, and since under threat a false positive error is a lot less costly than a false negative error, it may be adaptive for the stress response to bias the perceptual system toward reporting a signal (Haselton & Nettle, 2006). For example if you think that you may be attacked when you are walking alone at night (state of stress) it would seem sensible to interpret any potential sensory indications of the presence of another person as being genuine (change in response bias) even when the sensory information is ambiguous or otherwise unconvincing.

Given the absence of any research into the effect of state manipulations of stress on signal detection performance, a novel auditory signal detection task was designed where psychological stress was manipulated within healthy participants. In line with previous auditory signal detection studies relating to understanding AH (e.g. Barkus, et al., 2007; Bentall & Slade, 1985) a task was used where participants were required to detect the presence of speech within white noise. Speech was used as the to-be-detected signal because the majority of AH involve verbal content (Nayani & David, 1996). Stress was evoked through the presentation of aversive images interspersed between the auditory trials. This design ensured that the stressor would be independent of the stimuli being detected, and that any effect it may have would not be due to direct attentional interference by the images (i.e. attentional prioritisation of emotional stimuli over neutral stimuli). It was predicted, in line with ACT, that stress would serve to reduce sensitivity, thus causing an increase in the level of false positives experienced during the task. It was also predicted, based on the above discussion, that stress would evoke a more liberal response bias in participants, a change that would also serve to increase the number of false positive errors made.

As ACT predicts that manipulations of trait anxiety should have the same effect as manipulations of the state of stress, self-report trait anxiety was hypothesised to negatively predict signal detection sensitivity, with more anxious participants exhibiting lower sensitivity. Furthermore as more anxious participants have been found to display altered response bias during tasks involving emotionally neutral visual stimuli (Windmann & Kruger, 1998) it was predicted that more anxious participants would also exhibit a response bias towards reporting a signal during the current task. Finally, since anxiety determines the evaluation and response to stressful events it was hypothesised that trait anxiety would predict the influence of the stress manipulation on signal detection performance, with any effects of the stress manipulation being strongest for participants high in trait anxiety.

Expectation and signal detection

Signal detection tasks test the ability of participants to detect the presence of external auditory signals. In contrast AH are assumed to involve the misdetection of internal auditory signals as external. In Chapter 1 the theory was put forward that the disruption of goal-directed processing under stress might reduce the ability to distinguish between internal and external auditory signals, thus explaining why stress appears to encourage hallucination-proneness. A signal detection task which included a manipulation of the presence of internal auditory signals would allow this theory to be tested directly. If stress were to reduce the ability to distinguish internal from external signals then one would hypothesise that when internal signals are present, stress would make them more likely to be accepted as if they were the searched-for external signal, regardless of whether the external signal was actually present. This would in effect mean that when internal signals are present stress would induce a response bias towards reporting the presence of an (external) signal (i.e. under stress the presence of an internal signal would not only increase false-positive rate, it would also increase hit rate by making external signals more likely to be detected when they are present, assuming that the internal signal matches the external signal). There does not appear to have been any previous studies which have tested how the presence (vs. absence) of internal signals alters signal detection performance, let alone any that have performed this manipulation in conjunction with a variation in the levels of psychological stress that participants are exposed to. Given this it was decided to include a manipulation of the presence of internal signals within the signal detection paradigm used in the current study.

In terms of the internal auditory signals implicated in the generation of AH, those relating to predicted sensory input are the easiest to integrate into a signal detection paradigm. As the to-be-detected signals in the current task are speech sounds, predictive signals relating to their presence can be introduced by using sentence frames. A sentence frame is verbal sentential material which precedes the target stimulus (i.e. the stimulus which the participant is required to perform signal detection on). The semantic content of the sentence frame can be manipulated to alter the expectation as to the form that the to-be-detected signal might take. To this end the target stimuli in the current study (white noise stimuli that either did or did not contain speech) were presented such that they took the place of the final word in a sentence. The sentence frames were designed such that their semantic content either strongly suggested that a particular word completed the sentence (High constraint: e.g. ‘The person ate soup with a’ generates an expectancy for the word ‘spoon’) or did not (Low constraint: e.g. ‘The person spoke about the’ being too vague to generate any specific expectation relating to the final word). As the level of constraint within a sentence frame reflects its likelihood of eliciting specific predictions (Van Petten & Luka, 2012) it was assumed that predictive signals would be generated only by the high constraint frames, and therefore that perception of the target would occur in the context of predictive signalling only in the high constraint condition. In short, the level of constraint provided by the sentence frame alters the level of semantic expectation relating to the content of the (potential) signal, and therefore the likelihood that perception of the target would be accompanied by an internal predictive auditory signal. It was predicted that this manipulation of expectation would interact with the stress manipulation to produce a more liberal response bias in participants (as discussed in the previous paragraph).

Over and above any interaction with a stress manipulation, it is also of interest to identify how expectation might alter signal detection performance on its own. If, as suggested by some theories (e.g. Nazimek, et al., 2012) signals of predicted perceptual input provide the content for auditory hallucinations, one should expect that their presence (vs. absence) during a signal detection paradigm should increase the level of false positives that are experienced. Put another way if some AH are predictive signals misinterpreted as external sounds, then the presence of predictive signals during the perception of ambiguous sensory information should encourage false positive responding. Although this hypothesis does not appear to have been tested before, sentential context has been used to identify how the *veracity* (rather than presence) of expectation alters signal detection performance. Samuel (1981) probed the phonemic restoration effect (the illusory perception of a phoneme from within a word that has actually been replaced by noise) while varying the congruency of sentential context. Participants were asked to report the existence of a phoneme, which had either been masked or replaced by noise, from within a target word that was either congruent or incongruent with its sentential context. For example the target word 'battle' is congruent with the sentence frame 'the solider thought about the dangerous' but incongruent with the frame 'the pitcher thought about the dangerous'. As with the speech detection studies such as Bentall & Slade (1985) a false positive (i.e. phonemic restoration) reflects perceiving speech (the phoneme) when none is in fact present. Samuel (1981) found that when contextual information provided by the sentence frame was congruent to the word which has been altered, sensitivity improved but response bias also changed so that participants became more likely to report predictable words as being complete. As other studies have reported an increase in phonetic restoration due to sentence context (see Samuel, 1996) the biasing effect (which increases the likelihood of phonemic restoration) is presumably stronger than the improvement in sensitivity (which causes reduced errors and therefore reduced phonemic restoration).

While the findings of Samuel (1981) suggest that veridical expectation is capable of increasing false positive responding, they relate to the misperception of individual phonemes, rather than entire words. Indeed a study which tested the impact of the veracity of expectation on the detection of entire words, using sentential context in a similar manner to Samuel (1981) did not find an increase in false positive rate due to veridical expectation (Vercammen & Aleman, 2010). However Vercammen & Aleman (2010) used different target stimuli in the expectation-congruent and expectation-incongruent conditions, thus physical differences between the different sets of target stimuli may have confounded their results. This design characteristic also makes the application of signal detection analysis invalid, thus Vercammen & Aleman were unable to determine whether their manipulation of the congruency of expectation altered response bias or sensitivity. For the purposes of the current study it was hypothesised, based on the results of Samuel (1981) that the presence of expectation would induce both a response bias towards reporting a signal as being present, and an improvement in sensitivity. Furthermore this hypothesised liberal shift in response bias was predicted to increase false positive rate, thus supporting the idea that top-down signals of predicted sensory input are involved in the generation of hallucinations (Nazimek, et al., 2012).

Although Vercammen & Aleman did not find an effect of the accuracy of expectation on false positive rate, they did find that self-report hallucination-proneness predicted the number of false positive errors due to expectation that a participant made (i.e. the number of times the expected word was reported when an unexpected word, or no word was presented). This suggest that perceptual performance may be more susceptible to the biasing influence of expectation in hallucination-prone individuals, as predicted by models implicating predictive signals in the generation of AH (e.g. Nazimek, et al., 2012). The idea that hallucination proneness is associated with an increase in the susceptibility to the influence of expectation is also supported by Haddock et al (1995). Haddock et al studied the verbal transformation effect, where a constantly repeated word becomes heard as a different but phonetically similar word. They found that hallucinating schizophrenics were more likely than both clinical and healthy controls to (incorrectly) report transformations, but only when they were misled into expecting such transformations to take place (Haddock, et al., 1995). The self-report measures of positive schizotypy included within the current study were therefore used to test whether the predicted impact of expectation on response bias was greater in those who report hallucination-like experiences. The relationship between self-report positive schizotypy and general signal detection response bias was also assessed, in light of previous findings that hallucination-proneness and schizotypy predict false positive rate and response bias during signal detection tasks (e.g. Bentall & Slade, 1985; Tsakanikos & Reed, 2005a, 2005b). Finally the possibility that stress might have more of an effect on the auditory perceptual performance of hallucination-prone individuals was tested by assessing the relationship between the measures of positive schizotypy and the effect of stress on signal detection performance.

Summary of hypotheses

Participants performed a signal detection task involving the detection of speech from within white noise. During the task the presence of both psychological stress and semantic expectation (relating to the content of the word being detected) was manipulated. In line with the predictions of ACT it was hypothesised that:

- Sensitivity would decrease during the stress condition.

- Trait anxiety would negatively predict sensitivity (higher anxiety = lower sensitivity).
- Stress and expectation would interact to produce a more liberal response bias.

It was also predicted that:

- Stress would induce a more liberal response bias (greater tendency to report a signal).
- Trait anxiety would predict response bias (higher anxiety = more liberal response bias).
- Trait anxiety would positively predict the impact of the stress manipulation on signal detection performance (higher anxiety = greater impact of stress).
- The presence of expectation would increase sensitivity.
- The presence of expectation would induce a more liberal response bias.
- Levels of positive schizotypy would positively predict the effect of expectation on response bias (higher positive schizotypy = larger effect of expectation on response bias).
- Levels of positive schizotypy would positively predict the impact of the stress manipulation on signal detection performance (higher positive schizotypy = greater impact of stress).
- Levels of positive schizotypy would predict response bias (higher positive schizotypy = more liberal response bias).

Method

Power analysis

Two separate power analyses, calculated using the G*Power Software (Faul, et al., 2007), were conducted in order to determine a sufficient sample size for the study. Firstly to assess the sample size needed to identify a change in signal detection parameters, the effect found by Samuel (1981) was used (expectation effects response bias). Secondly to assess the sample size needed to identify a correlation between psychometric measures and signal detection performance, the effect found by Vercammen & Aleman 2010 (relationship between false positive rate and schizotypy) was used. As both forms of analysis were planned for the current study, it was decided to take the largest sample size estimate from the two calculations as a guide for the required sample size. Perhaps unsurprisingly, given the inherent variability of psychometric measures, the second calculation (power required for correlational analysis) produced a larger required sample size. This analysis suggested that a sample size of 68 (rounded up to 70) would be sufficient to provide a statistical power of 80% and a probability of type 1 error of $\alpha=0.05$ for the correlation analyses.

Participants

Seventy participants (39 female, mean age = 22.2yrs; $\sigma = 5.4$) recruited largely from the staff and student population of Sheffield University, took part in the study. All participants were naive to the hypotheses of the study. Potential participants were asked whether they currently experienced any difficulties with hearing or vision, and whether they had a current diagnosis for a psychiatric disorder. Those who answered in the affirmative to either question were excluded from the study. The study received ethical approval from the University of Sheffield Medical School Research Ethics Committee.

Task Design

The experimental paradigm was presented via a laptop and was arranged into 6 ‘blocks’ of trials, each comprising 48 auditory signal detection trials (A_SDT) and 8 instances of a visual task. The visual tasks were dispersed pseudo-randomly between the signal detection trials by placing one and only one task within each set of eight A_SDT (i.e. one visual task placed randomly within the first 8 A_SDT, one placed within A_SDT 9-16, one between 17-24 etc.).

Each A_SDT began with a 500ms, 440Hz sinusoidal tone, which served to alert the participant to the need to attend. This tone was followed by 500ms of silence. During this time the word ‘Listen’ appeared on the laptop screen. Following this, the experimental stimulus was presented; a sentence spoken in a neutral male voice, where the last word had either been masked, or replaced, by a

1000ms burst of white noise. Immediately after the cessation of this auditory stimulus the laptop displayed two response screens, one after the other. The first asked the participant to report whether they heard speech within the white noise using the left and right arrow keys on the keyboard. Once a response was made the second response screen appeared, prompting the participant to report how certain they were, on a 4-point scale, of their yes/no response. This rating of response certainty was included to facilitate the calculation of valid signal detection parameters (see data analysis section). Note that participants were not required to identify the word that was hidden within the white noise, but simply to report whether they thought any speech was present. The A_SDT concluded (after a response to the rating question) with a 1000ms interval where no stimulus was presented (Figure 2.).

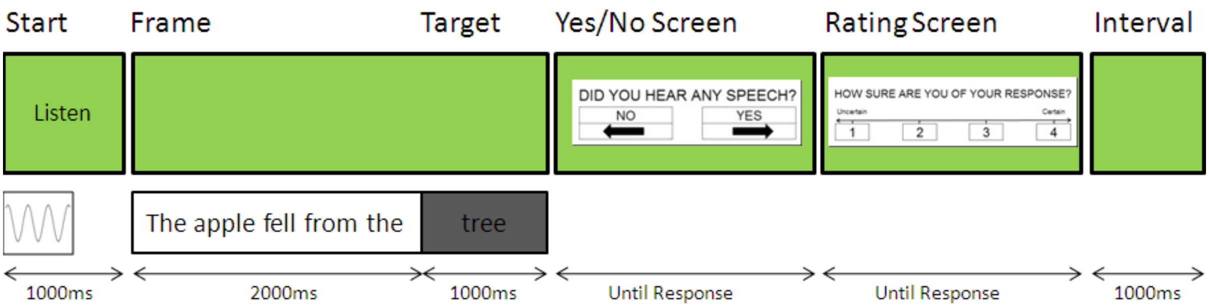

Figure 2: Pictorial representation of an auditory signal detection trial The second row relates to visual stimuli, the third row to auditory stimuli and the fourth row to timings. Each trial started with a sinusoidal tone followed, after 1000ms, by the presentation of the sentence frame and target stimuli. On cessation of the auditory stimuli two response screens appeared, requiring the participant to make a yes/no judgement regarding the presence of speech within the target and to rate their confidence in this response on a 4-point scale. The trial concluded with a 1000ms interval where no stimulus was presented.

The visual task involved the presentation of two images side-by-side which were otherwise identical apart for the presence of a small yellow dot on one of the images (Figure 3.). On the appearance of these images participants were required to indicate on which side the image with the yellow dot resided, again using the left and right arrow keys of the keyboard. The images remained on the screen until the participant made the correct response (to avoid participants just making any response to remove the images from the screen). A 1000ms interval was presented after each visual task.

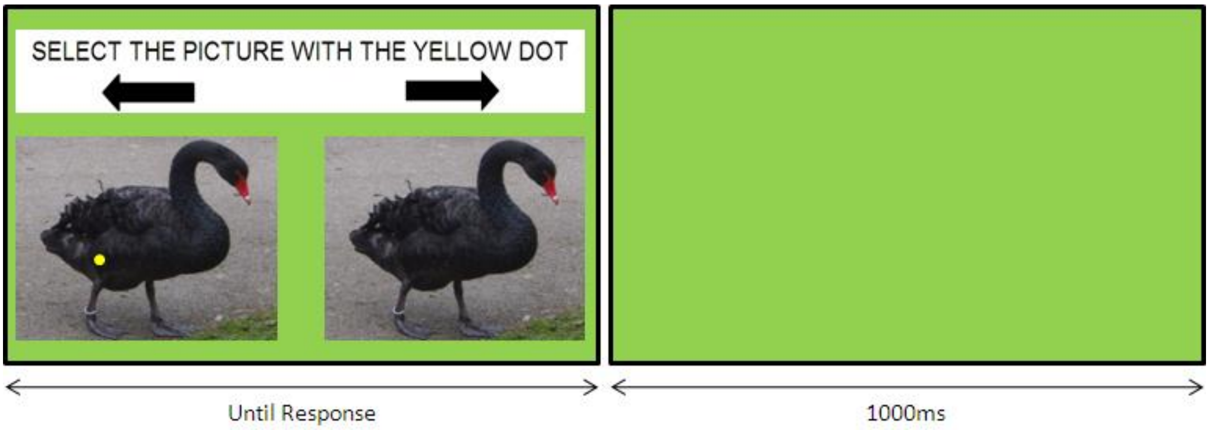

Figure 3: An example of the visual task presented during the signal detection study. During each task two images that were identical apart from the presence of a yellow dot on one image were presented. Participants had to indicate on which side of the screen the image with the yellow dot appeared. The images were removed following the correct response, with the trial concluding with a 1000ms interval where no stimulus was presented.

The experimental paradigm was constructed to provide three factors arranged in a fully factorial 2x2x2 design. The first factor (target type) related to whether in the A_SDT the target stimulus (the white-noise stimulus from which the participant was required to make a perceptual judgement) contained any speech. Half the A_SDTs were signal trials, where the target did contain speech. The other A_SDTs were noise trials, where the target did not contain speech. The presence of this target type factor in a fully factorial design allowed an identical number of signal and noise trails to be presented for each combination of the other two factors, thus permitting the calculation of signal detection parameters for each level of the other two factors.

The second factor within the experimental paradigm related to the presence of semantic expectation. This was manipulated via the content of the sentence frames which preceded the target during the A_SDT. Seventy two different frames were presented during the study. These frames were constructed during piloting (see Stimuli & Apparatus section) with half of the frames designed to create the expectation that a specific word would complete the sentence (high constraint frames) while the others were designed so they did not (low constraint frames). The perceptual judgement relating to the target was therefore performed in the context of the presence of predictive signals only during the high constraint trials[8]. Importantly the frames were designed in such a way that each of the 36 high constraint frames suggested a different concrete noun, and each

[8] As mentioned in the study introduction, the level of constraint provided by a sentence frame reflects its ability to generate specific predictions relating to the final word (Van Petten & Luka, 2012).

of these nouns could be combined with any of low constraint frames to produce a sentence that maintained semantic integrity. This allowed the same 36 nouns to be used as targets (when masked with white noise) during signal trials for both the high constraint and low constraint conditions. Each sentence frame was only ever paired with one particular noun (on signal trials) thus ensuring that any effect of repetition between a particular frame and target combination was equal across the high and low constraint conditions. In the high constraint condition the frames were always paired (on signal trials) with the noun that would be expected based on the frame's semantic content. In the low constraint condition the nouns were randomly assigned to each frame. Figure 4 shows examples of the four combinations of trial type and constraint that could appear during an A_SDT. Each of these trials occurred with equal probability during the task. Participants were not made aware of this manipulation of expectation, so as to reduce the possibility of participants consciously applying differing cognitive strategies between conditions.

Sentence Frame	Target	Condition
The apple fell from the	tree	High Constraint / Signal
The person looked at the	tree	Low Constraint / Signal
The apple fell from the		High Constraint / Noise
The person looked at the		Low Constraint / Noise

Figure 4: Examples of the four auditory trial types present during the signal detection task In the high constraint condition the sentence frame created an expectation regarding the content of the potential signal. In the low constraint condition the sentence frame does not generate any expectation regarding the content of the potential signal. Speech (the signal) was present within the target during signal trials, and absent during noise trials.

The third factor within the experimental design related to the presence or absence of psychological stress. Stress was manipulated via the content of the images that appeared during the visual tasks, thus allowing a stressor to be applied independent of the signal detection stimuli. In 3 of the 6 blocks (herein referred to as 'stress blocks') the images used in the visual tasks were always aversive, while in the other 3 (non-stress) blocks the images were always emotionally neutral. Participants were informed in advance of the type of images that would appear in each block and this information was reinforced by varying the background colour of the laptop screen during the different block types. A red background was used during the stress blocks and a green background during the non-stress blocks, the colours selected because of their intuitive association with danger and safety respectively (although the association between background colour and image valence was also be made explicit to the participant before the task commenced). The purpose of informing the participants in advance of the type of images to be presented, and implementing a constant reminder of this throughout the block, was to evoke anticipatory anxiety relating to the anticipation of, and exposure to, aversive images during the stress blocks.

As it has been found that aversive images have an enhanced distraction effect (relative to neutral images) of between 500 and 1500ms after image offset (Attar, et al., 2010; Ciesielski, et al., 2010; Most, et al., 2005) a gap of 2000ms separated the offset of the visual task from the onset of the next A_SDT. This comprised of the 1000ms interval at the end of each visual task and the 1000ms interval containing the sinusoidal tone at the beginning of each A_SDT. This gap ensured that processes relating directly the perception of the images (i.e. greater attentional capture by the aversive images) would not systematically affect signal detection performance between the stress and non-stress blocks. Additionally the sinusoidal tone at the start of the A_SDT served to re-orientate attention back towards the auditory modality.

Pseudo-randomisation of the presentation order of the A_SDT ensured that trials relating to each of the 4 combinations of the target type and expectation factors appeared with equal probability, both within each block, and also in the positions immediately after a visual task. In total 288 ADTs were presented during the 6 blocks. Each of the 72 frames (36 high constraint, 36 low constraint) were repeated 4 times during the entire task, twice with a signal and twice without, with those pairs split between stress and non-stress blocks. This ensured that exactly the same set of frames and targets were used in both the stress and non-stress blocks, making the design fully factorial and removing any confounds relating to stimulus content from the manipulations of psychological stress and expectation. The pseudo-randomisation also ensured that no combination of expectation and trial type occurred more than twice in succession in any block, and that the same target noun did not appear within the same block twice. The stress blocks were alternated with non-stress blocks during the task with the order counterbalanced between participants (i.e. half the participants experienced blocks 1, 3 & 5 as stress blocks and the other half experienced blocks 2, 4 & 6 as stress blocks).

After each block the participant was asked to rate the valence of the images seen during the previous block (during the visual task) on a 7-point Likert scale. This allowed the success of the psychological stress manipulation to be assessed via the subjective reaction of the participants to the images.

Stimuli and Apparatus

During a pilot study 31 participants who did not participate in the signal detection study (17 female, mean age 27.2yrs) were presented with a list of potential high and low constraint frames and asked to write down the first word that came into their heads (to complete the sentence) after reading the frames. It was assumed that the level of consistency in how the sentences were completed would reflect the constraint of the sentence frame (i.e. the frame's ability to generate a specific expectation relating to the identity of the final word). 36 frames were thus selected for use in the high constraint condition where at least 80% of participants used the same word to complete the sentence (average 91%) . 36 other frames, where less than 20% of the participants completed the sentence with the same word (average 13%) were selected for use in the low constraint condition. The two sets of frames were matched on duration, number of syllables and number of words. A list of the sentence frames and their associated target nouns (i.e. the speech signals to be detected) that were used in the study is shown in Appendix 2.

To produce the auditory stimuli, the sentence frames and target nouns generated from the pilot study were recorded in a neutral male voice using the freely available Audacity software, version 1.3.13 (http://audacity.sourceforge.net/). The target nouns and associated high constraint frames were recorded in separate sessions (rather than the entire sentence being recorded and the target noun later separated) in an attempt to avoid factors independent from semantic information (such as prosody) from influencing the effectiveness of the manipulation of expectation. Each frame lasted between 1500ms and 2000ms in duration. The Audacity software was also used to generate a 440hz sinusoidal tone (used to signal the start of each A_SDT) and a 1000ms burst of white noise (used as the target in noise trials and as a mask for the speech in signal trials). The target nouns were mixed with the white noise stimulus at various signal-to-noise ratios (SNRs). A second pilot study was then performed, again on participants who did not participate in the main signal detection task, in order to determine a SNR for each target noun that would allow the presence of speech to be identified approximately 80% of the time. The resulting SNRs varied between -15 to -25 across the different target nouns. In order to match all auditory stimuli on an objective measure of loudness, each auditory stimulus was normalised to the same average RMS amplitude using a custom script written in MATLAB version 7.5.0 (http://www.mathworks.com/products/matlab/).

The images used in the visual task were selected from the International Affective Picture System (IAPS) using their normative arousal and valence ratings (Lang, et al., 2008). 24 aversive images, depicting representations of severe human injury, animal death and unsanitary conditions were selected for use in the stress blocks (valence < 2.5, arousal > 5) while 24 non-emotional images (valence 4.5-5.5, arousal < 3.5) depicting either household objects or unexceptional landscapes, were selected for use in the non-stress blocks (see Appendix 3 for complete list of images). Yellow dots (RGB=240,230,46; Brush Width = 22) were added to copies of each image using the Microsoft Paint.NET software version 3.36 in order to produce the target stimuli for the visual task. Image selection was performed in such a way as to ensure that the images used during the visual task did not contain representations of any of the target nouns used in the A_SDT.

The experimental paradigm was written using Neurobehavioural Systems' Presentation software (http://www.neurobs.com/). Auditory stimuli were delivered through Sennheiser HD 265 headphones via an Edirol UA3D Stereo USB Audio Interface connected to the laptop. All stimuli were presented at an approximate volume of 70db.

Psychometric Assessment

Participants completed the following psychometric tests.

Spielberger State-Trait Anxiety Inventory (STAI: Spielberger, et al., 1983).

The STAI requires the participant to rate the extent to which 40 self-descriptive statements (e.g. 'I lack self confidence') apply to them. 20 statements have to be rated according to how the participant generally feels (producing a trait anxiety measure) and the other 20 have to be rated according to how the participant feels at the current point in time (producing a measure of state anxiety).

Launay-Slade Hallucination Scale (LSHS - Modified version: Laroi, et al., 2004)

The LSHS is a 16-point scale which probes the propensity of participants to experience hallucinatory or hallucination-like phenomena in various sensory modalities.

Schizotypal Personality Questionnaire (SPQ: Raine, 1991)

The SPQ is designed to assess the presence of schizotypal traits in healthy individuals. In particular, scores on the cognitive-perceptual sub-factor (SPQ_CP) were used during the current project, as this sub-factor measures the propensity to report experiences that are similar to positive psychotic symptoms such as hallucinations and delusions.

Procedure

The experiment was conducted in a quiet room. After giving informed consent, demographic information was acquired from participants via a questionnaire which incorporated the Edinburgh

Handedness Inventory (EHI: Oldfield, 1971). Participants then completed the STAI, which was administered before the paradigm to avoid the exposure to aversive images impacting on the measure of state anxiety. The nature of the task was then explained to the participants and they were then placed in front of a laptop and asked to put on headphones so as to complete the experimental paradigm. Participants first completed a practice block, which took the form of a non-stress block involving 20 A_SDT and 3 visual tasks but using different auditory and visual stimuli to that used in the main task. Following completion of the subsequent 6 experimental blocks, participants were asked to complete the remaining psychometric measures (SPQ & LSHS).

Data Analysis

Response data from the auditory signal detection paradigm were analysed subject to the tenants of signal detection theory (SDT). The standard model of signal detection assumes that the decision variable (the metric used by the participant to make a decision about the stimuli, in this case their auditory perceptual experience) is normally distributed in both signal and noise trials, with each distribution having equal variance. When these assumptions were tested on the response data generated in the current study it was found that the assumption of equal variance was not met. Alternative 'distribution-free' versions of the signal detection parameters, which do not rely on the aforementioned assumptions, were therefore used. These measures utilise the concept of a receiver operating characteristic (ROC) curve, which is a plot of the hit and false positive rates attained from the rating scale (see Stanislaw & Todorov, 1999 for a more comprehensive description). The exact calculations used are those proposed by Kornbrot (2006), where sensitivity is calculated via an estimate of the area under the ROC curve, and response bias is calculated by computing the proportion of the area between the ROC curve and the major diagonal that is above and below the midpoint criterion. Details concerning the method of testing signal detection data for compliance with assumptions of parametric signal detection analysis, and the subsequent calculation of distribution-free signal detection parameters, can be found in Appendix 4.

Comparison of signal detection parameters

Measures of sensitivity and response bias were calculated separately for each of the four conditions (high/low constraint, stress/non-stress). This allowed the main effects of psychological stress and expectation, and their interaction, to be ascertained for both these parameters. The predicted relationships between a participant's psychometric profile and these signal detection parameters were assessed by regressing one against the other. In order to test the hypothesised relationships between psychometric measures and the effect of the manipulations of stress and expectation, metrics relating to the latter were calculated by subtracting the value of the signal detection parameters computed across the conditions where the level of stress/expectation varied. For example a measure of 'stress effect on response bias' was calculated by computing the response bias across the stress blocks, and subtracting from it the response bias computed across the non-stress blocks. The 'stress effect on sensitivity' and the 'expectation effect on response bias' metrics were likewise derived. These metrics were then regressed against the relevant psychometric measures.

Mean reaction times to the visual task were computed and regressed against the self-report measures. No analysis was performed on the reaction times to the signal detection task because participants were asked to prioritise accuracy over speed during this task.

Results

Behavioural performance

Overall task performance (% of correct) during the auditory signal detection task was 81%, suggesting that participants were able to complete the task at above chance levels. A Wilcoxon Signed-Rank test performed on the participant's ratings found that the images in the stress blocks were rated as significantly more unpleasant than those in the neutral blocks ($z=-6.8$, $p< .001$, $r= -0.57$) suggesting that the stress manipulation was successful in altering mood. Reaction time to the visual task was also longer in the stress blocks ($z=-6.9$, $p<.001$, $r=-0.58$).

Signal detection analysis

Sensitivity and response bias were calculated using distribution-free metrics which utilise the area under the ROC curve (Kornbrot, 2006 - see Method section). Two participants (1 male, 1 female) were found to have performed below chance in at least one of the 4 conditions, thus making the calculation of ROC bias measures impossible (because there is no area above the major diagonal from which to calculate the ratio needed to determine response bias). Their data was therefore excluded from the signal detection analysis, although inclusion of this data, where possible, did not materially alter the results found.

Shapiro-Wilk tests of normality revealed that the majority of the ROC measures computed, and their residuals, differed significantly from the normal distribution. Given this, non-parametric statistics were used where possible. In lieu of a suitable non-parametric test, a 2X2 repeated-measures factorial ANOVA was performed on the signal detection parameters derived from each of the four conditions (Figure 5.). This analysis revealed that expectation had a significant effect on sensitivity ($F(1,67) = 8.12$, $P < 0.01$, $r = 0.33$) such that sensitivity increased in the high constraint condition (where expectation relating to the target word was present) compared to the low constraint condition (where no such expectation was present). There was no effect of stress on sensitivity, and no interaction between stress and expectation. Expectation also had a significant effect on response bias ($F(1,67) = 9.75$, $p< 0.01$, $r = 0.36$) with the response bias value become significantly higher when a particular signal was expected, reflecting a more liberal response bias. Once again there was no effect of stress. The predicted interaction between stress and expectation on response bias was also found to be non-significant.

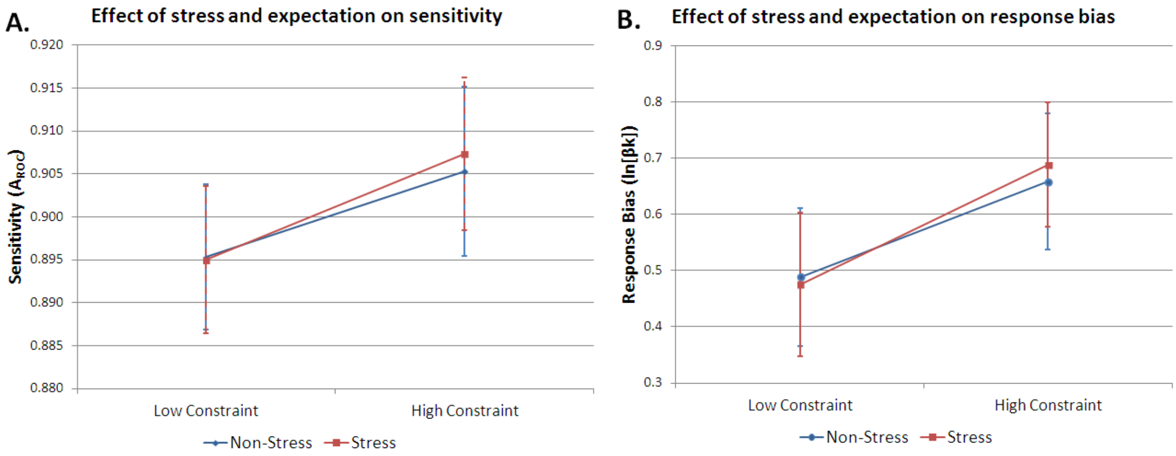

Figure 5: Effect of the manipulations of expectation and stress on sensitivity and response bias. The high constraint condition involves the generation of expectation (and therefore predictive signals) relating to the content of the target word, whereas the low constraint condition did not. A main effect of expectation was found for both sensitivity (A) and response bias (B). Sensitivity improved and response bias became more liberal (more likely to report a signal) during the high constraint condition. No main effect of stress, or any interaction between stress and expectation was found. Error bars represent standard error of the mean.

Although the factorial ANOVA is often considered robust to violations of the assumption of normality, we subjected both of these significant main effects to a Wilcoxon sign-rank test, a one-way repeated-measures non-parametric test, with the purpose of ensuring that the aforementioned significant effects were not sensitive to the violation of the assumption of normality. After Bonferroni corrections were applied to the resultant p values (to reflect the 3 contrasts inherent in the ANOVA, compared to the one performed during a one-way test) a significant difference in sensitivity ($z= -2.5$, $p=0.01$, $r=-0.21$) and response bias ($z= -3.2$, $p=0.001$, $r=-0.27$) due to the presence of expectation was again demonstrated.

As the effects of semantic expectation (improved sensitivity and more liberal response bias) have a divergent effect on false positive rate, with sensitivity reducing the overall level of errors, but response bias making errors more likely to be positive, we compared the false positive rate between the high and low constraint conditions using a one-way Wilcoxon signed rank test. A marginally significant increase in the rate of false positives was found when perception occurred in the presence of semantic expectation ($z=-1.83$, $p=0.067$, $r = -0.16$).

Psychometric measures

Spearman's rho correlation coefficients were calculated between each combination of the psychometric measures to assess their relationship with each other (Figure 6.). Trait anxiety correlated with state anxiety ($r_s = .38$, $p< .01$) cognitive-perceptual schizotypal personality (SPQ_CP)

(r_s = .37, p< .01) and hallucination proneness (LSHS) score (r_s = .35, p<.01). State anxiety was not found to correlate with either the SPQ_CP or LSHS scores. A positive relationship was however found between scores on the SPQ_CP and LSHS (r_s = .76, p<.01). Correlations were also performed between these self-report measures and mean reaction time to the visual task. Only trait anxiety correlated with the reaction time to the visual task (r_s = .24, p<.05) with more anxious participants taking longer to respond to the task.

	State Anxiety	Trait Anxiety	SPQ_CP	LSHS
State Anxiety		0.38**	0.00	-0.01
Trait Anxiety			0.37**	0.35**
SPQ_CP				0.76**
LSHS				

*Significant at the 0.05 level (2-tailed)
**Significant at the 0.01 level (2-tailed)

Figure 6: Spearman's Rho correlation coefficients between various psychometric measures taken during the signal detection task. Sample size = 70. State & Trait Anxiety relate to the Spielberger State/Trait Anxiety inventory. SPQ_CP = Cognitive-perceptual sub-factor of the Schizotypal Personality Questionnaire. LSHS = Launay-Slade Hallucination Proneness.

Relationship between psychometric measures and signal detection performance

Given the non-normal characteristics of both the signal detection and psychometric measures, the non-parametric Serlin-Harwell Aligned-Rank Procedure method (SHARP: Serlin & Harwell, 2004) was used to compute regression statistics between the self-report measures and signal detection performance. The effects of age, gender and presentation order (i.e. whether the participant received a stress or non-stress block first) were controlled for during these analyses. Counter to the hypothesised relationship between stress and signal detection performance, trait anxiety did not predict a participant's sensitivity or response bias. Trait anxiety was however found to predict the effect of the stress manipulation on response bias (see data analysis for details on computation) with more anxious participants tending to experience a greater shift in response bias toward positive responding (X^2=5.23, p<0.05, ΔR^2=0.08, Figure 7.). To identify whether this relationship was sufficient to cause an increase in false positives, this analysis was repeated using false positive rate as the dependent variable. Trait anxiety was again found to predict the effect of the stress manipulation (X^2=7.10, p<0.01, ΔR^2=0.11) with psychological stress triggering an increasing rate of false positives in more anxious individuals[9].

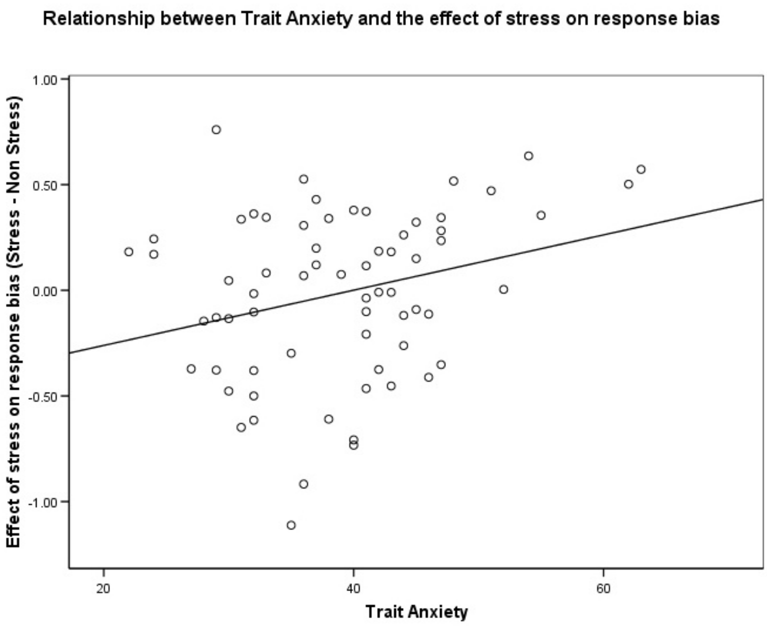

Figure 7: Relationship between trait anxiety and the effect of the stress manipulation on response bias.

Regressions analyses performed using the self-report scores of positive schizotypy (SPQ_CP and LSHS) failed to find the predicted relationship between these measures and response bias. These self-report measures also failed to predict false positive rate. As these negative findings contradict a significant amount of past research, two further analyses were performed. Firstly, the analyses relating to the SPQ were repeated using the scores from the whole scale, rather than just the cognitive-perceptual sub-factor. Secondly, as many of the prior studies which found an association between positive schizotypy and response bias used pre-selected groups of participants rating high and low on the relevant psychometric measure (e.g. Bentall & Slade, 1985) quartile splits were conducted on the SPQ_CP and LSHS measures in an attempt to identify whether differences in response bias could be identified by directly comparing the 1st and 4th quartiles in isolation[10]. Confirming the findings of the original regressions, no significant relationships were identified in either of these analyses. LSHS and SPQ_CP scores also failed to show the predicted positive relationship with the effect of expectation on response bias. Finally neither measure of positive schizotypy showed a relationship with the effect of the stress manipulation on response bias.

[9] State anxiety was also found to predict the stress effect on false positive rate, in a similar direction (X^2=4.40, $p<0.05$, ΔR^2=0.07) although the equivalent effect on response bias did not reach significance (p=.12).

[10] See DeCoster et al (2009) for a review of why quartile/median splits can sometimes lead to spurious results.

Discussion

The manipulation of the context within which an auditory signal detection task was performed revealed that the level of psychological stress experienced by a participant did not have a direct effect on either sensitivity or response bias. A relationship was however found between the trait anxiety of the participant and the effect of the stress manipulation, such that more anxious participants tended to adopt a more liberal criterion under stress, causing them to experience more false positives. In contrast a manipulation of the presence of expectation relating to the identity of the target word acted to both improve sensitivity and influence the response bias of participants, the latter effect making participants more likely to report detecting a signal regardless of its actual presence.

Impact of psychological stress on perceptual performance

The motivation for implementing this signal detection study was to assess whether attentional control theory (ACT: Eysenck, et al., 2007) might be able to explain the finding that psychological stress appears to encourage auditory hallucinations (AH) in those vulnerable to them. ACT proposes that stress disrupts goal-directed attention. It was hypothesised that this effect might encourage AH by reducing the ability of individuals to correctly identify external auditory signals. On this basis it was predicted that stress would serve to reduce sensitivity during an auditory signal detection task, thus causing an increase in false positive responding. ACT also proposes that more anxious participants exhibit weaker goal-directed attention. It was therefore predicted that trait anxiety would be negatively related to sensitivity. In the current study however signal detection sensitivity was not found to be affected by either the manipulation of psychological stress, or the participant's level of trait anxiety. Finally it was also predicted that the detrimental impact of stress on goal-directed attention would cause a response bias in favour of reporting a signal in the high constraint (expectation present) condition compared to the low constraint (no expectation) condition. This was thought possible because internal predictive signals (generated only by the high constraint sentence frames) would be more likely to be mistaken for genuine external signals during periods when goal-directed processing is disrupted by stress. This increased tendency to mistake an internal signal for an external one under stress would occur regardless of the presence of a genuine signal, and thus would cause a response bias towards reporting a signal. Once again however the predicted interaction between stress and the presence of expectation was not found to be significant.

What can explain the absence during the current study of evidence in support of the assertion from

ACT that stress disrupts goal-directed attention? One possibility is that participants were able to use greater cognitive effort to overcome the detrimental effects of stress on goal-directed processing, in line with the suggestion from ACT that stress affects processing efficiency more than processing effectiveness (Eysenck, et al., 2007, pp. 340-341). When stress disrupts goal-directed processing, participants may be able to use increased cognitive effort to prevent a decrease in processing effectiveness (measured by performance accuracy) but at the expense of reduced processing efficiency (i.e. longer reaction times). As no pressure was put on reaction times during the current task, it is not possible to assess whether this speed-accuracy trade off may have been responsible for the absence of evidence in favour of stress disrupting goal-directed attention.

Although ACT states that stress affects goal-directed attention even when no distraction is present (Eysenck, et al., 2007, p. 338) the majority of research literature which supports the theory that stress has a detrimental effect on goal-directed perceptual processing involves paradigms where distracters are present close to or during the goal-directed task. An alternative explanation for the absence of an effect of stress on goal-directed attention during the current study might therefore be that the effect is reliant on the presence during the task of stimuli that can evoke the competing stimulus-driven attention system. As such stimuli were absent in the current study this may explain the failure to find an effect of stress or anxiety on sensitivity. Notwithstanding these potential caveats regarding the experimental method, the results of the current study do not support the view that stress affects goal-directed auditory attention towards emotionally neutral auditory stimuli. These results also therefore do not support the idea suggest that stress may encourage AH by decreasing the ability of the auditory perceptual system to accurately distinguish between external and internal auditory signals.

Although psychological stress and anxiety were not found to impact of signal detection sensitivity, trait anxiety was found to predict the effect of the stress manipulation on both response bias and false positive rate during the signal detection task. The more anxious a participant was, the more likely they were to exhibit a more liberal response bias, and therefore experience more false positives, under stress. Although a main effect of stress on response bias was hypothesised, the mediating impact of trait anxiety on the effectiveness of the stress manipulation is in accordance with both theoretical and empirical evidence concerning hallucinations. For example there is a substantial body of evidence which suggests that the anxiety profile of the individual has an important influence on hallucinatory experience, to the extent that theories relating to the development of psychosis consider trait anxiety to be a risk factor in the development of the condition (e.g. Garety, et al., 2007; Jobe & Harrow, 2010). Trait anxiety has also been found to correlate with both perceptual distortions (Bell, et al., 2011) and self-report hallucination proneness in healthy individuals (Allen, et al., 2005; Paulik, et al., 2006) the latter finding being replicated in the current study. Most pertinently, trait anxiety has been found to predict the vulnerability of psychotic patients to increased positive symptoms in response to stressful life events (Docherty, et al., 2009). The interaction between trait anxiety and psychological stress on the signal detection performance of healthy participants during the current study therefore appears to mirror the influence of stress and anxiety on symptomatology in clinical populations.

How might situational stress and trait differences in anxiety interact to contribute towards both a response bias in signal detection tasks, and auditory hallucinations in clinical populations? Recent research has lent support to the view that trait anxiety reflects the level of top-down cognitive control one is able to exert (e.g. high trait anxiety reflects a deficiency in maintaining attention) whereas the state of anxiety (such as that instigated by the appearance of a stressor) is thought to influence bottom-up processes, making detection of unattended stimuli more likely (Pacheco-Unguetti, et al., 2010)[11]. Indeed in the current study trait anxiety was found to correlate with reaction times during the visual task (i.e. the stressor) presumably reflecting this deficit in attentional control which highly anxious individuals have, especially in response to threat stimuli (Eysenck, et al., 2007). Given this putative distinction between the effects of trait differences in anxiety and state manipulations of stress, it is possible to propose a cognitive mechanism to explain the effect of psychological stress on hallucination-proneness, while taking into account the important mediating role of trait anxiety (Figure 8.). Our perceptual systems may be designed to bias towards reporting the presence of signals under stress, as during periods of threat a false positive represents a less costly error than a false negative (Haselton & Nettle, 2006). However the magnitude of this bias may be modulated by the level of top-down control the individual is able to exert under stress (as reflected by trait anxiety). In the current task, where the stress caused by the images was presumably reasonably modest, many low trait participants may have been able to override any bias toward positive responding caused by the threat of exposure to aversive images, thus negating the main effect of the stress manipulation. In contrast the deficit in top-down control present in high trait anxious participants may have made them unable to override the biasing effect of stress. While this stress-induced biasing of perception may be adaptive in the general population,

[11] It is worth noting that this conceptualisation of the differing effect of variations in trait anxiety and variations in the state of stress contradicts ACT, since ACT suggests that either state and trait manipulations of stress should have both these effects (Eysenck, et al., 2007, p. 336).

in psychotic individuals who show reduced auditory functioning (C. S. R. Li, et al., 2002; McKay, et al., 2000; Sweet, et al., 2007; Sweet, et al., 2004) who may be overly reactive to stressors (Horan, et al., 2008) and who have deficiencies in attentional control (Waters, et al., 2003) it may manifest in such a way that it encourages the generation of percepts in the absence of concordant sensory information (Figure 8).

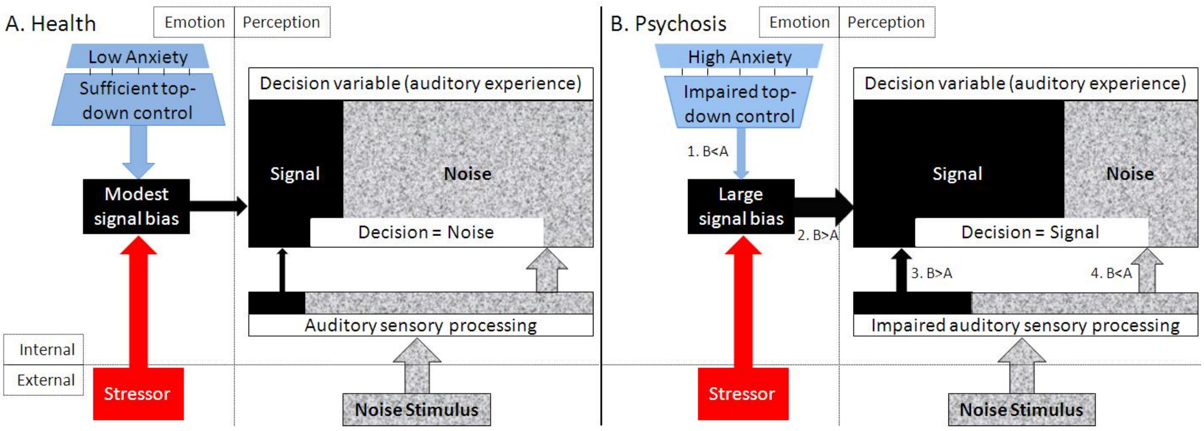

Figure 8: Potential mechanism explaining the propensity of stress to cause hallucinations in psychotic individuals. In general the psychological stress caused by the appearance of a stressor generates a perceptual bias towards reporting a signal. However this effect is mediated by the top-down control the individual is able to exert (as reflected by their trait anxiety). In healthy individuals (A) the biasing effect of stress is mitigated by top-down control, resulting in a low likelihood of noise being misperceived as a signal. In psychotic individuals (B) high anxiety leads to a failure to adequately mediate the biasing effect of stress (1 & 2). The increased biasing of perception under stress, in combination with deficiencies in auditory sensory processing which reduce the accurate identification of auditory signals (3 & 4) serve to make the erroneous perception of signals more likely in psychotic individuals.

Impact of the presence of predictive signals on perceptual performance

A manipulation of expectation (relating to the content of the target word) was included in the research design to allow an assessment as to how the presence of internal auditory signals during perception might affect perceptual performance. This manipulation allowed a test of the theory that top-down signals, such as those relating to predicted perceptual input, contribute to AH (Nazimek, et al., 2012). It was hypothesised that the presence of predictive signals would serve to improve sensitivity while also acting to shift response bias towards reporting a signal regardless of its actual presence. The results supported these hypotheses, as both improved sensitivity and a more liberal response bias (a bias towards reporting a signal) were found in the high constraint (expectation present) condition. The finding that veridical expectation improves sensitivity is not unexpected given that the development of the system of top-down predictive signalling during evolution was presumably contingent on it having a beneficial effect on perception. Similarly there are many reports of semantic expectation improving perceptual performance (calculated using non-signal detection measures) on a variety of tasks (e.g. Boulenger, et al., 2011; Jordan & Thomas, 2002; Sommers & Danielson, 1999). The concurrent shift in response bias suggests that predictive signals have the potential to be misperceived as external sensory input through an effect on the response bias of the perceptual system. This in turn suggests that predictive perceptual signals are a potential source of hallucinatory activity, especially as the manipulation of expectation in the current study was found to increase the level of false positives despite its aforementioned beneficial effect on sensitivity. Importantly, unlike the effect on response bias found during phonemic restoration (Samuel, 1981) the current findings suggest that the erroneous perception of speech, generated by expectation, can occur without the (genuine) presence of neighbouring phonemes, and is not therefore reliant on closely coincident signals that are veridical with expectation. This is in contrast to a recent study of visual signal detection which found that while the presence of expectation improved sensitivity, it only altered response bias when the noise stimuli had some characteristics in common with the expected stimulus (Krol & El-Deredy, 2011). However Krol & El-Deredy manipulated expectation through semantic priming, achieved via the presence or absence of a visual cue. This potentially confounds the effects of semantic priming with that of temporal priming, as the mere presence of the cue, even an uninformative one, can affect performance (Hackley, 2009; Rimmele, et al., 2011). Furthermore it is questionable whether priming paradigms evoke predictive signalling at all, since the presentation of the prime may simply make the (related) target more accessible (Enns & Lleras, 2008) without relying on any top-down predictive influence. The current study suggests that predictive signals can impose the perception of an expected auditory stimulus onto noise even when that noise contains no characteristics in common with the predicted stimulus.

Relationship between performance and measures of positive schizotypy

Self-report measures of hallucination-proneness (LSHS) and positive schizotypal personality (SPQ_CP) failed to predict the effect of semantic expectation on response bias. This finding appears to contrast with that of Vercammen & Aleman (2010) who found that LSHS score predicted the number of ‘top-down errors’ made (false positives occurring because the participant erroneously reports the word suggested by sentential context) during an auditory signal detection task. Vercammen & Aleman asked participants not only to report the presence of speech but also to identify the word they heard, with ‘top-down errors’ including instances where the participant correctly identified the presence of a word, but mistakenly identified it as the expected word. It is not clear therefore to what extent the relationship between hallucination-proneness and ‘top-down errors’ found by Vercammen & Aleman relates to mis-identifications rather than mis-detections of speech. Furthermore as Vercammen & Aleman manipulated the veracity, rather than the presence, of predictive signals, their results are not directly comparable to those of the current study. The results from the current task suggest the presence of expectation (and therefore of internal predictive perceptual signals) biases the perceptual system towards mis-detections, but that this effect is not particularly reliant on the hallucination-proneness of the individual.

Scores on the SPQ_CP and LSHS failed to significantly predict the response bias or false positive rate demonstrated by participants during the task. This finding is in contrast to studies of visual perception which have found that such measures predict false positive rate (Jakes & Hemsley, 1986; Reed, et al., 2008; Tsakanikos & Reed, 2005a, 2005b) and auditory signal detection studies which have found that LSHS score predicts response bias (Barkus, et al., 2007; Bentall & Slade, 1985). One possible explanation for the negative finding in the current study is that both auditory studies cited above involved a contrast of groups of high and low scorers on the LSHS, specifically recruited because of their extreme scores, rather than a regression using a representative sample of participants. It may be that, for the auditory modality at least, the relationship between positive schizotypy and response bias is not linear, but is instead a consequence of differences that exist only at extremes of the scale. However attempts to mimic a high/low group split in the current dataset (by splitting participants into quartile groups based off their scores on the LSHS and SPQ_CP) also failed to produce any significant effects. It could however be argued that the range of scores attained on these scales in the current sample was not divergent enough for this analysis to be successful[12]. On this topic it is worth noting that other studies, employing both regressions using a random sample (Crowe, et al., 2011) and high/low schizotypy groups (C. S. R. Li, et al., 2003) have also failed to demonstrate a relationship between auditory response bias and positive schizotypy. It is therefore of importance for future research to identify in more detail how positive schizotypy and hallucination-proneness in healthy individuals may be related to signal detection performance.

Limitations

An important caveat that needs to be considered when discussing the causes of any differences in signal detection parameters, is that signal detection theory represents a general model of evidence evaluation (Pastore, et al., 2003). It is a mathematical description of the performance of a system.

[12] The average SPQ score for the low and high groups were 7.6 (0-13) and 38.7 (30-58). The equivalent figures for LSHS were 6.3 (0-11) and 37.4 (30-57). A direct comparison between these values and those used in other studies is not possible because these other studies used different measures of schizotypy (either the O-Life questionnaire or an earlier version of the LSHS).

Caution therefore needs to be applied when interpreting how changes in sensitivity or response bias might relate to changes or differences in sensory, cognitive or neural processes. For example, although sensitivity and response bias are independent from a mathematical standpoint, this does not necessarily imply that different cognitive processes are responsible for their control (nor does it imply that sensitivity and response bias are each influenced by only one cognitive process). The discussion of the current findings assumes that changes in sensitivity and response bias are due to alterations in perceptual processes (i.e. either in sensory processing, or in perceptual decision making). However it is possible that such changes may reflect the workings of post-perceptual processes such as motor-response characteristics (e.g. a change in response bias may be the result of changes in the ability to inhibit particular responses).

It should also be acknowledged that the participant's rating of the valence of images seen during each block does not represent a direct measure of the effectiveness of the stress manipulation. Nevertheless as previous research has shown that the anticipation of aversive images is anxiety inducing (e.g. Simmons, et al., 2004) it is likely the stress manipulation in the current study was successful in inducing psychological stress in participants.

Conclusion

This study revealed that psychological stress alters the response bias of the auditory-perceptual mechanism in such a way as to increase the level of false positives experienced during a signal detection task, although the size of this effect is dependent on the anxiety profile of the individual. No evidence was found to support the hypothesis, arising for ACT, that stress would reduce the performance of the goal-directed attention system, and therefore signal detection sensitivity. A manipulation of the presence of expectation relating to predicted sensory input was found to alter response bias so that the reporting of signal became more frequent. While the presence of expectation also served to improve sensitivity, its overall effect was to increase the false positive rate experienced by participant, a finding which supports the view that predictive perceptual signals may be involved in the generation of AH.

Chapter 3

Introduction

The signal detection task detailed in Chapter 2 was designed to identify how psychological stress affects goal-directed auditory perception. Attentional control theory (ACT: Eysenck, et al., 2007) posits that stress and anxiety serve to disrupt the performance of the goal-directed attention system. It was therefore predicted that during the signal detection task, sensitivity (the ability to distinguish between signal and noise) would decline in the stress condition, and be smaller in those showing high levels of trait anxiety. However neither hypothesis was supported by the data. It was also predicted that the negative impact of stress on goal-directed attention might cause participants to exhibit an increased propensity to mistake internal predictive signals (when they were present) for the searched-for (external) signal. However this hypothesis was also not supported by the data. The results of the signal detection task did not therefore support the hypothesis that stress might encourage hallucinations by disrupting goal-directed auditory processing.

There are two methodological issues with the signal detection task that may potentially explain this failure to find support for the prediction that stress disrupts goal-directed attention. Firstly, the absence of any noticeable effect of stress or anxiety on goal-directed attention may have been due to the absence within the paradigm of stimulus capable of attracting the competing stimulus-driven attentional system. Although a reduction in attentional control under stress is assumed to occur even in situations where there are no distracting stimuli (Eysenck, et al., 2007, p. 338) it is possible that, especially at modest stress levels, goal-directed attention might only deteriorate when stimuli are present that are capable of activating the competing stimulus driven system. Secondly ACT suggests that stress initially impacts on processing efficiency rather than processing effectiveness. This stems from the idea that by recruiting extra cognitive resources, threats to processing effectiveness (i.e. task accuracy) can sometimes be overcome at the cost of increased effort and therefore an increased reaction time (lower processing efficiency). As signal detection parameters relate solely to performance accuracy they would not have been able to capture any effect that stress might have on processing efficiency. A goal-directed task where some pressure is exerted on response time would therefore be required to test the impact of stress on the efficiency of goal-directed auditory processing.

A further issue that is yet to be addressed in this thesis is the validity of the other hypothesis relating to the generation of AH that was described in Chapter 1. It was hypothesised that since ACT predicts an enhancement of stimulus-driven attention under stress, the resulting greater vulnerability to distraction might enable internal auditory signals to attract stimulus-driven attention as if they were external signals. As mentioned in Chapter 1 there are very few studies which have tested whether, in line with this prediction, emotionally neutral auditory distracters are processed to a greater extent under stress. A paradigm where emotionally neutral auditory stimuli are presented outside the focus of goal-directed attention is required to test this hypothesis.

In light of the issues regarding the assessment of the effect of stress on goal-directed auditory attention during the signal detection task, and the need to test the effect of stress on stimulus-driven auditory processing, a further behavioural study was designed. This study utilised the passive oddball paradigm, a paradigm which allows the interplay between stimulus-driven and goal-directed attention to be assessed, while providing a measure of processing efficiency.

The passive oddball paradigm

Oddball stimuli involve the regular presentation of a string of identical stimuli (known as 'standard' stimuli) that is occasionally interrupted by a stimulus that varies from the standard on one or more attributes (a 'deviant')[13]. In passive oddball paradigms the participant is required to ignore the change in sensory stimulation represented by the deviant, and is often instead asked focus on a separate goal-directed task (e.g. Schroger & Wolff 1998). In such paradigms the unexpected appearance of the deviant stimulus (from within the oddball stream) draws goal-directed attention away from the ongoing task. This distraction causes an increase in reaction time to the goal-directed task in trials where the deviant is presented (deviant trials) when compared to trials where the standard stimulus is presented (standard trials). This increase in reaction time is henceforth referred to as the 'oddball effect'. The oddball effect can be taken as a measure of the balance between the stimulus-driven and goal-directed attention systems since its size reflects the ability of changes in the sensory environment (as detected by stimulus-driven attention) to interrupt goal-directed processing (Parmentier, et al., 2010).

In addition to allowing the interplay between goal-directed and stimulus-driven attention to be tested within the same paradigm, passive oddball tasks also allow a measure of processing efficiency to be acquired. Indeed reaction time is the metric that is generally used for assessing the impact of

[13] For purposes of clarity, the entire stream of stimuli delivered in this pattern is referred to as the 'oddball stimulus'. The unexpected stimuli within this stream are referred to as 'deviants' rather than 'oddballs' to avoid confusion between the individual unexpected stimulus and the entire train of stimuli.

the oddball stimuli on performance of the goal-directed task, since reaction time is a more sensitive measure of distraction than error rate. The passive oddball paradigm therefore addresses the possible shortcomings concerning the testing of the impact of stress on goal-directed perception that were present in the signal detection task. It also allows the effect of stress on stimulus-driven auditory attention to be assessed.

Stress and passive oddball studies

As discussed in Chapter 1, there is not conclusive evidence in support of the prediction, derived from ACT, that stress enhances the stimulus-driven processing of emotionally neutral auditory stimuli. Neuroimaging studies have found that the neural response to deviant stimuli within an oddball paradigm increase regardless of whether the oddball stimuli are the subject of goal-directed attention (Alexandrov, et al., 2007) or stimulus-driven attention (Cornwell, et al., 2007). It is not therefore clear from such studies whether stimulus-driven auditory attention is genuinely prioritised over goal-directed attention during stress. In contrast recent studies testing the effect of emotion on the behavioural response to emotionally neutral auditory distracters have found results that appear to coincide with the predictions on ACT. These studies have used cross-modal passive oddball designs where participants have to ignore auditory oddball stimuli while focussing their goal-directed attention on a separate visual task. Dominguez-Borras et al (2008a) varied the emotional content of images which appeared in a visual discrimination task. They found that the oddball effect (generated by task-irrelevant sounds presented before each visual task) was greater when the visual task involved aversive rather than neutral images. The aversive images which appeared in the visual task were assumed to create a negative emotional context (and therefore presumably some form of psychological stress) in comparison to the control condition. It could therefore be interpreted that the increase in the oddball effect during the negative emotion condition reflects an enhancement of stimulus-driven attention due to stress. This increased behavioural distraction was accompanied by increased auditory cortex response (deviant > standard) in the negative condition compared to the control condition, a finding which also suggests that there was enhanced sensory processing of the deviant sound in the more stressful condition (Dominguez-Borras, et al., 2008a; Dominguez-Borras, et al., 2009).

The results of the Dominguez-Borras studies appear to support the prediction from ACT that stress causes an enhancement of the stimulus-driven attentional network, even when only emotionally neutral auditory distracters are present. However a methodological issue that exists with the Dominguez-Borras studies concerns the use of emotive images within the goal-directed task. An inevitable consequence of using task stimuli to vary emotional context is that the task itself becomes subtly different between conditions. Although the visual task used in the Dominguez-Borras studies required participants to ignore the content of the images, there is still likely to have been a difference in task difficulty between conditions as emotional content is harder to ignore than neutral content (e.g. Hodsoll, et al., 2011). A possibility therefore exists that the effects attributed to changes in emotional context may in fact be due to differences in task demands. For example the greater attentional control required to ignore the content of the aversive images may have caused a fatiguing of the attentional control system in the negative emotional condition. This wearing down of attentional control may have led to a greater processing of deviant stimuli during the negative emotional condition which was unconnected to the emotional reaction to the images. A further consequence of using different tasks between emotional conditions is that it prevents a direct comparison of performance across conditions. For example it is not possible to compare the standard trial reaction time between the emotional conditions because any differences found could be due to either a difference in emotional context or a difference in task demands. This makes it impossible to ascertain whether the increased oddball effect found in the negative emotional condition was actually due slower reaction times to deviant trials when compared to the neutral condition (as would be predicted by ACT). The same result (increased oddball effect under stress) could also be caused by quicker reaction times to standard trials under stress, an effect that would run counter to the predictions of ACT. Without the use of the same task between emotional conditions, and therefore the ability to directly compare reaction times between the emotional conditions, it is impossible to distinguish between these two possibilities. A final problem with the Dominguez-Borras studies is that the stimuli were arranged in blocks whose appearance was randomised so that blocks involving only the emotionally neutral task were more likely to appear at the start of the paradigm, while the blocks involving the aversive task were more likely to appear near the end. It is not clear why this design was adopted, but it obviously introduces the potential for fatigue and practice effects to confound the contrast between the two conditions.

Task Design

Given the methodological issues surrounding the Dominguez-Borras studies, and the potential relevance of these studies to the understanding of the impact of stress on hallucination-proneness, it was decided to attempt to replicate the findings of Dominguez-Borras et al (2008a; 2009) while using an experimental design where stress was manipulated independently from the visual goal-directed task. To this end a cross-modal passive oddball task was designed that was as close to that used in the Dominguez-Borras et al studies as possible. In common with many other crossmodal passive oddball studies (e.g. Parmentier, et al., 2011; Parmentier, et al., 2010) a visual, odd/even number classification task was used as the goal-directed task, replacing the task involving aversive and neutral images used in the Dominguez-Borras et al studies. Participants had to complete this odd/even task while ignoring an emotionally neutral speech sound delivered a short time before each number. These speech sounds were delivered so that the word content varied in an oddball pattern, thus allowing the oddball effect to be generated. Psychological stress was manipulated as before, by presenting aversive or neutral images between experimental trials. This design therefore allowed the effect of stress on the stimulus-driven processing of emotionally neutral auditory stimuli to be assessed. It was predicted that stress would increase the distraction caused by the presentation of deviant speech stimulus, and therefore also increase the size of the oddball effect. Such a finding would support the prediction from ACT that stress strengthens stimulus-driven auditory attention at the expense of goal-directed processing.

While the results of Dominguez-Borras et al appear to support the predictions of ACT, there are other theories concerning the impact of stress on attention that produce different predictions. During tasks involving selective attention (where two stimulus compete for attention at the same time) it has been suggested that stress reduces the impact of distracting information (e.g. Easterbrook, 1959) an effect herein referred to as ‘goal-shielding’ (Plessow, et al., 2011). In brief it is proposed that neurochemical changes that occur during stress serve to inhibit processing within the prefrontal cortex (Arnsten, 2009). One of the consequences of this change is thought to be a reduction in the level of attentional resources available. This reduction in attentional capacity is proposed to preferentially reduce the processing of task-irrelevant information during perception, thus improving the ability to selectively attend to task-relevant parts of a sensory scene (Chajut & Algom, 2003). The most convincing evidence for this theory comes from studies of the Stroop effect. Stroop interference is demonstrated by asking participants to name the colour of some text while varying the word that is printed. Interference in colour naming is seen in trials where the word’s semantic content refers to a different colour to that which it is printed in (e.g. the word ‘blue’ printed in red) when compared to trials where the content of the word has no relationship with the colour of the text (e.g. the word ‘boat’ printed in red). Stroop interference is reduced during stress (Booth & Sharma, 2009; Chajut & Algom, 2003) suggesting that stress enables a greater focusing on the task-relevant elements of the stimulus in comparison to the task-irrelevant elements.

These results from the Stroop task, and indeed goal-shielding theory in general, appear to contradict ACT, which would predict that stress should increase the processing of the distracting information (word content in the Stroop task) due to the enhancement of stimulus-driven attention. The results Dominguez-Borras et al (2008a; 2009) also conflict with the goal-shielding theory, although this conflict is most likely due to the fact that the cross-modal passive oddball design used by Dominguez-Borras et al does not test selective attention, since the distracting oddball stimuli are presented before the task stimulus in the crossmodal paradigm. The differing effect of stress on attention evident in the results of the Dominguez-Borras studies when compared to the results of studies using the Stroop task suggests that the temporal relationship between task-relevant and task-irrelevant (distracting) information influences how stress affects attentional performance. In light of this possibility a purely auditory passive oddball task was included in the current study to allow the impact of stress on selective auditory attention to be tested. The inclusion of an auditory selective attention task also allowed the effect of stress on auditory goal-directed attention to be tested in the presence of stimulus-driven distraction, thus addressing one of the shortcomings of the signal detection task[14].

The selective auditory attention task utilised the same verbal oddball stimuli that were used in the crossmodal oddball task, thus keeping the method of distraction identical between the two tasks[15]. Participants were required to ignore the content of the speech (which varied in an oddball pattern) and instead attend to its spatial location. This ‘speech oddball’ task thus tests selective attention as the participant has to selectively attend to one characteristic of a stimulus, while ignoring another. The goal-shielding theory predicts that the oddball effect caused by the appearance of the deviant speech sounds would be smaller in the stress condition, whereas ACT predicts that the appearance of the deviant would induce a greater increase in reaction time in the stress condition.

Self-report measures of anxiety were administered during the study, thus allowing an assessment of how between-participant differences in anxiety might influence the oddball effect. ACT proposes that highly anxious individuals have greater difficulty inhibiting stimulus-driven attention compared to less anxious participants. ACT therefore predicts that anxiety levels should positively correlate with the size of the oddball effect (i.e. more anxious participants should exhibit larger oddball

[14] A visual (rather than auditory) goal-directed task was used during the crossmodal task to keep the design as close as possible to that of the Dominguez-Borras studies, thus reducing any potential issues with interpreting the results of the crossmodal task in the context of those from the Dominguez-Borras et al studies.

[15] The possibility of testing selective attention using a direct replication of the crossmodal task, but with the latency between the auditory and visual stimulus reduced to 0ms was rejected due to concerns that differences in conduction times of auditory and visual sensory information might prevent the task from truly testing selective attention.

effect). While previous studies using emotionally neutral oddball stimuli have found that participants with differing trait anxiety profiles exhibit differing neural responses to deviants, they have not tended to find any differences in reaction times (Bryant, et al., 2005; Kimble, et al., 2000; Y. Z. Li, et al., 2011; although see Wise, et al., 2009). The inclusion of self-report measures of anxiety also allowed as assessment of how a participant's level of anxiety might interact with the stress manipulation. In light of the results of the signal detection study it was predicted that any changes in the oddball effect due to stress would be larger in those with higher trait anxiety.

Oddball studies and positive schizotypy

Might performance on these auditory passive oddball tasks be predicted by self-report measures of positive schizotypy? One consistent finding in schizophrenic participants is that neural reaction to deviant stimuli within oddball paradigms (the MMN signal) is reduced (Umbricht & Krljes, 2005). This effect suggests that the change in stimulation represented by the deviant is not processed fully in psychotic individuals. One might interpret from this that those high in schizotypy should show less behavioural distraction in response to the deviant stimulus, as they may process the change in stimulation it represents to a lesser extent. However the reduced MMN evident in those with psychosis is not always found in first degree relatives of schizophrenic patients, a finding which suggests that differences in the response to unexpected stimuli may be a consequence of the psychotic condition, rather than a pre-morbid sign (Magno, et al., 2008). Thus the decreased processing evident in psychotic individuals may not apply to healthy individuals who exhibit schizotypal traits. Indeed the fact that there does not appear to be any demonstrations of altered MMN in high schizotypal healthy participants appears to support this conclusion. In contrast there is evidence that both hallucination-prone psychotic patients (Waters, et al., 2003) and highly schizotypal healthy individuals (Ferraro & Okerlund, 1996) show a reduced ability to inhibit irrelevant information when compared to control populations. This suggests that highly schizotypal individuals may instead demonstrate *greater* behavioural distraction on encountering unexpected deviant stimuli during a passive oddball paradigm. The relationship between positive schizotypy and the size of the oddball effect was therefore assessed in the current study. Whether the impact of stress on the oddball effect differs depending on the schizotypal profile of the participant was also assessed, thus allowing an identification as to whether the vulnerability to stress-induced distraction might be greater in those prone to hallucinatory experiences.

Stress manipulation

During both oddball tasks stress was manipulated using in a similar method to that employed during the signal detection task, with aversive images sporadically appearing between experimental trials. However the frequency of image presentation was increased compared to the signal detection task, a change made possible by the relatively short trial times inherent in an oddball paradigm. Another change to the stressor (in comparison to the signal detection task) was to alter the task required of the participant in relation to the image. Instead of the 'yellow dot' task, participants were just required to view a single image and then, at the end of each block, identify images that had appeared during the block from sets of two alternatives. This change was deemed necessary because the yellow dot task requires the participant to make a response to the image during its presentation. The yellow dot task would therefore introduce task-switching demands during an oddball paradigm which might affect task performance. Task-switching demands were not considered to be a problem during the signal detection study because trial responding was self-paced during that task, with the consequence that responses to the yellow dot task were unlikely to interfere with responses to the signal detection task.

The fact that responding is not self-paced during the oddball tasks may itself serve to enhance the effectiveness of the stressor. The self-paced responding during the signal detection task allowed the participant a modicum of control over their exposure to the stressor, as they knew that it could not appear until after they had made their response to the ongoing signal detection trial. This control was absent during the oddball tasks as the conclusion of each trial is independent of the timing of the participant's response[16]. A final change to the stressor was the introduction of speech relevant to the content of the image during the period the images were onscreen. This speech was added in an attempt to further enhance the emotional difference between the aversive and neutral images.

Improvements (when compared to the signal detection task) were also introduced to the assessment of the effectiveness of the stress manipulation. The wording of the self-report rating scale administered at the end of each block was altered so that it more directly asked participants to report their stress levels. In addition, measures of skin-conductance were also taken during the study. The skin conductance response (SCR) is believed to measure the activation of the sympathetic nervous system, and therefore physiological arousal. A measure of SCR therefore allows an objective measure of the effectiveness of the stress manipulation to be collected. If the stress manipulation is

[16] Oddball stimuli are usually presented at a constant rate, regardless of the timing of a participant's responses. A consistent latency between oddball stimuli is required in order to generate an expectation regarding the appearance of the standard stimulus, and therefore distraction when a deviant stimulus appears.

successful in evoking psychological stress then one would expect measures of SCR to be heightened in the stress condition when compared to the control (non-stress) condition.

Summary of hypotheses

The level of stress was manipulated during the performance of two passive auditory oddball tasks. Alongside the presence of self-report measures of anxiety, this allowed an assessment as to the impact of psychological stress on the relative performance of goal-directed and stimulus-driven attentional systems. In line with the predictions of ACT it was hypothesised that during both tasks:

- Stress would increase the size of the oddball effect.
- Trait anxiety would positively predict the size of the oddball effect (higher anxiety = larger oddball effect).

It was also hypothesised that during both tasks:

- Levels of positive schizotypy would positively predict the size of the oddball effect (higher positive schizotypy = larger oddball effect).
- Trait anxiety would positively predict the increase in the oddball effect under stress (higher anxiety = greater increase in the oddball effect during stress).
- Levels of positive schizotypy would positively predict the impact of stress on the oddball effect (higher positive schizotypy = greater effect of stress).

Method

Power analysis

The power analysis was conducted using a similar method to that described in Chapter 2. The set of experiments by the Dominguez-Borras group (Dominguez-Borras et al., 2008a, 2009) were used as the basis for assessing the sample size required to detect the influence of emotion on the oddball effect. To assess the sample size required to detect a correlation between psychometric measures and attentional performance, the effect found by Steel et al (2002 - relationship between positive schizotypy and distractor inference) was used. Once again the correlational analysis produced the larger required sample size, with a sample of over 40 (rounded up to 50) required to achieve a statistical power of 80% and a probability of type 1 error of α=0.05 for the correlation analyses.

Participants

Fifty-three participants, recruited mainly from the staff and student population of Sheffield University, took part in the study. 2 participants withdrew due to discomfort with the aversive images, and data from a further participant was excluded due to poor performance[17]. This left 50 participants (28 female, mean age 27.2, σ=7.79) whose data was analysed, although data from the speech task for 1 participant was lost due to a software malfunction. The sample size of 50 was determined via power calculations so that the planned main effect and interaction analysis could be examined with a 20% probability of a type 2 error. All participants were naive to the hypotheses of the study. Participants reporting difficulties with hearing or vision, or a current diagnosis for a psychiatric disorder, were excluded from the study. The study received ethical approval from the University of Sheffield Medical School Research Ethics Committee.

Task Design

Crossmodal passive oddball task

In this task the participant was required to categorise visually presented single digit numbers (from 1 to 8) as either odd or even while ignoring a stream of auditory speech stimuli. Each oddball trial began with a 250ms auditory stimulus, which preceded the visual presentation of the single-digit number by 300ms. After 400ms this visual stimulus was removed from the screen and no further stimulus was presented for 550ms, at which point the trial terminated. The visual stimuli were presented in black, size 36 font in the middle of a white window (200 pixels square) against a black

[17] The participant's performance was at chance levels during the crossmodal task, and far inferior to all other participants during the speech oddball task

background. The participant was required to press the left arrow on the keyboard when an odd number was presented, and the right arrow when an even number was presented. The participant was given 800ms to make a response (to the number) encompassing the 400ms during which the number appeared on the screen and the 400ms immediately after this. Responses made more than 800ms after visual stimulus onset, or within 150ms of stimulus onset were treated as errors (the latter being assumed to represent reflex responses, rather than a genuinely indication of the perceptual, cognitive and motor actions required to make a correct response). The total trial length was 1250ms (Figure 9). Participants were told to respond as fast as possible to each number, while retaining accuracy. The relative timings of the different stimuli within each trial were chosen to match as closely as possible those used in the Dominguez-Borras studies (2008a; 2009).

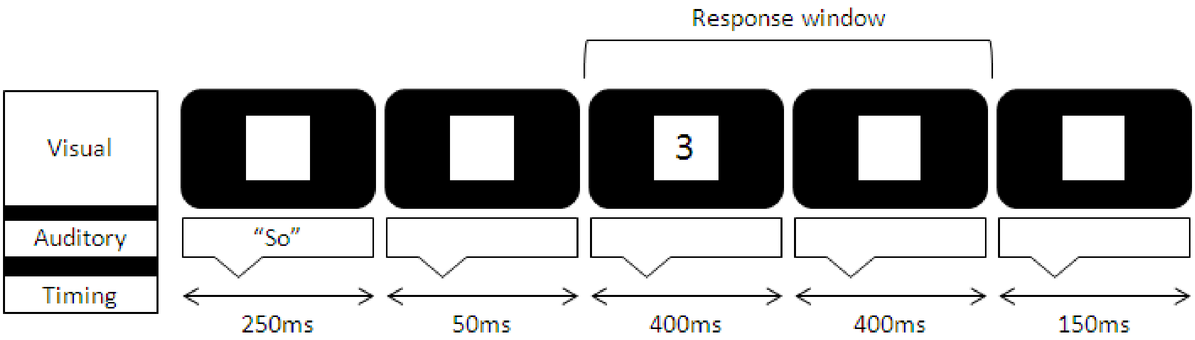

Figure 9: Example of an individual trial during the crossmodal oddball task. Each trial started with the presentation of an auditory stimulus for 250ms which followed, after a 50ms gap, by the appearance of a number. The number disappeared after 400ms, after which the participant has a further 400ms to respond as to whether the number was odd or even. The trial concluded with a 150ms interval during which no stimuli was presented and no responses were recorded.

The oddball trials were presented in blocks. Each block included 76 oddball trials alongside 6 presentations of audio-visual stimuli. The audio-visual stimuli were included to provide the manipulation of psychological stress. In half the blocks (herein referred to as 'stress blocks') the visual component of these stimuli involved the presentation of an aversive image against a red background, while the auditory component involved the presentation of speech relevant to the content of the image. In the other half of the blocks ('non-stress blocks') neutral images were presented against a green background while the speech was again content-relevant to the image (see Appendix 5 for details of the images and speech used). Each audio-visual stimulus was presented for 2500ms, with an additional 150ms gap between the offset of the audio-visual stimulus and the start of the next oddball trial. Each block began with the presentation of one audio-visual stimulus with the remaining 5 stimulus arranged in a pseudorandom pattern within the block such that at least 8, but no more than 20 oddball trials were presented between each audio-visual stimulus, and after the last audio-visual stimulus. Each block therefore lasted approximately 2 minutes (Figure 10.).

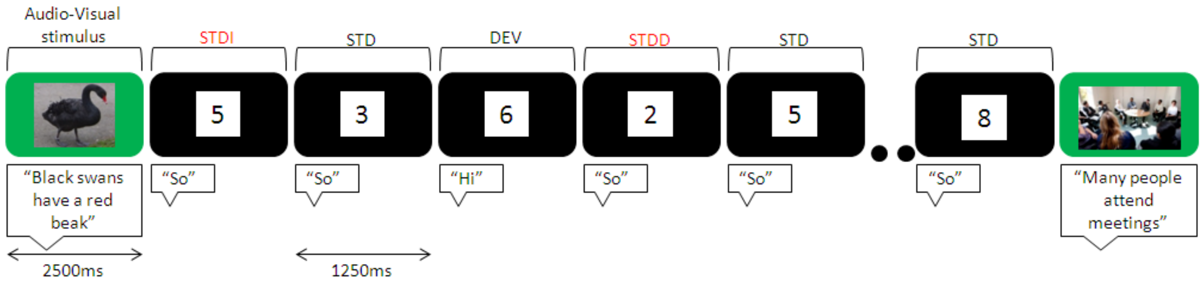

Figure 10: Example of the arrangement of oddball trails within each block. Each block began with the presentation of a 2500ms audio-visual stimulus. In the non-stress blocks (shown) this involved an emotionally neutral image presented against a green background accompanied by speech relevant to the content of the image. Similar audio-visual stimuli were presented within the block, sporadically interrupting the train of oddball trials. In stress blocks (not shown) the images were aversive and presented against a red background alongside speech that was also content-relevant. The oddball pattern of trial presentation meant that most trials were standard trials [STD] where the standard speech sound was presented. Occasional deviant [DEV] trials (frequency = 15.8%) involved the presentation of a speech sound that was different from the standard. The standard trials that occurred immediately after either a presentation of an audio-visual stimulus (STDI) or a deviant trial (STDD) were excluded from the data analysis.

Across trials, the auditory stimuli were arranged in an oddball pattern such that one particular word was used as the standard stimuli, and three different words were used as deviants. Trials were therefore split into those where the single digit number was preceded by the presentation of the standard auditory stimulus (standard trials) and those that involved the presentation of a deviant auditory stimulus (deviant trials). Only 12 of the 76 trials within each block were deviant trials (15.8%) thus ensuring that the deviant stimulus were unexpected. Each of the three different deviant stimuli were presented 4 times within each block. The position of the deviant and standard trials was pseudo-randomised such that 1) each block started with at least 5 standard trials to set up the expectation of the standard auditory stimulus, 2) each audio-visual stimulus was followed by at least 2 standard trials based on the assumption that the presentation of the audio-visual stimulus interrupts the process of perceptual prediction, thus requiring the nature of the standard stimulus to be re-established 3) each deviant trial was separated by at least 2 standard trials 4) each train of oddball trials between audio-visual stimuli, and after the last audio-visual stimulus, contained at least one deviant trial and 5) that successive deviant trials did not involve the presentation of the same deviant stimulus.

The single-digit number that appeared in each trial was also pseudo-randomised to ensure 1) that the same number did not appear twice in succession, 2) that the correct response was not the same more than 5 times in a row, 3) that each number appeared with an equal probability, both in standard and deviant trials across the entire paradigm and also across the stress and non-stress blocks separately. In addition, the type of response required for each trial in comparison to the preceding trial (e.g. either maintaining or switching from the previous response) was pseudo-randomised such that an equal number of 'switch' and 'stay' responses were required for both standard and deviant trials. The responses were arranged in this way on the assumption that the proportion of responses that represent a switch should be equal across the conditions that are being contrasted as a 'switch' response will, all other factors being equal, take longer since it requires the inhibition of the previous response.

Five auditory stimuli were used as the oddball stimuli, four common one-syllable words ('Do', 'So', 'My' and 'We' – see Appendix 6 for details) and a silent stimulus (i.e. 250ms of silence). The crossmodal oddball task comprised of 10 blocks, with each of the 5 stimuli acting as the standard stimuli within two blocks. In the 8 blocks that used speech as the standard stimuli, the 3 remaining speech stimuli were used as the deviant stimuli. As each of the four speech stimuli therefore acted as the standard in 2 blocks, and a deviant in the other 6 block, this design ensured that any physical or lexical differences between the speech sounds would not contribute to the oddball effect demonstrated during the task (see Appendix 7 for an analysis of the oddball effects by standard word type). The remaining 2 blocks used silence as the standard stimuli. For the purposes of brevity these silent blocks are not discussed further[18].

The blocks were arranged so that stress and non-stress blocks were alternated. Each pair of blocks that employed the same standard stimulus was presented in succession, thus keeping the number of times the identity of the standard stimulus changed during the task to a minimum. This block arrangement also ensured that the stress and non-stress blocks involved exactly the same combinations of auditory stimuli in the standard and deviant positions. In addition, across participants the position of the 5 pairs of blocks was randomised using a 5x5 Latin square formation to ensure that each pair of blocks using a particular standard stimulus appeared in each of the

[18] The silent blocks were included to test whether stress had an impact on the 'cuing effect', the improvement in reaction time seen when the oddball stream in present compared to when no oddball stimuli are presented (Escera, et al., 1998). However as only 2 silent blocks were included in the paradigm, one per emotional condition, it was concluded that the experiment did not offer sufficient statistical power to assess the impact of stress. This analysis is not therefore discussed further.

available position (first to fifth) an equal number of times.

Speech passive oddball task

The speech oddball task involved the presentation of stimulus in an identical manner to the crossmodal oddball design, with the exception that during each oddball trail, the auditory stimuli were presented monaurally (i.e. in one ear only). In contrast to the crossmodal task, participants were required to respond to the auditory stimulus rather than the visual stimulus. Participants were asked to press the arrow button that corresponded to the ear in which the sound had been played. The response window was again 800ms (Figure 11.). The auditory stimuli were pseudo-randomised in a similar way to the visual stimuli in the crossmodal task, such that the type of stimulation (left or right ear) and the nature of response required (stay or switch) was distributed evenly, both across the standard and deviant trials, and also across the stress and non-stress blocks. The randomisation of both the visual stimuli (the numbers) and the position of the audio-visual stimulus, were equivalent to that implemented during the crossmodal task.

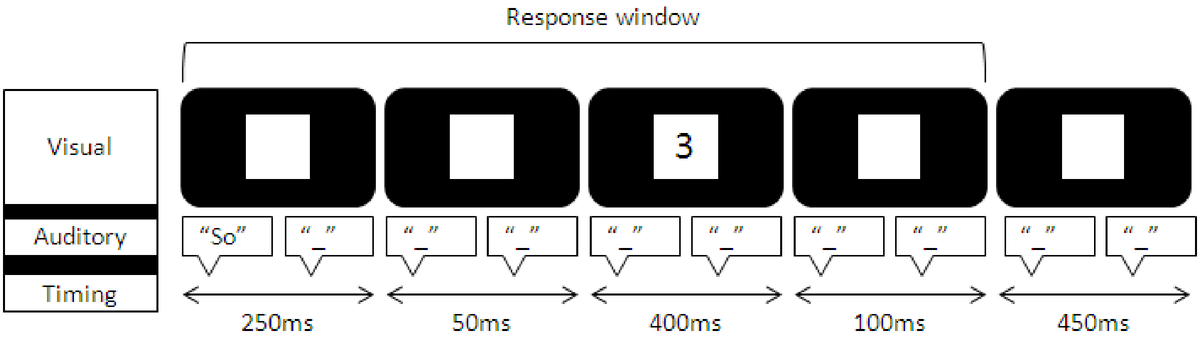

Figure 11: An individual trial during the speech oddball paradigm. Each trial started with the presentation of a monaural auditory stimulus for 250ms which is followed, after a 50ms gap, by the appearance of a number. Participants had 800ms from the presentation of the speech to respond as to whether the speech was presented in the left or the right ear. A 450ms gap concluded the trial.

The speech oddball task utilized the same four speech stimuli present in the crossmodal task. Due to the omission of the silent stimulus the speech oddball task only comprised of 8 blocks, split into 4 pairs of blocks where the same speech sound was used as the standard stimulus. The position of these 4 pairs of blocks was randomised in a similar way to that described for the crossmodal task.

General experimental design

All participants performed the crossmodal task before the speech oddball task, under the assumption that if the speech task were completed first the attention required to the auditory oddball stimulus may interfere with later attempts to ignore the same stimulus during the crossmodal task. Each particular audio-visual stimulus was presented only once throughout the whole study (across the two tasks) ensuring that habituation to particular images could not occur. After each block, participants were asked to provide a rating on a seven point likert scale as to how stressful they found it to complete the block.

Recognition Task

To ensure that attention was paid to the audio-visual stimuli during both oddball paradigms, each block of trials concluded with the presentation of three recognition tasks. In each recognition task two images were presented side-by-side and the participant was required to indicate which of the two images had appeared in the preceding block (using the same left and right arrow button used during the oddball trials). Each recognition task ended once the participant had made a response (whether correct or not). During the first four blocks of the crossmodal task the lures used within this recognition task (i.e. the image that had not been presented in the preceding block) were images that were not otherwise used within the study. The lures used during the remaining 6 blocks of the crossmodal task, and during the entire speech oddball task, were images that were used in earlier blocks of the study. This ensured that the first appearance of any particular image within the paradigm was always as part of the audio-visual stimulus, and therefore that the participant did not become habituated to individual images before their use in the stress manipulation.

Stimuli and Apparatus

The images used during the study were selected largely from the International Affective Picture System (IAPS) using their normative arousal and valence ratings (Lang, et al., 2008). 43 aversive IAPS images (valence < 3.15, arousal > 4.3) were selected for use in the stress blocks. These images contained representations of severe human injury, animal death and unsanitary conditions. These were supplemented by 11 images of human bodily damage sourced from the internet. 54 emotionally neutral IAPS images (valence 4.5-5.6, arousal < 3.5) were selected for use in the non-stress blocks. Sentences were generated to compliment each picture on the basis that the content of the sentence should relate to the content of the image and be factual or otherwise uncontroversial. A complete list of images and associated sentences are given in Appendix 5.

The auditory stimuli were recorded in a male voice using the Audacity software, version 1.3.13 (http://audacity.sourceforge.net/). The sentences for the audio-visual stimuli were edited so that they were no longer than 2500ms. The five auditory oddball stimuli were edited so that they each lasted exactly 250ms. Auditory stimuli were normalised to the same average RMS amplitude using a custom script written in MATLAB version 7.5.0 (http://www.mathworks.com/products/matlab/). The experimental paradigm itself was written using Neurobehavioural Systems' Presentation software (http://www.neurobs.com/) and presented via a laptop. Auditory stimuli were delivered at around 70db through Sennheiser HD 265 headphones connected to the laptop.

Skin conductance response (SCR) data was collected using SCR equipment built by the Department of Medical Physics, University of Sheffield, based on the configuration detailed in Shastri et al (2001). 8mm diameter Ag / AgCl electrodes were attached to the medial phalange of the index and middle fingers of the participant's non-response hand. Data was sampled at a rate of 20Hz throughout the duration of the behavioural tasks.

Psychometric Assessment

Participants completed the same psychometric tests that were implemented during the signal detection study. These included the Spielberger State-Trait Anxiety Inventory (STAI: Spielberger, et al., 1983) Launay-Slade Hallucination Scale (LSHS - Modified version: Laroi, et al., 2004) and the Schizotypal Personality Questionnaire (SPQ: Raine, 1991) from which the cognitive-perceptual sub-factor (SPQ_CP) was extracted.

Procedure

After reading an information sheet and signing a consent form, the procedure of the study was explained to that participants. Before starting the behavioural tasks, participants were given two questionnaires. The first was a basic demographic questionnaire which contained the Edinburgh Handedness Scale (Oldfield, 1971). The second questionnaire was the STAI. Once the questionnaires were complete the SCR recording equipment was attached to the participant. Participants were then given instructions relating to the crossmodal passive oddball task, before completing a practice run of the task. Having completed the practice block, participants were then started on the task proper. Participants then performed the speech passive oddball task in a similar manner. Once both tasks were complete, the SCR kit was removed and participants were asked to fill in the remaining psychometric measures (SPQ & LSHS) before being debriefed.

Data Analysis

Although the oddball effect (OE) relates to the difference in performance between standard and deviant trials, not all standard trials were included in the data analysis. Standard trials that immediately followed the presentation of the audio-visual stimuli (STDI)[19] were excluded because it

[19] The audio-visual stimuli were only ever followed by standard trials.

was assumed that the interruption of the ongoing task instigated by the appearance of the image would disrupt the expectation relating to the appearance of the standard stimulus. Additionally it was thought wise to remove STDI trials because the enhanced attentional capture that aversive images provoke relative to neutral images (Attar, et al., 2010; Ciesielski, et al., 2010; Most, et al., 2005) was considered likely to confound the effectiveness of the stress manipulation during STDI trials. Standard trials that occurred immediately after deviant trials (STDD) were also excluded from the analyses because, like deviant trails, the STDD trials involve the processing of a perceptual change (vs. the previous trial). This characteristic makes them different from the rest of the standard trials, resulting in increased reaction times when compared to other standard trials (Parmentier & Andres, 2010; Parmentier, et al., 2011). The remaining standard trials (STD) were used in the main analysis.

A 2-way repeated measures ANOVA was performed on the data from the crossmodal task using trial type (STD, DEV) and Stress (stress, non-stress) as the factors. This ANOVA was only performed on data from the sound blocks (i.e. the two blocks involving the silent stimulus were excluded from this analysis). This ANOVA allowed the presence of the oddball effect, and the influence of stress upon it, to be assessed. For the speech oddball task a 3-way repeated measures ANOVA was performed using trial type (STD, DEV), stress (stress, non-stress) and side of presentation (left, right) as the factors. The ANOVAs were performed using both reaction time and error rate as the dependent variable.

Psychometric measures were only regressed against reaction time data. In order to calculate whether the various psychometric measures predicted the oddball effect, each participant's OE was calculated separately by subtracting the reaction time to STD trials from that during DEV trials. These OE values were then regressed against the scores from the relevant psychometric measures. Finally in order to identify whether the self-report measures predicted the impact of stress on the OE, values for the impact of stress on the OE were calculated as per the method used in the signal detection study (see Chapter 2 - Method). To this end values for the OE calculated for the non-stress condition were subtracted from the equivalent value for the stress condition.

Bayesian Analysis

During the data analysis it became evident that employing a Bayesian approach to understand the data further would be advantageous. Orthodox inferential statistics do not enable the interpretation of null results in a satisfactory way, because inferential statistics do not test the plausibility of competing theories; they merely provide the probability that the attained results would occur if the null hypothesis were true. Negative findings attained via inferential statistics cannot therefore be used as evidence against the experimental hypothesis (or in support of the null hypothesis). As an alternative a Bayesian analysis can be applied. The procedure developed by Dienes (2011) was used. This procedure involves calculating a 'Bayes Factor' (BF) that gives the ratio of the probability of the experimental hypothesis being true given the data over the probability of the null hypothesis being true given the data. This Bayes Factor therefore represents a direct contrast of the likelihood of each hypothesis given the data. In general a BF of under 1/3 is considered to be strongly supportive of the null hypothesis, whereas a BF of over 3 supports the experimental hypothesis. Any values in between are taken as being inconclusive. In order to calculate the BF one is required to identify the mean difference between the conditions (i.e. the size of the effect) and the standard error of this effect. The effect evident from the data is then compared to an (estimated) probability distribution of the predicted experimental effect. The results of the previous studies of the impact of emotion on the oddball effect were used to create a probability distribution of the expected effect. As the increase in the oddball effect due to negative emotion has previously been found to be 10ms (Dominguez-Borras, et al., 2008a) and 16ms (Dominguez-Borras, et al., 2009) it was assumed that the experimental effect could be modelled using a normal distribution with a mean of 13ms and a standard deviation of 13/2. No BF was calculated for the error rate data as all previous supporting evidence for ACT from oddball paradigms relates to effects on reaction time rather than error rate[20].

Skin Conductance Response

Skin conductance data was analysed using Ledalab V3.4.1 (www.ledalab.de). The raw SCR data were first smoothed via convolution with a Hann window. The data was subsequently fitted to a bi-exponential Bateman function and then optimised using a conjugated gradient descent algorithm. This pre-processed SCR data was then decomposed into its phasic and tonic components using continuous decomposition analysis (Benedek & Kaernbach, 2010). Two indices of phasic SCR were retrieved from this analysis; an area measure of the phasic SCR response, and a count of the number of individual skin conductance responses (SCRs). Individual responses were identified as those with

[20] A Bayesian analysis was not applied to the negative results in the signal detection study because it was not deemed possible to ascertain meaningful estimates of the predicted effect size. For example a valid predicted effect size could not be generated for the relationship between LSHS/SPQ_CP and response bias because all previous research suggesting that such a relationship might exist was subject to one or more of the following issues a) the effect was acquired using a visual rather than auditory task b) the effect was acquired using different psychometric measures of schizotypy c) the effect was acquired by comparing groups of high/low scorers, rather than through regressions against a representative sample and/or d) the effects were reported in such a way as to make extracting comparable effect sizes impossible.

an amplitude of at least 0.05µS, a threshold which is commonly used when analysing SCR data (e.g. Alexander, et al., 2005)[21]. The skin conductance response for the entire duration of each block (105s) were analysed because what was of interest was not the response to the individual images per se, but the arousal levels throughout the entire period in which the oddball tasks were being performed. SCR data for the periods at the end of each block during which the recognition tasks and the rating scale were administered, were not analysed.

[21] Note that this threshold has no effect on the area measure.

Results

Behavioural performance

Average task performance (% correct) was 88.6% for the crossmodal task and 93.7% for the speech task. Wilcoxon signed-rank tests performed on the stress ratings collected after each block revealed that in both the crossmodal (z=5.25, p<.0001, r=.53) and speech (z=5.07, p<.0001, r=.51) task the stress blocks were rated as more stressful to complete than the neutral blocks. The crossmodal task was also rated as more stressful than the speech task when both aversive (z=5.68, p<.0001, r=.56) and neutral (Z=5.51, p<.0001, r=.57) blocks were compared. Trait anxiety correlated with these valence ratings, with more anxious participants returning higher ratings of stress. This relationship was significant in the speech task (r=.38, p<.01) and approached significance during the crossmodal task (r=.24, p<.1).

Error rates from the recognition task (performed after each block) did not differ between the stress and non-stress blocks. The recognition task error rate was higher during the crossmodal paradigm than the speech paradigm (z=-2.42, p<.05) however across both tasks the error rates were very low (mean of 1.8% and 0.6% for the crossmodal and speech tasks respectively).

Psychometric Measures

The correlations between the different psychometric measures are shown in Figure 12. State anxiety only correlated with trait anxiety (r=.45, p<.01). Trait anxiety significantly predicted SPQ_CP Score (r=.48, p<.01) and LSHS score (r=.35, p<.05). The SPQ_CP and LSHS were also found to be correlated with each other (r=.75, p<.01).

	State Anxiety	Trait Anxiety	SPQ_CP	LSHS
State Anxiety		0.45**	0.08	0.16
Trait Anxiety			0.48**	0.35*
SPQ_CP				0.75**
LSHS				

*Significant at the 0.05 level (2-tailed)
**Significant at the 0.01 level (2-tailed)

Figure 12: Spearman's Rho correlation coefficients between the psychometric measures collected during the first oddball study. Sample size = 50, State and Trait Anxiety relate to the Spielberger State/Trait Inventory, SPQ_CP = Cognitive-perceptual sub-factor of the Schizotypal Personality Questionnaire, LSHS = Launay-Slade Hallucination Proneness Scale.

Crossmodal oddball study

Main Analysis

As the reaction times to the crossmodal oddball study were found to be normally distributed, a 2x2 repeated measures ANOVA was performed on the reaction time data with trial type (Deviant, Standard) and stress (Stress, Non-stress) as factors (Figure 13A.). There was a main effect of trial type (F=47.7, p<.001, r=.7) which reflected the standard oddball effect; reaction time to the deviant trials (DEV) being on average 13ms slower than those to the standard (STD) trials (484ms to 471ms). There was no main effect of stress (p=0.47) and no interaction between trial type and stress (p=0.82).

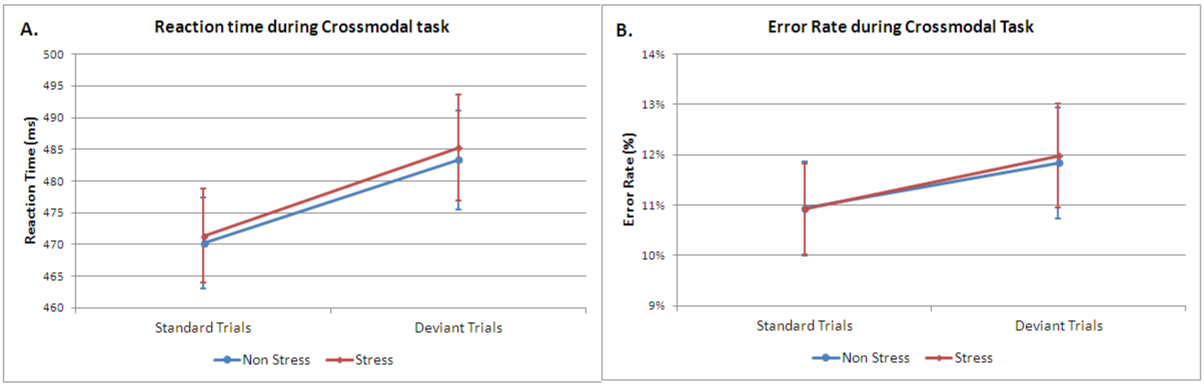

Figure 13: Mean reaction time and error rate during the crossmodal oddball task. A significant main effect of trial type was found, with both reaction time (A) and error rate (B) being higher for deviant compared to standard trials. No main effect of stress or a stress*type interaction was found. Error bars represent the standard error of the mean.

The absence of an interaction between stress and trial type suggests no effect of stress on the oddball effect (OE), thus conflicting with both attentional control theory (ACT) and the results of prior research. A Bayesian analysis was therefore applied to test whether the current data was genuinely supportive of the null hypothesis. To this end the Bayes Factor (BF) calculation developed by Dienes (2011) was used to test the observed difference in the OE between the stress and non-stress conditions against a model of the putative effect size for this contrast (see the data analysis section). The observed mean difference between the OE in the stress and non-stress conditions of 0.77ms (standard error 3.36) provided a BF of 0.12, suggesting that the results can be taken as evidence in support of the null hypothesis.

A 2x2 repeated-measures ANOVA, performed on the error rate from the crossmodal study, also revealed a main effect of trial type (F=4.9, p<.05, r=.3) with the error rate being higher during the deviant trials (12%) compared to the standard trials (11%). Once again no effect of stress, or an interaction between stress and trial type was found (Figure 13B.). As the error rates were found to be non-normal, the main effect of type was re-tested using the Wilcoxon Signed Rank test to identify whether it may be sensitive to the non-normal characteristics of the data. Once again it was found that more errors were made on deviant compared to standard trials ($z=2.0$, $p<.05$, $r=.2$).

Relationship between performance and psychometric measures

The relationship between scores on the psychometric measures and the various metrics from the oddball tasks were assessed using the non-parametric Serlin-Harwell Aligned Rank Procedure (SHARP: Serlin & Harwell, 2004) with the effect of age, gender and stress order (i.e. whether the participant received a stress or non-stress block first) controlled for. None of the psychometric measures predicted the extent of the oddball effect, or the impact of stress upon it.

Speech passive oddball task

Main Analysis

A 3-way ANOVA performed on the reaction time data from the speech oddball task revealed a 3-way interaction between stress, trial type and side of presentation ($F(1,48)=5.11$, $p<.05$). As the interaction between stress and trial type was of primary interest, this 3-way interaction was examined by running separate 2x2 ANOVAs (stress*type) on reaction time for stimuli presented to each ear. This thereby allowed an identification of how the stress*type interaction differed depending on which ear the stimulus was presented in (Figure 14.).

The ANOVA for the left ear revealed a main effect of type ($F(1,48)=163.6$, $p<.001$, $r=.88$) representing the standard oddball effect (OE) with trials involving the deviant stimulus evoking a longer reaction time than those involving the standard stimulus (477ms vs. 417ms). There was also a stress*type interaction ($F=8.66$, $p<.01$, $r=.39$) with the difference between reaction times to the standard and deviant trials being smaller in the stress condition (54ms vs. 66ms). This interaction equates to a reduced oddball effect during the stress condition. The equivalent analysis for the right ear also revealed a similar main effect of type ($F(1,48)=134.3$, $p<.001$, $r=.86$). The main effect of stress was marginally significant ($F(1,48)=4.1$, $P=.05$, $r=.28$) with reaction times being longer in the stress condition (434ms vs. 429ms). Unlike the left ear, there was no interaction between stress and trial type ($F=0$, $p>.05$). The overall stress*type interaction was significant from the 3-way ANOVA ($F(1,48)=4.25$, $p<.05$, $r=.29$) suggesting that the reduced oddball effect under stress evident for left ear stimuli was sufficient to produce an equivalent interaction effect when the data was collapsed across side of presentation.

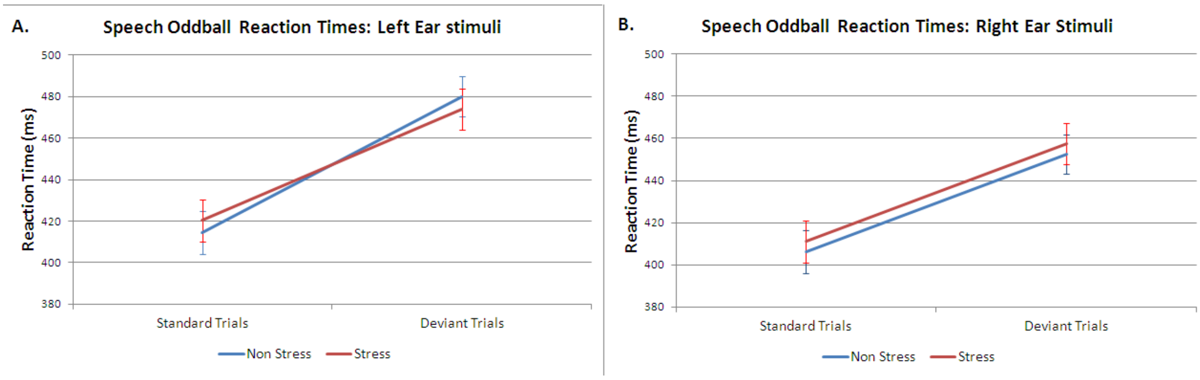

Figure 14: Mean reaction times (ms) during the speech oddball task. The analysis revealed differing results for stimuli delivered to the left (A) and right (B) ears. Errors bars represent the standard error of the mean.

As the reaction times to the standard trials from the speech task were found to differ significantly from the normal distribution using the Shapiro-Wilk test, non-parametric statistics were used to assess whether the positive findings from the ANOVAs might be sensitive to the violations of the assumption of normality. Wilcoxon signed-rank tests revealed that the main effect of type (Dev>Std) was indeed significant in both the left (z=6.1, p<.001, r=.61) and right ears (z=6.0, p<.001, r=.61). A Wilcoxon signed-rank test also confirmed that for the left ear the oddball effect was smaller in the stress compared to non-stress condition (z=2.8, p<.005, r=.29). The main effect of stress found in the right ear was no longer significant when a Wilcoxon signed-rank test was performed (z=1.5, p=.13).

The 3-way ANOVA of error rates during the speech task did not reveal any significant effects.

Relationship between performance and psychometric measures

None of the psychometric measures predicted the extent of the oddball effect during the speech task, or the impact of stress upon the oddball effect. As the impact of stress was only significant for stimuli presented to the left ear, the psychometric measures were also regressed against the impact of stress calculated for just left ear stimuli. This analysis revealed marginally significant relationships between the impact of stress on the left ear oddball effect and both LSHS (X^2=3.7, p=.05, ΔR^2=0.09) and SPQ_CP (X^2=3.1, p<0.1, ΔR^2=0.07). Participants who reported more positive schizotypal experiences demonstrated a larger reduction in the oddball effect under stress.

As the laterality of both behavioural and brain responses appear to be related to handedness (e.g. Hubrich-Ungureanu, et al., 2002; Willems, et al., 2009) we sought to identify (post-hoc) whether the differing effects of stress between stimuli delivered to the left and right ears could be predicted by the handedness of the individual. To this end interaction terms for the effect of stress in both left and right ears were calculated (by subtracting the oddball effect for the non-stress condition from that for the stress condition). Handedness was then regressed against the difference in this interaction term between the left and the right ear, controlling for the full interaction term (i.e. the impact of stress on the oddball effect calculated regardless of the side of presentation)[22]. Handedness was found to predict the laterality of the stress*type interaction, with less right handed participants displaying a smaller difference between the two ears (X^2=4.35, p<.05, ΔR^2 = .1, Figure 15.).

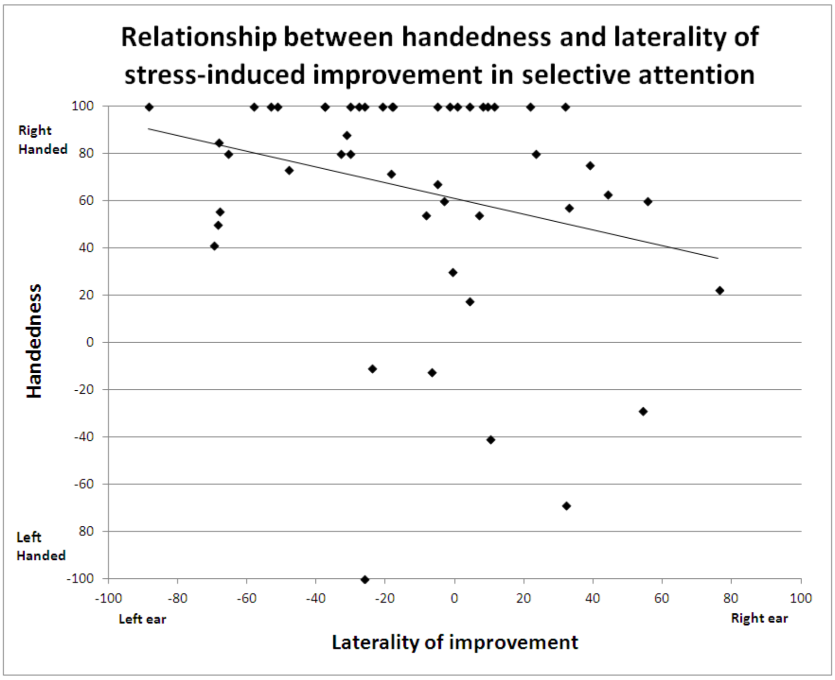

Figure 15: Relationship between handedness and the difference in the stress-induced reduction in the oddball effect between ears during the speech oddball task. More negative values on the x-axis indicate that stress produced a greater reduction in the oddball effect to left ear stimuli than to right ear stimuli. Handedness was measured using the Edinburgh Handedness Scale.

Skin Conductance Data

SCR data was collected from 43 participants during the crossmodal oddball task and 44 participants during the speech task. For the crossmodal task the area SCR value was significantly greater in the stress blocks (z=2.56, p<.01, r=.28) as was the count of the number of SCRs (z=2.34, p<.05, r=.25). There was no significant difference between the stress and non-stress blocks in either of the SCR

[22] Laterality differences are usually calculated using the formula (L-R)/(L+R) with the denominator controlling for overall performance. It was not possible to use this formula in the current design as the dependent variable (in this case the impact of stress on the oddball effect) can be negative, a characteristic that renders the aforementioned formula inaccurate. To counter this the overall interaction term (effectively L+R) was used as a controlling variable in the regression.

measures acquired during the speech task. Figure 16 shows both SCR measures for each oddball task. Given that self-report stress ratings were found to be larger for the crossmodal task, average SCR response per block was compared across the two tasks. Blocks of the crossmodal task produced on average a greater number of SCRs ($z=4.93$, $p<.01$, $r=.78$) and a greater phasic response ($z=3.3$, $p<.01$, $r=.53$) than the speech task[23].

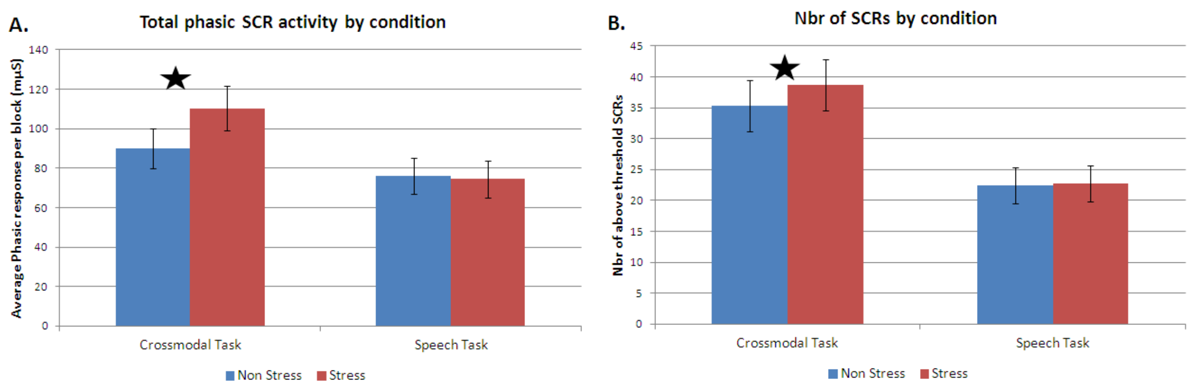

Figure 16: SCR measures for both the crossmodal and speech oddball tasks. The total phasic (area) measure (A) represents the area under the curve of the SCR signal during the period when the oddball task was ongoing. The count measure (B) is the number of individual SCRs during the task which passed a threshold of 0.05µS. Crossmodal data is only shown for the sound blocks. Asterisks signify significant differences between Stress and Non Stress blocks at p <.05. Error bars represent the standard error of the mean.

[23] The SCR data from the crossmodal blocks which involved the silent standard stimulus were excluded from all the SCR analyses. This allowed the data from the crossmodal and speech tasks to be compared, since it meant that each task had the same number of blocks, with each block involving similar levels of auditory stimulation.

Discussion

Participants performed two passive auditory oddball tasks requiring them to focus their (goal-directed) attention away from the occasionally changing content of a repeatedly-presented speech stimulus. In such paradigms the increase in reaction time during trials where the deviant oddball stimuli is presented is known as the 'oddball effect'. The oddball effect represents an index of the balance between goal-directed and stimulus-driven attention because the appearance of the deviant represents the sort of salient change in the sensory environment which the stimulus-driven system is designed to detect. The level of psychological stress was varied during each task, allowing an assessment of the impact of stress on the relative balance between goal-directed and stimulus driven attention. During the crossmodal passive oddball task, where the distracting stimuli preceded the task, stress had no impact on the oddball effect. Bayesian analysis further revealed that this negative finding could be taken as evidence in favour of the null hypothesis. In the speech passive oddball task, where the distracting information occurred at the same time as the goal directed task, stress served to reduce the oddball effect, although only for stimuli presented in the left ear. This reduced oddball effect equates to an increased ability to selectively focus on task-relevant elements of left-ear stimuli under stress, and therefore a reduced influence of stimulus-driven attention. The differing influence of stress in the left compared to right ear during the speech oddball task was predicted by the handedness of the individual, with more right-handed participants showing a larger difference in the stress effect between left ear and right ear stimuli.

Previous crossmodal oddball studies

The absence of an impact of stress on the oddball effect in the crossmodal study conflicts with the findings of Dominguez-Borras et al (2008a; 2009) who demonstrated, using a similar crossmodal passive oddball paradigm, that the oddball effect increased during a condition involving emotionally negative visual stimulus. In the Dominguez-Borras studies emotion was varied via the content of the task stimulus, which contained emotional content in one condition and neutral content in the other. In contrast emotion was manipulated independently of the task stimulus in the current study, with the task stimuli always being emotionally neutral. It could therefore be argued that the increased oddball effect found by Dominguez-Borras et al may not have been caused an alteration in emotional state, but instead by a difference in task demands. Indeed it could be argued that there may have been little or no variance in emotion between the conditions used in the Dominguez-Borras studies, as the participant's attention was directed away from the emotional content of the task-stimulus in their studies. Furthermore Dominguez-Borras et al did not provide any evidence that the participants experienced differences in emotion between the conditions. They did demonstrate, via neuroimaging indices, that the emotional task stimuli evoked greater processing in sensory areas of the brain than the neutral task stimuli. This finding may however simply reflect the greater distraction caused by emotional stimuli (e.g. Hodsoll, et al., 2011) rather than an emotional response to the task stimulus. In contrast during the current study participants were required to attend to the content of the images used in the manipulation of emotion. Furthermore self-report ratings and (in the crossmodal task) measures of skin conductance response (SCR) suggested that the emotion manipulation was successful in increasing the participant's experience of stress.

If the results of Dominguez-Borras et al (2008a; 2009) are not due to changes in emotional state, what might they be due to? The oddball effect that arises during crossmodal passive oddball tasks is due to the salience of the deviant stimulus evoking an increased delay in switching attention back towards the goal-directed task (SanMiguel, et al., 2010). It is possible that this delay might have more of a behavioural effect when greater attentional control is required during the goal-directed task itself (which was presumably the case in the negative emotion condition when the task required emotional information to be ignored). Alternatively the increased distraction generated by the emotional task images might have provoked a more generalized vulnerability to distracting information, thus causing an increased processing of the subsequent deviant auditory stimulus, and therefore an increased oddball effect. In effect the requirement to ignore salient, task-irrelevant information in one stimulus might briefly exhaust attentional resources, thus reducing the participant's ability to inhibit processing of distracting information in a subsequent stimulus regardless of the emotional content of either. On this point it is interesting to note that the same group found equivalent results (i.e. increased reaction to deviant stimuli in the 'negative emotion' condition) when the emotional content of the task stimulus was manipulated on a trial-by-trial basis rather than in blocks (Dominguez-Borras, et al., 2008b). This suggests that the effect is transient, and therefore reliant specifically on the characteristics of the immediate task stimulus, rather than a more sustained change in emotional context.

Attentional Control Theory

The effect of stress on passive oddball task performance was assessed primarily to test the predictions of attentional control theory (ACT: Eysenck, et al., 2007). ACT suggests that anxiety and stress alter the balance between the stimulus-driven and goal-directed attentional systems such that the stimulus-driven system becomes relatively stronger at the expense of the goal-directed system. During a passive oddball paradigm this change should result in the deviant stimulus (which evokes stimulus-driven attention) creating a greater distraction during stressful conditions. Stress was therefore predicted to increase the oddball effect during both tasks. However in the current study a systematic manipulation of stress did not increase the oddball effect in either task. ACT also predicts that highly anxious participants should exhibit a larger oddball effect than participants with low anxiety, as anxiety is associated with a difficulty in inhibiting task-irrelevant information (Eysenck & Derakshan, 2011). However self-report anxiety did not predict the size of the oddball effect a participant demonstrated, or the impact of the systematic manipulation of stress upon this oddball effect, during either task. Together these results contradict the prediction from ACT that stress and anxiety increase the reaction of the stimulus-driven attentional system to emotionally neutral sounds. These results also contradict the associated prediction that goal-directed auditory perception is disrupted during stress. It must therefore be concluded that, as with the signal detection study, the current study has not provided any evidence in support of ACT in relation to the perception of emotionally neutral auditory stimuli.

How might the failure to support the predictions of ACT during the current project be interpreted? Unlike the results from the signal detection task, the absence of evidence supporting ACT during the current study cannot be attributed to an absence of stimuli which attract stimulus-driven attention, or to a failure to measure processing efficiency. ACT proposes that the enhancement in stimulus-driven attention due to anxiety is greatest when the distracting stimuli are threat-related (Eysenck, et al., 2007). Indeed the majority of studies that have found enhanced stimulus-driven processing during anxiety have used emotional distracters. Although there is evidence that the attention towards emotionally neutral distracters also increases under stress (Moser, et al., 2012; Pacheco-Unguetti, et al., 2010) there are several examples of failures to find this effect (e.g. Caparos & Linnell, 2012; Osinsky, et al., 2012; Stelton & Ferraro, 2008) despite the possibility of a publication bias towards positive results. It could therefore be concluded that the stress induced enhancement of stimulus-driven attention (and the associated disruption of goal-directed attention) only applies when threat-related distracters are present.

An alternative explanation for the fact that findings in favour of ACT are most common when emotional stimuli are used is that differences in the processing of neutral distracters between anxious and non-anxious individuals (or between stress and non-stress conditions) might be more sensitive to task characteristics than the differences in processing of affective distracters. One task characteristic that might explain the absence of evidence in favour of ACT during the current study is the use of auditory distracters. The past research demonstrating that ACT can be applied to the perception of emotionally neutral stimuli has used visual stimuli. It could therefore be concluded that the impact of stress on the reaction to emotionally neutral distracters differs between the visual and auditory modalities. One argument against concluding that ACT doesn't apply to the perception of emotional neutral sounds is the existence of neuroimaging evidence which shows that stress causes an increased neural reaction to task-irrelevant emotionally neutral sounds (Cornwell, et al., 2007; Elling, et al., 2011)[24]. Interpreting these studies as supporting the predictions of ACT relies however on the assumption that increased neural processing is indicative of increased attention. As discussed in Chapter 1, there is some evidence that stress may enhance the neural response to all auditory stimuli, regardless of the focus of attention. The finding of greater neural response to emotionally neutral auditory distracters under stress may not therefore be indicative of increased stimulus-driven processing.

A further criticism of studies showing increased neural response to auditory distracters under stress it that they have not included a demanding task from which the oddball stimuli are supposed to distract. Cornwell et al (2007) did not require their participants to perform any task, while Elling et al (2011) just required participants to perform a silent counting task. It is therefore possible that an increased proneness to distraction by emotionally neutral stimuli under stress (as suggested by the neuroimaging indices used in these papers) might only manifest when there are little or no demands on goal-directed attention. While this explanation may have an intuitive appeal, there is in fact evidence that the opposite might be true. Both Sato et al (2012) and Sadeh & Bredemeier (2011) found that participants only became more distractible under stress when the demands of the goal-directed task (as manipulated via perceptual load) were increased. These results are explained by proposing that as tasks with greater perceptual load place greater demands on attention, it is more likely that stress-related deficits in attentional control will appear (Sadeh & Bredemeier, 2011). This may also explain why much of the evidence in favour of ACT comes from studies using goal-directed tasks which require more complex cognitive functions such as working memory or reading comprehension. It could therefore be argued that basic perception (as tested during the tasks presented in this thesis) may be less vulnerable to the disruptive effects of stress predicted by ACT than more demanding cognitive functions.

As regards the absence of any effects relating to differences in self-report anxiety, it is worth noting

[24] The Dominguez-Borras studies that also show an increased neural response to emotionally neutral auditory distracters are not included in this discussion due to the (previously discussed) concerns of the methodology used in these studies.

that the participants in the current study reported reasonably modest levels of anxiety (trait anxiety quartile range 33 – 49). It is therefore possible that a relationship between anxiety and task performance might become evident when individuals with extreme anxiety scores are considered.

Goal-shielding theory

During the speech oddball task, where the distracting information was present within the task stimulus itself, stress was found to reduce the oddball effect. The participant's reaction time tended to increase less in response to the deviant stimulus during the stress condition. This result appears analogous with findings from the Stroop paradigm, where the cost to reaction time caused by the incongruent, task-irrelevant, content of a word is reduced when the task is performed in stressful circumstances (Booth & Sharma, 2009; Chajut & Algom, 2003; Hu, et al., 2012). The current findings therefore lend support to the goal-shielding theory, which suggest that a decrease in perceptual resources under stress reduces the processing of task-irrelevant information, thus improving selective attention. The current study extends previous findings supporting this theory to a different type of distracter (based on stimulus probability rather than inherent incongruence) and a different modality (auditory rather than visual). This result also supports the conclusion arising from the signal detection study that, contrary to the prediction discussed in Chapter 1, stress does not disrupt goal-directed auditory attention.

The reduction in the oddball effect found during the speech task was only significant for stimuli presented in the left ear (although the interaction between stress and trial type remained significant when the side of presentation was ignored). Interestingly handedness was found to predict the extent of the difference between left and right ear stimuli, with participants who reported being more right handed showing a larger difference in stress effect between the left and right ears. As the initial cortical processing of auditory information largely occurs in the hemisphere contralateral to input, and as handedness is related to the laterality of brain responses (e.g. Hubrich-Ungureanu, et al., 2002; Willems, et al., 2009) the results of the speech oddball task suggest that the goal-shielding effect was only evident for stimulus processed largely in the right auditory cortex. An effect localised to the right auditory cortex suggest a right-hemisphere stress mechanism, a conclusion which coincides with the large amount of evidence in favour of the idea that strong negative emotions such as stress are predominately processed in the right hemisphere (Demaree, et al., 2005; Gainotti, 2012). However it is not clear why this putative right brain process was unable to produce any noticeable effect for auditory stimuli processed in the left auditory cortex. It is possible that the ease of the task resulted in the relevant perceptual processing being completed in the left auditory cortex before signals from any right-brain stress mechanism could have an impact. Indeed responses were generally quicker to right ear/left hemisphere stimuli[25], possibly due to left-hemisphere's dominant involvement in the processing of speech information.

The goal-shielding theory of stress fits into wider explanations of the impact of stress on cognition. The stress response generates neurochemical changes in the brain which impair functioning within prefrontal regions (Arnsten, 2009). The behavioural consequences of this impairment are widespread. In addition to a reduction in attentional capacity they also include reduced working memory capacity, a switch from flexible to habitual behavioural responses and reduced top-down control over attention. It is worth noting that the loss of cognitive control during stress results in an inability to flexibly allocate the more limited attentional resources in a context relevant manner (Plessow, et al., 2011). The goal-shielding effect which results from stress is therefore implemented regardless of its overall utility. In selective attention tasks where the nature of the task-relevant and task-irrelevant information is certain (such as the speech oddball task and the Stroop task) this strategy serves to improve performance because no cognitive flexibility is required to ignore the same task-irrelevant information on each trial. In contrast during selective attention tasks where the characteristics of the task-relevant and task-irrelevant information are uncertain, stress reduces performance. For example when participants perform a dual-task paradigm, the goal-shielding effect of stress reduces performance because information that is relevant to the second task is (mal-adaptively) shielded to protect processing on the first task (Plessow, et al., 2012). Likewise stress will reduce performance in single task paradigms if the nature of the task-relevant information in not known to the participant before each trial. For example Gable & Harmon-Jones (2010) asked participants to identify whether a stimulus contained an 'T' or an 'H' using Navon letters (a large letter constructed using many identical smaller letters, for example a H made from many L's). As the participants did not know whether the target letter would appear as the large or small letter, an inflexible focus on one area of the stimuli would not prove adaptive. Gable & Harmon-Jones found that the presentation of disgusting images (compared to the neutral images) caused an increase in reaction time, but only when the target was the large letter. This suggests that stress was causing participants to inflexibly focus on the small letter, even though such an approach would not always be adaptive. It is interesting to note that with Navon letters reaction time is general quicker for the large letter, because it is easier to identify. The increased focus on the small letter under stress

[25] The 3-way ANOVA for the speech task reaction times revealed a main effect of side of presentation, with reaction times to left ear stimuli being slower than to right ear stimuli (447ms vs. 432ms, $F(1,48)=23.3$, $p<.01$).

perhaps suggests that in situations of task-uncertainty the brain tend to focus stress-limited attentional resources on the part of the task which is most demanding. This may occur because the cognitive control required to switch attention to the inhibited large letter is less than would be required to switch attention towards the small letter.

It is worth considering whether the goal-shielding theory can explain why the impact of stress differed between the crossmodal and speech tasks. During selective attention tasks such as the speech task, the distracting and task-relevant information are in direct competition, thus task performance is presumably dependent on the amount of processing that can be directed toward the task stimulus whilst the distraction is being delivered. In contrast during the crossmodal task the oddball effect is due to the delay that the deviant stimulus (relative to the standard) evokes in switching attention back of the task stimulus (SanMiguel, et al., 2010). Thus while the reduced attentional capacity under stress predicted by goal-shielding theory may cause less processing of distracting information during selective attention, it might not have much of an effect when the distracter and task stimuli are perceived in series (as in such circumstances there is no competition between the two stimuli for the reduced processing resources). Although this explanation fits with the current data, it should be noted that during the speech task the distracting information was not only presented at the same time as the task stimuli, but also within the same modality and indeed within the same stimulus. In contrast during the crossmodal oddball task the distracting information was presented as part of a different stimulus in a different modality to the task stimulus. As there are multiple differences in the relationship between the task-relevant and task-irrelevant information across the two oddball tasks, one cannot say for certain that it is the temporal relationship between task and distracter that is responsible for the differences seen in the impact of stress on performance.

Relevance to Auditory Hallucinations

The motivation for using the passive oddball paradigm to test whether ACT can be applied to the perception of emotionally neutral auditory stimuli was to determine a cognitive basis for the impact of stress on proneness to auditory hallucinations (AH). It was postulated that an increased reactivity to changes in the auditory environment under stress might be mal-adaptively applied (in hallucination-prone individuals) to internal signals, thus causing those internal signals to be mistakenly identified as arising from an external source. It was also postulated that the disruption in goal-directed auditory attention predicted by ACT to occur under stress might reduce the ability of hallucination-prone individuals to distinguish between internal and external auditory signals, thus also encouraging AH. Given the failure to find any support for the predictions of ACT during both the current study, and the signal detection study, it must be concluded that these theories do not represent plausible explanations of how stress might encourage auditory hallucinations.

The potential explanations for the impact of stress on hallucination-proneness described in Chapter 1 conceptualise AH as being, in effect, the result of distractions from normal auditory processing. This conceptualisation may not however be valid, as it assumes that the processing of external stimuli is the goal of perception during periods when an individual is hallucinating. It has been proposed that those who hallucinate regularly may 'listen out' for their voices, if only unconsciously (Ford, et al., 2009; Hoffman, 2010). A related idea is that psychotic individuals may hold cognitive biases that promote the tendency to focus inwards onto the self (and therefore towards internal signals) and that such tendencies are crucial in determining the experience of positive psychotic symptoms (Wells, 2007). It could therefore be argued that AH occur not because the sensory consequence of internal signals attract goal-directed attention, but because various top-down factors cause goal-directed attention to be focused inwards, towards the internal signals from which auditory hallucinations arise, *before* the hallucinations occur.

If AH tend to occur when attention is already focussed internally, how might stress act to encourage hallucinations? It could be posited that stress may itself encourage attention to be focussed inwards, thus making hallucination more likely in individuals who have source monitoring deficits (Waters, Woodward, et al., 2012). Certainly real-life stressors tend to encourage internal 'perseverative cognitions' such as worry and rumination, which in turn generate prolonged stress responses (Brosschot, et al., 2005) and therefore presumably prolonged periods of focussing on (internal) thoughts. Likewise there is recent evidence that individuals experiencing stress are more self-focussed than those who are not experiencing stress (Deiters, et al., 2013). Once attention is directed towards internal signals, the goal-shielding effect may allow stress to encourage hallucinations in another way. The goal-shielding effect should improve focus on attended-to internal signals by reducing the processing of other competing signals and any neural noise that may also be present. This increased focus would serve to enhance the perceptual impact of those internal signals which are the focus of attention, potentially making them more likely to be misperceived as external. In situations where no internal signals are present, stress may encourage the perceptual system to focus on the elements of the internal auditory milieu that most resemble a meaningful signal. Thus when the 'goal' of the perceptual system is to detect and analyse internal auditory signals, stress may make it more likely that searched-for internal signals are perceived by reducing the processing of competing information. The relevance of the goal-shielding effect to the impact of stress on hallucination-proneness is supported by the fact that both measures of positive schizotypy predicted (at $p<.1$) the size of the goal-shielding effect towards left-ear stimuli (i.e. those stimuli for which the goal-shielding effect was evident). More schizotypal participants showed a greater goal-shielding effect than less schizotypal participants, suggesting that stress serves to focus auditory attention to a greater extent in those who are prone to hallucination-like symptoms.

What sort of competing information might stress be able to shield the processing of internal signals from? As all perceptual processing occurs in the context of at least some neural noise, it is likely that stress may be able to attenuate the interference which this noise might cause. Here an analogy can be drawn with the results of the signal detection task, potentially allowing goal-shielding theory to provide a cognitive explanation for the response bias effect of stress found during the signal detection study. When the terminology of selective attention is applied to the signal detection task the speech sounds can be considered as being the task-relevant information and the white noise can be considered task-irrelevant information. According to goal-shielding theory stress should cause an increased focus onto the task relevant information (i.e. the speech). During signal trials, when the target stimulus contains speech, this effect should serve to improve the ability to detect the speech signal (and therefore improve hit rate) as there should be an improved focus onto the traces of the speech stimulus that are identifiable from within the white noise. However during noise trials, where no speech signal exists, the goal-shielding effect might cause the perceptual system to focus on the aspects of the noise that appear most like the participant's internal representation of how the searched-for speech should sound. This might lure the participant into occasionally reporting a stimulus that is not in fact present, causing an increased false positive rate. This may explain the bias towards positive responding seen in highly anxious individuals under stress during the signal detection task. It may further explain why those vulnerable to hallucinations are more likely to hallucinate when they are experiencing psychological stress.

An additional way that the goal-shielding effect of stress may serve to encourage AH is by protecting the processing of internal signals from interference posed by external sounds. As auditory hallucinations rarely occur in complete silence, one would normally expect that the presence of genuine external stimuli would be able to distract from any ongoing hallucinations. Indeed training sufferers to flexibly direct their auditory attention away from their (hallucinated) voices does appear to ameliorate the severity of AH (Valmaggia, et al., 2007). If, when attention is focussed internally, the goal-shielding impact of stress were to reduce the processing of (unattended) external sounds, this might explain why AH tend to occur when the sufferer is stressed. It should be noted however that, as with the speech oddball task, previous results supporting the goal-shielding theory have tended to involve measuring the response to task-irrelevant information that occurs within the stimulus the participant is attending to. These studies do not therefore necessarily support the assertion that stress might serve to reduce the processing of external sounds when attention is focussed internally, since external sounds are by their nature spatially separate from internal signals. A demonstration that the same goal-shielding effect occurs when the distracting information resides in a different stimulus to the one being attended to would be required to support the assertion that stress might protect hallucinatory processing from interference generated by external sounds.

Relationship between performance and measures of positive schizotypy

Self-report measures of positive schizotypy did not predict the size of the oddball effect in either task. As with the signal detection study, the random sample used in the current study may have resulted in few participants demonstrating extreme scores on the psychometric measures[26]. This leaves open the possibility that differences in oddball performance might appear when participants demonstrating a wider variance in schizotypy are examined. Alternatively, as discussed in the study introduction, an increased susceptibility to distraction may be a consequence of psychosis, rather than a pre-cursor. Thus one should not expect to find a larger oddball effect in healthy individuals who show schizotypal traits. Indeed differences in susceptibility to distraction have not always been found when high/low schizotypy groups have been contrasted (Stelton & Ferraro, 2008). There also appears to be no demonstrations of different MMN amplitudes between high/low schizotypy groups.

Conclusion

The results of two passive oddball studies provided no support for the hypothesis, inspired by ACT, that psychological stress increases the ability of emotionally neutral information to distract attention away from an ongoing task. The applicability of ACT towards the perception of emotional neutral sounds, and therefore its use in explaining the impact of stress on proneness to auditory hallucinations, is therefore questionable. The results of this study instead suggested that during selective attention stress may function to reduce the processing of distracting information. This ‘goal-shielding’ effect may contribute to generation of AH, although further research is required before the relevance of the effect to AH can be established.

[26] The quartile range was 11 (2 – 13) for the SPQ_CP and 19 for the LSHS (6 – 25)

Chapter 4

Introduction

The oddball study detailed in Chapter 3 was designed to test two related hypotheses arising from attentional control theory (ACT: Eysenck, et al., 2007). ACT predicts that stress should act to both disrupt goal-directed auditory attention and enhance stimulus-driven auditory attention. It was thought that these predicted effects might act as a basis for explaining why psychological stress appears to encourage auditory hallucinations (AH) in those vulnerable to them. However as with the signal detection study (Chapter 2) no evidence was found during the oddball study to suggest that the predictions arising from ACT apply to the perception of emotionally neutral auditory stimuli. The results presented in this thesis so far do not therefore support the theories designed to explain the effect of psychological stress on AH that were proposed in Chapter 1.

The results of the oddball study suggested that stress increases the ability of participants to selectively attend towards task-relevant aspects of the auditory environment. This improvement of selective attention under stress is referred to as the goal-shielding effect. An alternative explanation for the effect of stress on hallucination-proneness, which utilises the goal-shielding effect, was put forward in Chapter 3. Although there is a significant literature in support of the goal-shielding theory (see Chajut & Algom, 2003 for a review) this evidence originates largely from studies testing either visual perception, or cognitive faculties that are predominately non-perceptual (e.g. decision making). The application of the goal-shielding effect to auditory perception is therefore not supported by a substantial research literature. This lack of research makes it difficult to assess how (if at all) the goal-shielding effect might apply to the generation of AH, as the parameters of the effect (i.e. in what situations it occurs) as regards auditory perception are largely unknown. A further study into the effects of psychological stress on auditory selective attention was therefore conducted.

Laterality of goal-shielding effect

One question that arises from the results of the speech passive oddball task detailed in Chapter 3 relates to the reason for the laterality of the effect. Improved selective attention during the stress condition was only found to be significant for stimulus presented to the left ear. This result can be explained with reference to past research suggesting that the right hemisphere controls the processing of negative affective material (Demaree, et al., 2005). As the processing of left ear stimuli also predominately takes place in the right hemisphere it is plausible that any neural effects of stress might impact the processing of left ear stimuli earlier than the processing of right ear (left hemisphere) stimuli. It follows that during a relatively simple perceptual task that can be completed quickly, stress might only have a noticeably effect on the perception of left ear stimuli. Alternatively as the processing of speech is generally thought to be lateralised to the left hemisphere (although see Hickok & Poeppel, 2007) it could be argued that the left-sided effect found during the speech task might be an artefact of the lateralised processing of the speech stimuli used in the task. For example it may be that the distracting speech content was processed more quickly for right ear/left hemisphere stimuli, thereby preventing stress from having a significant effect on such processing regardless of any cortical lateralisation of the stress response. The veracity of these competing explanations can be tested relatively simply, by repeating the previous speech oddball task using an auditory stimulus that is not associated with preferential processing in the left hemisphere. If the left-sided effect found previously is genuinely a reflection of right-brain affective processing then it should occur regardless of the type of auditory stimulus used during the task. In contrast if the left-ear lateralisation of the goal-shielding effect is an artefact of the laterality of speech processing, then it should not be evident when non-speech stimuli are used.

Location of distraction

Another issue which arose from the discussion of the goal-shielding effect in Chapter 3 concerns whether the effect extends to protecting task processing from interference which occurs outside the task stimulus. The distraction that occurs during the speech task, and during the Stroop and Navon Letter tasks that have also been used to demonstrate the goal-shielding effect, relies on task-irrelevant changes that occur within the task stimulus itself. There are few demonstrations that the goal-shielding effect also applies when the distraction occurs separately from the task stimulus, and those studies that do exist relate to visual perception (e.g. Lazar, et al., 2012; Sato, et al., 2012). It cannot therefore be concluded that the auditory goal-shielding effect might provide a way in which stress could reduce the processing of external sounds during periods of hallucination, since such an effect would require stress to be able to attenuate the influence of auditory information that occurs in a separate location to the focus of attention.

Impact of perceptual load on the goal-shielding effect

The results of Sato et al (2012) highlight a further issue concerning the goal-shielding effect that is of relevance to the discussion of AH. Sato et al used a visual search task where participants had to report the presence of a particular letter from within a circle of letters. Distraction came from the placement of (task-irrelevant) target letters outside the circle. Sato et al only found a goal-shielding effect of stress at low 'perceptual load', when the task involved just one letter being presented in the circle. When the task was repeated at a higher perceptual load (e.g. when the circle contained 5 letters, rather than just 1) stress increased the amount of interference caused by the distracting letter, in line with the predictions of ACT (Eysenck, et al., 2007). This suggests that perceptual load (defined as the amount of perceptual information that is processed during a task) may alter how stress impacts on selective attention. The influence of perceptual load is of relevance to the discussion of AH as there is evidence that increasing what might be termed auditory 'load' (e.g. by listening to music or talking out loud) can serve to attenuate AH in some patients (Hayashi, et al., 2007; Nayani & David, 1996). It is possible that this attenuation might occur partly because the increased load reduces the ability of stress to enhance attention towards hallucinatory content.

Task Design

In order to understand the reason for the laterality of the goal-shielding effect found in the previous oddball study, it was decided to repeat the speech oddball task using tones differing in frequency as the oddball stimulus instead of speech. As frequency discrimination is not considered to be lateralised to the left hemisphere (Mathiak, et al., 2002) this 'tone oddball' task allows a test of the contrasting explanations put forward for the laterality of the findings from the speech oddball task. Importantly, this task also provides an opportunity to replicate the goal-shielding effect as regards auditory selective attention, potentially providing confirmation that the original effect was not due to chance.

How the goal-shielding effect is influenced by both perceptual load and the location of distracting information can be assessed by adapting the speech oddball task so that two separate streams of speech are presented, one in each ear (e.g. a male voice in one ear and a female voice in the other). During this 'dichotic' oddball task both streams of speech would be delivered in an oddball pattern. However the participant would only be required to respond to one of the streams (the male voice) by indicating in which ear it appears. As with the speech oddball task, this task requires the participant to ignore the speech content (i.e. the characteristic of the speech stimulus which varies in an oddball pattern). Deviants that occur within the male voice (herein referred to as 'internal deviants', which cause an 'internal oddball effect') are therefore equivalent to the deviant stimuli which appeared during the speech oddball task. However they occur in the context of a higher perceptual load (because of the presence of auditory stimuli in the other ear). An analysis of the impact of stress on this internal oddball effect therefore allows a test as to whether the goal-shielding effect is maintained at a higher perceptual load. Deviant stimuli that occur within the female voice (herein referred to as 'external deviants', which cause an 'external oddball effect') relate to distraction occurring at a different location to the attended, task stimulus. An analysis of the impact of stress on the external oddball effect therefore allows a test of whether stress also reduces the influence of task-irrelevant information that occurs at a different location to the focus of attention. It should be noted that in this design the external oddball effect reflects an alteration of both perceptual load and distracter location when compared to the oddball effect produced by the original speech task. Nevertheless as the internal oddball effect reflects only a manipulation of perceptual load compared to the original speech task, a comparison between the external and internal oddball effects should allow the impact of the location of the distracting information on the goal-shielding effect to be isolated.

During both tasks stress was manipulated in an identical way to that used in the previous oddball study (Chapter 3). Measures of skin-conductance were again recorded in order to ascertain physiological confirmation of the effectiveness of the stress manipulation, as such confirmation was only partly successful during the previous oddball study. Self-report measures of anxiety and positive schizotypy were again included to identify whether they would predict the size of the oddball effects, or the impact of stress upon them.

Summary of hypotheses

Two further passive oddball studies were conducted in order to test the parameters of the goal-shielding effect of stress on auditory perception found during Chapter 3. The tone oddball task involved a replication of the speech task from Chapter 3, but using tonal rather than speech stimuli. Given the results of the speech task, it was hypothesised that during the tone task:

- Stress would reduce the oddball effect only for stimuli presented in the left ear.
- Levels of positive schizotypy would positively predict the reduction in the left-ear oddball effect due to stress (higher positive schizotypy = greater reduction due to stress).
- Trait anxiety would *not* predict the size of the oddball effect.
- Trait anxiety would *not* predict the impact of stress on the oddball effect.

The dichotic oddball task involved two streams of speech oddball stimuli, one in a male voice and the other in a female voice, being presented simultaneously in opposite ears. Participants were required to report the ear in which the male voice was presented. This presence of deviants in the male voice allowed a test of whether the reduction of the oddball effect under stress is maintained at a higher level of perceptual load. The presence of deviants in the female voice allowed the paradigm to also test whether stress can attenuate the processing of task-irrelevant information that occurs in a different location to the focus of attention.

Method

Participants

48 participants (29 female, mean age 25, σ=8.4) recruited mainly from the staff and student population of the University of Sheffield, took part in the study. This sample size being deemed sufficient based on the same power calculation performed for the previous oddball study (Chapter 3). Data for one participant was excluded from the dichotic task due to a high error rate. All participants were naive to the hypotheses of the study. Participants reporting difficulties with hearing or vision, or a current diagnosis for a psychiatric disorder, were excluded from the study. The study received ethical approval from the University of Sheffield Medical School Research Ethics Committee.

Task Design

The study involved two separate tasks that bore close resemblance to the speech oddball task detailed in Chapter 3. The main differences in task design were as follows:

1. The block design was altered so that each block involved 100 oddball trials, alongside 9 presentations of the audio-visual stimulus (i.e. the stressor). The overall length of each block was 148s. Each block of the speech oddball task had involved 76 oddball trials and 6 audio-visual stimuli, and had lasted 129s.

2. Only two different auditory stimuli were used within the oddball train for each task, one acting as the standard and the other acting as the deviant. A consequence of this design change is that only one stimulus acts as the deviant at any one time whereas in the previous oddball study 3 different deviants were employed. However piloting revealed that the use of just one deviant did not reduce the size of the oddball effect. The use of just two oddball stimuli (rather than 4) removed the necessity of having 8 blocks of each task.

3. The lures in the recognition task (i.e. the images that had not been presented in the preceding block) were always images that were not presented elsewhere in the study. This was in contrast to the speech oddball task where some lures were images that had been previously used within the crossmodal task.

Unless otherwise stated (below) all other aspects of the task design, such as the counterbalancing of stress vs. non-stress blocks, the positioning of the standard and deviant stimuli and the distribution of stay and switch responses were maintained from the design of the previous oddball tasks.

Tone oddball task

Notwithstanding the alterations mentioned above, this task was identical to the speech passive oddball task described in Chapter 3 with the exception that tonal rather than speech stimuli were used. Participants had to indicate in which ear a 250ms tonal stimulus had been presented (Figure 17.). Tones with frequencies of 300 Hz and 1200Hz respectively were used during the task. Participants completed 4 blocks of this task, 2 non-stress and 2 stress blocks with each tone appearing as the standard (and the other as the deviant) in one non-stress and one stress block. The order of block presentation was counterbalanced between participants so that an equal number of participants experienced each of these four block types in each position (1st – 4th).

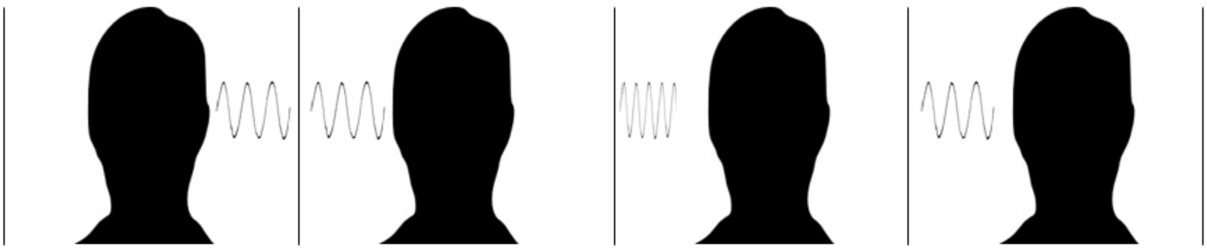

Figure 17: Graphical illustration of the tone oddball task. Participants had to respond as to which side a tonal stimuli was delivered while ignoring task-irrelevant changes in the pitch of the tone which were introduced by delivering the tones in an oddball pattern. Each tone lasted 250ms and each trial lasted 1250ms (inclusive of the tone presentation).

Dichotic oddball task

This task was again conceptually similar to the speech oddball task detailed in Chapter 3. Participants again had to report the ear in which a male voice was presented. However instead of being presented in isolation, a female voice was presented at the same time as the male voice, but in the opposite ear. The task therefore becomes one of dichotic listening, with the participant required to ignore the female voice and respond only to the male voice (Figure 18.). Both the male and female voices were presented in an oddball pattern, using the words ‘So’ and ‘Do’. The result of this stimulus arrangement is to produce two different sets of deviants, leading to two separate oddball effects. The ‘internal deviants’ were those which occurred in the to-be attended male voice. The ‘external deviants’ were those which occurred in the to-be ignored female voice. Standard trials were taken to be those that involve neither deviant. As regards the pseudo-randomisation of the oddball stimuli, both the internal and external deviants were treated as being equivalent to the deviants in the previous oddball study. For example at least 2 standard trials were presented between each deviant, regardless of the type of deviant involved. Likewise the number of stay and switch responses required for each deviant type was balanced.

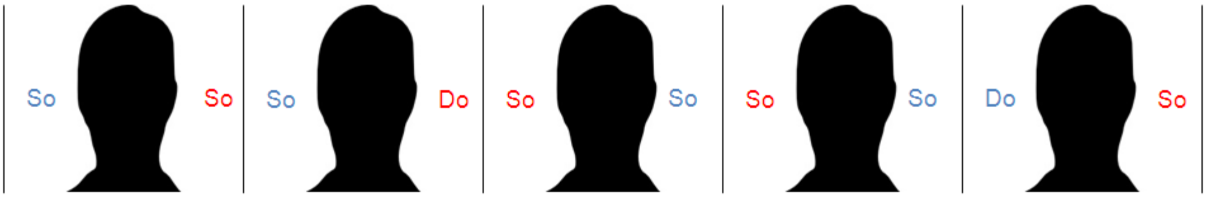

Figure 18: Graphical illustration of the dichotic oddball task. On each trial participants were presented with a male (blue font) and female (red font) voice, each appearing in different ears. Participants were required to report the side the male voice was presented while ignoring task-irrelevant changes in the content of the speech which could occur in either voice. Each speech sound lasted 250ms and each trial lasted 1250ms.

Participants completed 8 blocks of the dichotic task, 4 stress and 4 non-stress blocks. The 4 blocks presented for each emotional condition involved each of the 4 possible combinations of the speech sounds across the two voices (Figure 19.). This allowed half the blocks to have the same word acting as the standard for both voices (e.g. A and C from Figure 19.) while the other half had different words acting as the standard for the two voices (B & D). Such an arrangement was deemed preferable because it removed any differences in stimulus congruence (two different words being presented rather than one) from the overall contrast of standard and deviant trials[27]. A design utilising an entirely different set of words for the male and female voices (e.g. 'So' and 'Do' for Male, 'He' and 'My' for female) was rejected because piloting revealed that it encouraged the participant to track the word spoken rather than the gender of the voice[28].

[27] A design where standard trials always involve the same word for each gender complicates the oddball effect because the deviant trials (whether external or internal) would inevitably have to always involve two different words being presented, whereas the standard trials would always involve just one word being presented. The difference in stimulus congruence between the standard and deviant trials might therefore contribute to the oddball effect, making it conceptually different from the distraction that the deviant stimuli evoke during the speech oddball task.

[28] The presentation of blocks was arranged so that the blocks where the male and female voice shared the same word as the standard always preceded blocks where the standard trials involved different words being spoken between the male and female voices (e.g. from Figure 19, A always preceded B and C always preceded D). This arrangement encouraged participants to discriminate on gender rather than word content, as blocks A and C (Figure 19) make it impossible to identify the male voice based on word content.

Ref	Male standard	Female standard
A	So	So
B	So	Do
C	Do	Do
D	Do	So

Figure 19: The four different arrangements of standard stimuli during the dichotic task. The deviant for each voice was always the other word (e.g. 'Do' when the standard is 'So').

Stimuli and Apparatus

The images and spoken sentences used for the audio-visual stimulus were identical to those detailed in Chapter 3. A complete list of images and associated sentences are given in Appendix 5. 18 images that did not appear within the audio-visual stimulus were used as lures for the recognition task. These additional images were again sourced either from the IAPS database, or the internet.

The male and female speech stimuli (used during the dichotic study) were recorded in a neutral tone using the Audacity software, version 1.3.13 (http://audacity.sourceforge.net/). They were edited such that the waveform for each word was similar across the male and female voices (Appendix 9.). Audacity was also used to create the two tones used during the tone oddball task. Both the tone and speech oddball stimuli were edited to last 250ms and were normalised to the same average RMS amplitude using a custom script written in MATLAB version 7.5.0 (http://www.mathworks.com/products/matlab/). The experimental paradigm was written using Neurobehavioural Systems' Presentation software (http://www.neurobs.com/) and presented via a laptop. Auditory stimuli were delivered at around 70db through Sennheiser HD 265 headphones connected to the laptop.

Skin conductance response (SCR) data was collected using an identical method to that previously described in Chapter 3.

Psychometric Assessment

Participants completed the same psychometric tests required for the previous two studies.

Procedure

After reading an information sheet and signing a consent form, the procedure of the study was explained to that participants. Before starting the behavioural tasks, participants were given two questionnaires. The first was a basic demographic questionnaire which contained the Edinburgh Handedness Scale (Oldfield, 1971). The second questionnaire was the Spielberger State-Trait Anxiety Inventory (STAI: Spielberger, et al., 1983). Once these questionnaires had been completed the SCR recording equipment was attached. Participants were then given instructions relating to the general structure of the tasks, before being given the specific instructions for the task they would complete first. Specific instructions for the second task were delivered after the first task had been completed. Each task was preceded by a short ‘practice’ version of the task which utilised different stimuli to those presented in the task proper. Whether participants performed the tone or dichotic task first was counterbalanced between participants[29]. Once both tasks were complete, the SCR kit was removed and participants were asked to fill in the Launay-Slade Hallucination Scale (LSHS:Laroi, et al., 2004) and the Schizotypal Personality Questionnaire (SPQ: Raine, 1991).

Data Analysis

As with the previous oddball study, standard trials that immediately followed the presentation of the audio-visual stimuli (STDI) and standard trials that occurred immediately after deviant trials (STDD) were removed from the analysis. In the dichotic task STDD were removed regardless of the ‘type’ of deviant (internal or external) that preceded it. A 3-way repeated measures ANOVA were performed on the data from both tasks, using trial type (Tone: standard, deviant / Dichotic: standard, internal deviant, external deviant), Stress (stress, non-stress) and side of presentation (left, right) as factors. As there were three levels to the trial type factor in the dichotic task the Greenhouse-Geisser correction was used for any contrasts where Mauchly’s test indicated that the assumption of sphericity had been violated. Each ANOVA was performed using both reaction time and error rate as the dependent variable.

In order to calculate whether the various psychometric measures predicted the oddball effect (OE) each participant’s OE was calculated separately by subtracting the reaction time to STD trials from that during DEV Trials. The ‘internal oddball effect’ from the dichotic task was calculated by subtracting the data for standard trials from that for internal deviant trails. Likewise the ‘external oddball effect’ was calculated by subtracting data for the standard trials from the external deviant trials. These OE values were then regressed against the scores from the relevant psychometric measures. In order to identify whether anxiety predicted the effect of stress on the oddball effects, each OE was calculated separately for the stress and non-stress conditions, and then the difference

[29] Unlike the previous oddball study there was no concern regarding the task stimulus from one task being used as distracters in the other task, since the two tasks utilised different oddball stimuli.

between the two was regressed against the relevant psychometric measure, as per the previous oddball study. Finally the measure of handedness (EHI) was regressed against the 3-way interaction term from the tone oddball task, in an attempt to replicate the finding from the equivalent analysis during the speech oddball task. Unless otherwise stated psychometric measures were only regressed against reaction time data using, as before, the SHARP Procedure (Serlin & Harwell, 2004) with age, gender and block order (i.e. whether the participant experienced a stress or non-stress block first) controlled for.

The skin conductance data was analysed in an identical way to that described in Chapter 3. Bayesian analysis was also applied where appropriate, using the same method as described in Chapter 3.

Results

Behavioural performance

Overall task performance (% correct) was 96% for the tone task and 86% for the dichotic task. The stress blocks were rated as more stressful than the non-stress blocks for both the tone (Z=-5.6, p<.001, r=.57) and dichotic (z=5.53, p<.001, r=.56) tasks. The blocks of the dichotic task were also rated as being more stressful than the blocks of the tone task (z=4.58, p<.001, r=.47). Trait anxiety positively correlated with these stress ratings such that more anxious participants rated both the tone task (r=.25, p=.09) and the dichotic task (r=.33, p<.05) as being more stressful than less anxious participants.

The error rates for the recognition task at the end of each block were very low (tone task = 2%, dichotic task = 1%) thus confirming that participants attend to the audiovisual stimuli of which the stress manipulation comprised.

Psychometric Measures

The relationship between the various psychometric measures, calculated using Spearman's Rank Correlation Co-efficient, are shown in Figure 20. SPQ_CP correlated with Trait Anxiety (r=.32, p<.05) LSHS (r=.47, p<.01) and state anxiety (r=.29, p<.05). State and trait anxiety were also strongly correlated (r=.54, p<.01).

	State Anxiety	Trait Anxiety	SPQ_CP	LSHS
State Anxiety		0.54**	0.29*	0.11
Trait Anxiety			0.32*	0.14
SPQ_CP				0.47**
LSHS				

*Significant at the 0.05 level (2-tailed)
**Significant at the 0.01 level (2-tailed)

Figure 20: Spearman's Rho Correlation Coefficients between the psychometric measures used in the second oddball study. Sample size = 48, State and Trait Anxiety relate to the Spielberger State/Trait Inventory, SPQ_CP = Cognitive-perceptual sub-factor of the Schizotypal Personality Questionnaire, LSHS = Launay-Slade Hallucination Proneness Scale.

Tone Oddball Task

Main Analysis

The 3-way ANOVA performed on the reaction time data, with stress (Stress, Non-stress) trial type (standard, deviant) and side (left, right) as factors, only revealed a significant main effect of trial type. Reaction times were slower for deviant trials reflecting the standard oddball effect (F(1,47)=202, p<.001, r=.9). Neither the three-way interaction (F(1,47)=1.3, p=0.26) or the two-way stress*type interaction (F(1,47)=2.3, p=.13) reached significance. However inspection of the data (Figure 21.) revealed a similar trend to that seen in the speech oddball task (Chapter 3) with a reduction in the oddball effect evident in the stress condition for left ear stimuli. Indeed 2-way ANOVAs, run separately for each ear, revealed that in addition to the main effect of type, there was a marginal type*stress interaction in the left ear (F(1,47)=3.7, p=.06, r=.27) whereas there was no such interaction in the right ear (F(1,47)=.35, p=.85).

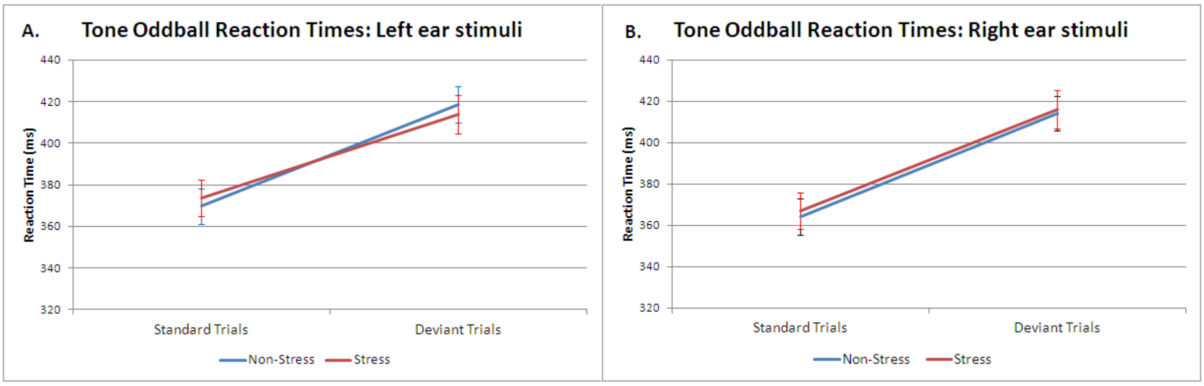

Figure 21: Reaction times during the Tone Oddball task for both left and right ear stimuli. Error bars represent the standard error of the mean.

Given the failure to find the expected 3-way interaction using inferential statistics, a Bayesian analysis was conducted to assess which of the experimental and null hypotheses were more likely to be correct given the data. The 12ms mean interaction term from the speech oddball task (the impact of stress on the oddball effect in the left – right ear) was taken as the putative effect size for this analysis. The probability distribution of this effect was modelled on a Gaussian distribution with a standard deviation equal to half the mean (i.e. 6). The mean (7.7ms) and standard error (6.7) of the interaction term from the tone oddball task was then contrasted against this probability distribution. This analysis returned a Bayes Factor (BF) of 1.29, which is usually taken to be inconclusive. Nevertheless as the Bayes factor is the ratio of the probability of getting the data given the experimental hypothesis over the probability of getting the data given the null hypothesis, it can be concluded that the tone oddball data is more in favour of the experimental hypothesis (as the BF is greater than 1).

No significant effects were found when the 3-way ANOVA was repeated on the error rate data.

Relationship between performance and psychometric measures

The measures of positive schizotypy (LSHS and SPQ_CP) failed to significantly predict the size of the oddball effect demonstrated during the tone oddball task. State Anxiety was found to marginally predict the size of the oddball effect, with participants who displayed higher anxiety showing a reduced oddball effect (X^2=3.5, p=.06, ΔR^2=.1: Figure 22a.). The relationship was in the same direction for Trait anxiety, but did not approach statistical significance (p=.26). None of the psychometric measures predicted the effect of stress on the oddball effect. The measures of positive schizotypy were additionally regressed against the effect of stress on the left ear stimuli only, so as to replicate the analysis performed during the speech oddball task. No significant relationship was found, although the data was in a similar direction to that found in the speech oddball task (SPQ_CP: p=.4, LSHS: p=.2, larger reduction in the oddball effect under stress in those with higher schizotypy). An analysis of the (non-significant) difference in the stress effect between the left and right ears did not reveal a relationship with the handedness of the participant.

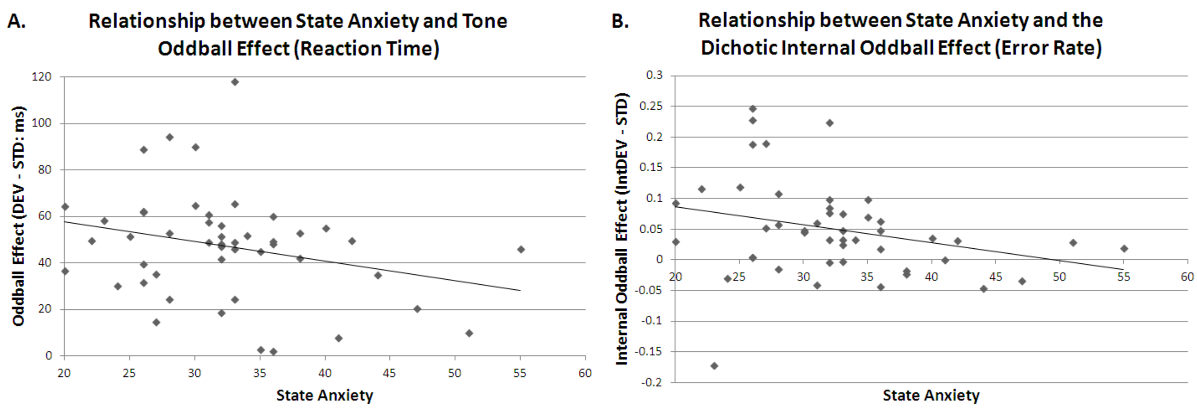

Figure 22: Negative relationship between state anxiety and the size of the oddball effect during the tone and dichotic oddball tasks. A relationship between state anxiety and the oddball effect was evident during (A) the tone oddball task when reaction times were analysed (i.e. reaction time to deviant trials – reaction time to standard trials) and (B) in the internal oddball effect calculated using error rate during the dichotic task (i.e. error rate to internal deviants trials – error rate to standard trials).

Dichotic Oddball Task

Main Analysis

The three-way ANOVA of the reaction time data from the Dichotic task revealed the expected main effect of trial type. Both the internal (F(1,46)=246, p<.001, r=.9) and external (F(1,46)=173, p<.001, r=.9) deviants induced an increase in reaction time compared to the standard trials. There was however no significant difference in reaction time between the two types of deviant. The other main effects and interactions were not found to be significant (Figure 23.). The impact of stress on the internal OE was however in the same direction as that predicted by the results of the speech task (i.e. smaller oddball effect in the stress condition for left ear stimuli). In order to assess what this data might reveal about the applicability of the goal-shielding effect at high perceptual load, a Bayesian analysis was applied to the interaction term describing the difference in the impact of stress on the internal oddball effect between the left and right ears[30]. This analysis was performed in the same style as described for the tone oddball task. The relevant interaction term for the dichotic task was 6.3ms, with a standard error of 11.7. When this interaction term was compared against the putative effect size distribution (as calculated from the speech oddball task) a BF of 0.94 was returned. The data can therefore be considered inconclusive, although the Bayes Factor does suggest that the data marginally favours the null hypothesis.

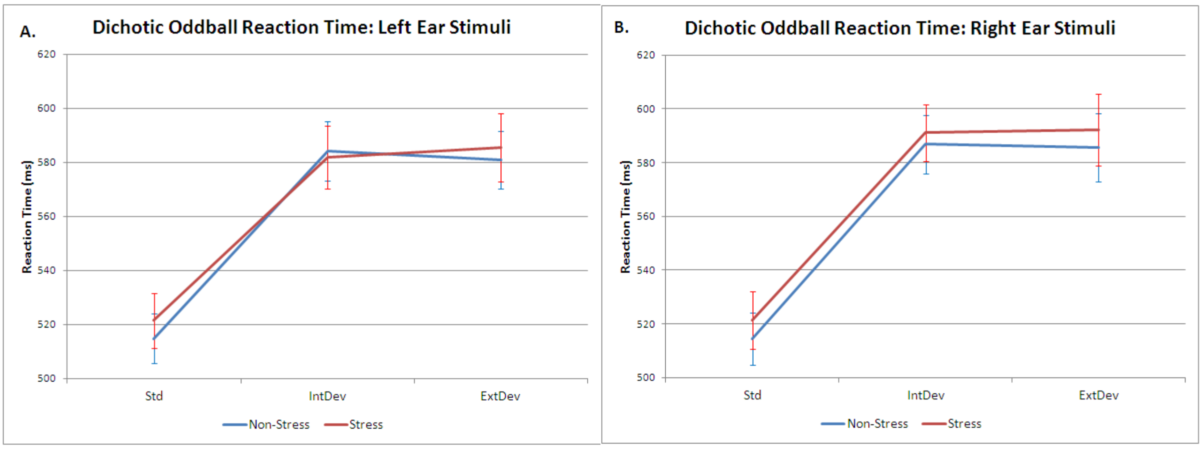

Figure 23: Reaction times during the dichotic oddball task. Data is shown for trials where the target stimulus (male voice) was presented in the left (A) and right (B) ears. Error bars represent the standard error of the mean.

The ANOVA performed on the error rates during the dichotic task (Figure 24.) revealed a similar main effect of trial type to that shown by the reaction time data, with there being an increase in error rate during both internal ($F(1,46)=18.9$, $p<.001$, $r=.53$) and external ($F(1,46)=34.3$, $p<.001$, $r=.65$) deviants trials when compared to the standard trials. Although there was no 3-way interaction, there was a stress*type interaction ($F(1.7,76.8)=3.6$, $p<.05$, $r=.21$) and a type*side interaction ($F(2,92)=4.4$, $p<.05$, $r=.21$). A simple effects analysis revealed that the stress*type interaction was caused by a greater error rate in the stress condition, which occurred only during the internal deviant trials ($F(1,46)=5.9$, $p<.05$, $r=.34$). This interaction generated a marginal main effect

[30] The external oddball effect was not assessed in this way as the external deviants from the dichotic task have no equivalent in the original speech task, and therefore a putative effect size cannot be validly calculated.

of stress from the 3-way ANOVA ($F(1,46)=3.3$, $p=.07$, $r=.26$). The type*side interaction was driven by the presence of more errors for right ear stimuli but only during internal deviant trials ($F(1,46)=8.0$, $p<.01$, $r=.38$).

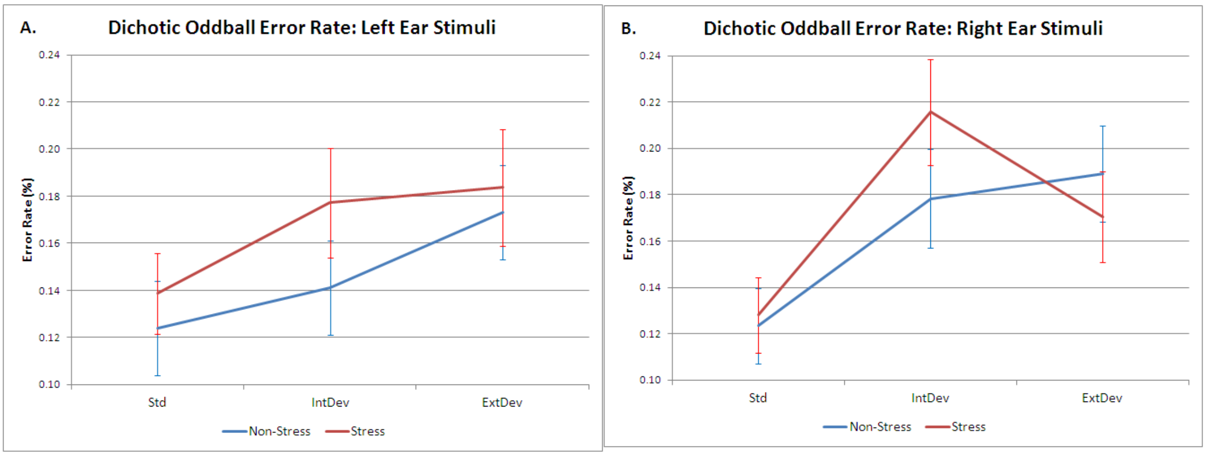

Figure 24: Error rates during the dichotic oddball task. Error rates are shown for trials where the target stimulus (male voice) was presented in the left (A) and right (B) ears. Error bars represent the standard error of the mean

Relationship between performance and psychometric measures

No significant relationships were found between the psychometric measures and the size of the oddball effects or the effect of stress upon them, when these metric were calculated using the reaction time data. Given the significant effects found within the ANOVA of the error rate data, the psychometric measures were additionally regressed against a metric of the internal oddball effect calculated using error rate. State Anxiety negatively predicted the internal oddball effect for error rate, with more anxious participants demonstrating a smaller difference in errors between internal deviant and standard trials ($X^2=5.2$, $p<.05$, $\Delta R^2=.1$: Figure 22b.). No other psychometric measure predicted the internal oddball effect for error rate, or the impact of stress upon it.

Skin Conductance Data

SCR data was analysed separately for each task (Figure 25.). SCR recordings were taken from 46 participants, although the data for one participant during the tone task was missing due to an equipment malfunction. For the tone oddball task the number of SCRs was significantly larger during the stress blocks ($z=2.10$, $p<.05$, $r=.23$). The area SCR value was also larger in the stress condition, although this difference did not reach significance ($p=.14$). For the dichotic task the difference between the number of SCRs in the stress and non-stress conditions approached (2-tailed) significance ($z=1.68$, $p<.1$, $r=.18$). The same comparison for the area SCR value was found to be statistically significant (z=2.3, p<.05, r=.24).

As the dichotic task was rated as being significantly more stressful than the tone task, the average SCR response per block was compared across the two tasks. No significant differences were found between the two tasks using either SCR measure.

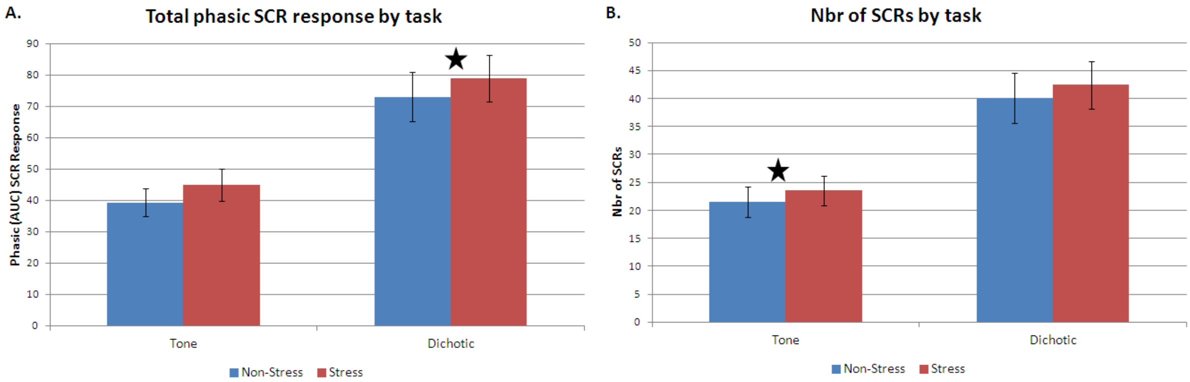

Figure 25: Skin Conductance response data collected during the tone and dichotic oddball tasks. Starred comparisons are those which are significant at the p<.05 level (2-tailed). Note that the dichotic values are higher in general because the dichotic task was longer than the tone task. Error bars represent the standard error of the mean.

Discussion

Participants performed two passive auditory oddball tasks. During the tone oddball task participants had to report the side that a monaural tonal stimulus was presented, while ignoring task-irrelevant changes in the pitch of the tone. During the dichotic oddball task participants were presented with a male voice in one ear and a female voice in the other. Participants were required to report the side of the presentation for the male voice, while ignoring task-irrelevant changes in speech content that could occur in either of the voices. Distraction was quantified via the oddball effect, the increase in reaction time occurring during trials involving an unexpected, task-irrelevant, change in stimulus content. The level of psychological stress was manipulated in both tasks through the occasional appearance, between auditory trails, of either aversive or neutral audio-visual stimuli. Stress did not have a statistically significant impact on performance during the tone task, although the direction of the data did point in support of the hypothesis that there would be a reduction in the oddball effect to left-ear stimuli in the stress condition. Stress did however have a statistically significant effect on the error rates during the dichotic task, with errors becoming more frequent in the stress condition, although only significantly so during trials where a task-irrelevant change occurred within the task stimulus. State Anxiety negatively predicted the size of the oddball effect in both tasks.

Tone Oddball Task

The results of the speech oddball task were not fully replicated during the tone task, as neither the 3-way stress*type*side, or the 2-way stress*type interaction reached statistical significance. However, when the data was split by side of presentation a marginal stress*type interaction was evident for the left ear stimuli, showing the predicted reduced oddball effect under stress. Also as predicted, there was no evidence of a similar interaction for the right ear stimuli. A Bayesian analysis of the 3-way interaction term revealed that the data could not be taken as supporting the null hypothesis, and in fact revealed that there was a higher likelihood of the data occurring in a situation where the experimental hypothesis was correct. In short, it seems reasonable to conclude that the 'goal-shielding' effect found during the speech task is genuine.

Although the laterality of the goal-shielding effect of stress found in the speech oddball task (left > right ear) was maintained during the tone task, there was no evidence that this laterality was related to handedness. This is in contrast to the results of the speech task, where more right-handed participants were found to show a greater difference in stress effect between stimuli presented in the left and right ears. It may be that the relationship with handedness found during the speech task was a consequence of the laterality of speech processing, rather than of the effect of stress, hence its absence during the tone task. As the number of participants reporting being strongly left-handed was low in both studies, a design comparing identically sized groups of left and right-handed individuals might have more statistical power to determine the influence that handedness has on the laterality of the auditory goal-shielding effect.

Despite the absence of a relationship with handedness in the current study, the left ear laterality of the goal-shielding effect evident in both the tone and speech oddball tasks does suggest that this effect is driven by a right brain stress mechanism. Right brain processing relating to stress would presumably impact on auditory processing in the right auditory cortex (which is largely dedicated to input from the left ear) before that in the left auditory cortex. Thus it can be inferred that the left-ear laterality of the auditory goal-shielding effect, which occurs regardless of the type of auditory stimuli being perceived, is likely to be a consequence of a predominately right sided stress response. However as behavioural responses represent an indirect measure of the neural location of cognitive functions, this conclusion would benefit from confirmation via neuroimaging techniques.

Auditory hallucinations are often considered to be a result of erroneous activation arising in the left auditory cortex (Hugdahl, et al., 2012; Hugdahl, et al., 2008). One might therefore expect that if an effect of stress were to have any consequence for proneness to AH, it should be demonstrable in the left auditory cortex. In contrast the goal-shielding effects found within the current project have been noticeable only for sounds presented in the left ear, sounds which are predominately processed by the right auditory cortex. However the failure to demonstrate a goal-shielding effect towards right ear stimuli during the current project does not necessarily indicate a restriction of the effect to the right auditory cortex. It is likely that a task involving more sustained auditory processing would enable any right hemisphere stress processing to also affect auditory processing occurring in the left auditory cortex. An absence of an effect for right ear stimuli during simple, monaural tasks should not therefore be too dissuasive as regards the applicability of the goal-shielding effect to the understanding of AH. Even if the goal-shielding effect of stress was restricted to the right auditory cortex, it might still have some explanatory power in terms of the generation of AH. There is for example evidence that the right temporal cortices may be both overactive in hallucinating individuals (Woodruff, et al., 1997) and activated during the experience of hallucinations (Kompus, et al., 2011). Indeed there is a great deal of evidence that speech processing is less left-lateralised in those with schizophrenia (Alary, et al., 2013). This rightward shift in speech processing might allow a predominately right-sided stress effect more opportunity to generate AH in clinical populations, thus explaining the greater negative effect of stress on hallucinatory symptomatology in psychotic populations. Alternatively there is also evidence that the activation of right auditory cortex during AH might be related to the emotional content of the hallucination (Sommer, et al., 2008). A stress-induced alteration that is largely restricted to the auditory signals processed in the right auditory cortex may therefore explain the preponderance of threatening material within the content of AH.

The finding from the speech oddball task, that the left-ear goal-shielding effect was predicted by measures of positive schizotypy, was not replicated during the tone-oddball task. As these effects during the speech task were only significant at $p<.1$, this failure to replicate them raises doubts as to whether the goal-shielding effect is genuinely greater in those healthy individuals who are prone to experiences that are analogous to the positive symptoms of psychosis. Further research, perhaps comparing groups with high and low levels of positive schizotypy, might be required to provide more definitive evidence on this topic.

State anxiety negatively predicted the size of the oddball effect during the tone oddball task, such that more anxious participants demonstrated a smaller increase in reaction time due to the appearance of deviant stimuli. This is the opposite to what would be predicted by attentional control theory (ACT: Eysenck, et al., 2007) which assumes that more anxious individuals are more sensitive to distracting information. Instead this result appears to lend further support to the goal-shielding theory, which predicts that the more stress an individual experiences, the less attentional resources they have available to process task-irrelevant information. Thus those higher in state anxiety would commit less processing towards the change in stimulation represented by the appearance of the deviant stimuli, than those in a lesser state of anxiety. It could be argued that this relationship between anxiety and the size of the oddball effect may be spurious given that (across the entire thesis) a number of comparisons between oddball effect sizes and anxiety have been conducted. However a similar significant negative correlation between state anxiety and the size of the oddball effect was also found during the dichotic task (albeit for error rate, rather than reaction time). Furthermore inspection of the data from the previous oddball study (Chapter 3) reveals that in both tasks state anxiety also negatively correlated with the respective oddball effects, although in neither case did this correlation reach statistical significance ($r=-.13$, $p=.37$ for the crossmodal task and $r=-.17$, $p=.25$ for the speech task). As with the impact of the stress manipulation, there does therefore seem to be some evidence that the state of anxiety[31] functions to reduce the impact that changes in

[31] Note that it is the *state* rather than trait anxiety measure which is related to the size of the oddball effect. Thus the effect discussed is more closely related to situational changes in stress (such as the stress manipulation used in these tasks) rather to than dispositional differences in anxiety.

task-irrelevant sensory information has on performance.

Dichotic Oddball Task

The dichotic task was designed to assess two forms of distraction. In some trials, labelled internal deviants, a task-irrelevant change occurred within the speech stimulus to which the participant was required to attend. In other trials, labelled external deviants, the task-irrelevant change occurred in the speech sound which the participant was required to ignore.

The internal deviant trials can be considered equivalent to the deviant trials in the speech and tone oddball tasks, in as much as the distracting information arises from within the task stimulus (as with the stroop task, e.g. Chajut & Algom., 2003). The difference between the distraction measured during the speech oddball task and that from the internal deviants during the dichotic task was the presence of a separate stream of stimulus in the opposite ear to the task stimulus during the dichotic task. This difference was assumed to produce an increase in the perceptual load during the dichotic task when compared to the speech task, as the participant was effectively exposed to twice the level of auditory stimulation during the dichotic task (thus making the manipulation equivalent to alterations of perceptual load in visual tasks e.g. Sato, et al., 2012). The reduction in the oddball effect under stress that was evident (at a lower load) during the speech oddball task was not found to be significant when the reaction times to the dichotic task were analysed, although once again the data was in the expected direction with a reduced oddball effect under stress in the left ear and no noticeable effect in the right ear. A Bayesian analysis however suggested that this effect was slightly more likely to have occurred if the null hypothesis were true than if the experimental hypothesis were true.

A different picture emerged when the dichotic task error rate data was analysed. A significant interaction between trial type and stress was found, with participants demonstrating significantly more errors in the stress condition compared to the non-stress condition, but only during internal deviant trials. In contrast to the (non-significant) differences seen in the reaction time data, this suggests that stress acts to increase the impact of task-irrelevant changes in stimulation on task performance at higher levels of perceptual load. Previous studies of visual selective attention have also found that selective attention performance can deteriorate under stress during tasks with higher levels of perceptual load (Sadeh & Bredemeier, 2011; Sato, et al., 2012). There therefore seems to be some evidence that the goal-shielding effect is vulnerable to the presence of a high level of stimulation in the modality where task processing is occurring. If the goal-shielding effect of stress is responsible for encouraging AH, this suggests that increasing the ‘load’ on the auditory perceptual mechanism might help negate this effect. This interpretation would fit with the use of increased exposure to external auditory stimuli as a coping technique for AH. For example listening to music or talking out loud are methods often used by sufferers to attenuate their auditory hallucinations (Hayashi, et al., 2007; Nayani & David, 1996) although the success of these methods may rely more on the ability of the external sound to attract attention away from the hallucination, rather than in dampening any effect of stress. The results relating to the internal oddball effect also suggest that ACT may indeed apply to the perception of emotionally neutral auditory stimuli, but only during tasks involving a high perceptual load.

There are a few caveats that need to be placed on the conclusion that the goal-shielding effect of stress is removed at higher levels of perceptual load. Firstly the conclusion that stress enhances distractibility at high load runs appears to run counter to the finding that participants who reported higher state anxiety exhibited a smaller internal oddball effect (on error rate) during the dichotic task. It could however be argued that as individuals experiencing greater stress tend to shield task processing more, this effect may be disrupted to a lesser extent by increased load in such individuals. Hence a disruption of the goal-shielding effect by increased perceptual load, and a positive relationship between experienced anxiety levels and the size of the goal-shielding effect during a high load task are not necessarily contradictory findings.

More problematic for the conclusion that the goal-shielding effect disappears at high perceptual loads is the finding that while this effect was evident in the error rate data, the reaction time data actually pointed in the opposite direction (albeit to a non-significant extent). The goal-shielding effects evident during the speech and tone tasks were both found in relation to reaction times rather than error rates. One might therefore expect that any effect found using error rates during the dichotic task should be evident to at least the same extent in the reaction time data. However the error rates during the speech and tone oddball tasks were so low that even the standard oddball effect (signified by a main effect of type) was absent. Therefore it could be argued that a ceiling effect may have prevented stress from having any noticeable impact on error rate during these simpler passive oddball tasks. The presence of this ceiling effect makes it difficult to draw any conclusions about the different relative effects of stress on reaction time and error rate between the passive oddball tasks described in this thesis. Nonetheless the absence of anything approaching an equivalent effect on reaction time does raise doubts about whether the error rate finding during the dichotic task is caused by the same processes that produced the goal-shielding effects seen in the other oddball tasks. Further research is therefore needed in order to understand exactly how perceptual load influences the goal-shielding effect.

During the dichotic task the external deviants appeared within the auditory stream which the participants were asked to ignore. These deviant stimuli were included to test whether the improvement in selective attention under stress found during the original speech oddball task also applies when the distracting information occurs at a different location to that which is the focus of attention. However as the original speech task occurred at a lower level of perceptual load than the dichotic task, the impact of stress on the external oddball effect can only validly be compared to the impact of stress on internal oddball effect (as a comparison with the impact of stress on the oddball effect in the speech task would represent a variation in both perceptual load and deviant location). Unfortunately the failure to replicate the goal-shielding effect for internal deviants complicates the interpretation of the findings regarding external deviants. While stress increased the (error rate) oddball effect for internal deviants, it had no such impact on the external oddball effect, whether measured using reaction time or error rate. This data could be used to argue that the impact of perceptual load on the goal-shielding effect is lessened when the distracting information occurs in a separate stimulus to that being attended to. This might in turn suggest that, were perceptual load lower, the goal-shielding effect would be maintained for distracters which occur outside the task stimulus. However this conclusion remains speculative in the absence of a demonstration that the goal-shielding effect is applicable to distracting information which occurs at a different location from the task stimulus. It follows that the theory that the goal-shielding effect may contribute to AH by attenuating the processing of external sounds during periods of hallucinations is also as yet unsupported.

Effectiveness of stress manipulation

The SCR data collected during the previous oddball study (Chapter 3) provided some evidence to suggest that the stress manipulation used was capable of producing a physiological increase in arousal. However as the increase in SCR response under stress was only significant for one of the two tasks performed during that study this evidence was not conclusive. The SCR data from the current study provides additional support for the effectiveness of the stress manipulation. At least one of the two SCR indicators was significantly higher in the stress condition during both tasks, with the data for the other SCR indicator in each task also being strongly suggestive of the stress manipulation having the desired effect.

Distinction between task difficulty and stress

The self-report ratings of stress, taken at the end of each block, suggested that many participants found the dichotic task more stressful than the tone task (although this increase in reported stress was not evident in the comparison of the SCR response across the two tasks). During the oddball study detailed in Chapter 3 the crossmodal task was rated as more stressful than the speech task, a difference that was also evident from the SCR data. In both cases the more difficult task (as determined by the general error rate) was rated as being more stressful. Under the assumption that an increased perceptual load is inevitably going to increase the difficulty of a task, this finding raises the question as to whether the effects of perceptual load seen in the current study are really due to a separate mechanism to stress, or whether perceptual load is just an indirect way of generating a stress effect via task difficulty. Indeed in many behavioural studies stress is manipulated via the difficulty of cognitive tasks (e.g. Siegwarth, et al., 2012). It could therefore be argued that by manipulating stress and load one may in fact be altering the level of one psychological dimension rather than two. The apparent reversal of the goal-shielding effect of stress at high loads could therefore be argued to simply reflect the effect of stress on selective attention being distributed in a way that is analogous to the Yerkes-Dodson law, with the combined manipulation of emotion and difficulty allowing ‘stress’ to reach a point where its influence on performance becomes detrimental rather than advantageous[32]. The applicability of the Yerkes-Dodson law, and the utility of generalising it to different emotion-task combinations has however been questioned (Hanoch & Vitouch, 2004)[33]. Furthermore it could be argued that the manipulations of stress and perceptual load as performed in the current project are testing separate cognitive mechanisms, even if they might both have be termed under the aegis of stress in other research. The threat of/reaction to aversive images is presumed to provoke a defensive response in preparation for/in response to an unpleasant experience. In contrast the stress caused by task difficulty is more likely to relate to the effect of increased demand on attentional resources, although the unpleasant experience of having to perform a difficult task might also contribute. It would therefore seem fair to argue that despite the similar effects on stress ratings and SCR measures, a separation of perceptual load and psychological stress in terms of their effect on auditory perception is justified. Indeed there is some evidence that emotional stress and mental workload provoke activation in neural networks that are at least partially separable, even when measured using neuroimaging techniques with low spatial

[32] A simple description of the Yerkes-Dodson rule is that the relationship between emotional arousal and performance takes the form of an ‘inverted U’ curve such that, at low levels, increases in arousal improve performance until a point is reached (at the top of the curve) where further arousal serves to diminish performance.

[33] The original ‘inverted U’ curve was generated by looking at habit formation in mice threatened with different strengths of electric shock, and only applied to the more difficult version of that particular task.

resolution (Simoens, et al., 2007). Nevertheless this issue does highlight the general nature of the term 'stress' as used in the research literature, and the lack of specificity within the measures that have been used to infer the success of the psychological stress manipulation during the current project.

Relationship between performance and measures of positive schizotypy

As with the previous oddball study, no statistically significant relationship was found between self-report measures relating to positive schizotypy and the size of the oddball effects generated in either task. As discussed in Chapter 3, it is possible that changes in distractibility are a consequence rather than a prerequisite of the psychotic condition and therefore that differences in the size of the oddball effect are not readily identifiable in healthy individual varying in positive schizotypy.

Conclusion

This study provided modest support for the goal-shielding effect of stress on selective auditory attention found during the speech oddball task detailed in Chapter 3. This goal-shielding effect was replicated, albeit to a non-significant extent, when tonal rather than speech sounds were used as the oddball stimuli. This data from the tone oddball task also provides support for the theory that the goal-shielding effect is generated by a right brain mechanism. Additionally measures of state anxiety negatively predicted the size of oddball effect that a participant demonstrated in both tasks, again suggesting that an increase in stress may focus attention on task relevant aspects of sensory stimuli (in accordance with the goal-shielding theory). In contrast the increase in perceptual load represented by the dichotic task produced the opposite effect on error rates, with increased errors to internal deviant trials in the stress condition. This finding, although difficult to interpret in the context of the other results, does appear to provide initial evidence that the goal-shielding effect may not be maintained during tasks involving a high level of perceptual load.

Chapter 5: General Discussion

The aim of this thesis was to investigate how psychological stress affects the perception of emotionally neutral auditory stimuli. The purpose of this investigation was threefold. Firstly the investigation was designed to fill a gap in the existing psychological literature as regard the effect of stress on the perception of emotionally neutral auditory stimuli. Secondly, this investigation was focussed so that it would allow the applicability of Attentional Control Theory (ACT: Eysenck, et al., 2007) to the perception of emotional neutral sounds to be tested. Finally it was hoped that the project would allow the identification of a potential cognitive mechanism to explain how psychological stress acts to facilitate the occurrence of auditory hallucinations (AH) in those vulnerable to them.

Summary of findings

Chapter 1 involved a review of literature relevant to the topic of this thesis. A discussion of the aetiology of AH highlighted the key role that psychological stress plays in both the development and expression of the symptom. In particular, attention was drawn to a phenomenological characteristic of AH; that periods of psychological stress often precede periods of hallucination in those vulnerable to them. This discussion was followed by a review of existing theories concerning the generation of psychotic auditory hallucinations, which concluded that AH are best considered as arising from dysfunctions within the early auditory perceptual areas of the brain. Given the desire to understand the impact of stress on AH, and the underlying role of auditory-perceptual dysfunction in the generation of AH, the existing literature concerning the effect of stress on the perception of emotionally neutral auditory stimuli was reviewed. This review highlighted the potential that ACT has for providing an explanation of the effect that stress has on hallucination-proneness. ACT predicts that stress reduces the ability to inhibit task-irrelevant information, causing an enhancement of the stimulus-driven attention system (which is involved in re-orientating attention towards stimuli based on their sensory features) at the expense of goal-directed attention (which functions to direct attention on the basis of current goals). More specifically as relating to auditory perception, ACT predicts that stress should 1) disrupt performance on auditory-perceptual tasks while 2) increasing the processing of salient task-irrelevant auditory signals. It was posited that both or either of these putative effects might explain the impact of stress on proneness to AH. The following (non-mutually exclusive) potential explanations for the stress effect on AH were generated:

1) The increased reactivity towards distracting signals under stress may, in hallucination-prone

individuals, become mal-adaptively applied to internal signals. This might allow attention to be attracted towards these internal auditory signals during stressful situations, leading to them becoming experienced as if they were external.

2) The deterioration in goal-directed attention under stress may reduce the ability of hallucination-prone individuals to distinguish between internal auditory signals and genuine external sounds, to the extent that the two types of signals become confused, allowing hallucinations to occur.

The remaining chapters detail experimental work conducted to test the plausibility of these theories. Chapter 2 describes the details of an auditory signal detection task designed to test how stress affects the ability to detect auditory signals. This revealed, contrary to what would be predicted by ACT, that stress did not reduce the ability of participants to distinguish between instances where an auditory signal was or was not present. This result therefore conflicted with the 2nd hypothesis (above). The results of this study instead suggested that in highly anxious individuals stress biases the responding of the auditory perceptual system towards reporting the presence of a signal.

Chapter 3 describes a further attempt to test the predictions of ACT using two passive oddball tasks. During such tasks the appearance of unexpected 'deviant' stimuli distracts attention away from task performance when compared to trials when the expected 'standard' stimulus is presented. This methodology allowed the impact of stress on the vulnerability to distracting signals, and therefore the theory that stress enhances stimulus-driven attention at the expense of goal-directed attention to be tested. Once again no evidence was found in support of ACT. Stress was not found to increase the distraction caused by emotionally neutral auditory stimuli, or to disrupt goal-directed auditory attention. Instead the results suggested that stress serves to improve the ability of the auditory system to selectively attend to the task-relevant aspects of an emotionally neutral sound. This 'goal-shielding' effect was discussed in terms of how it might provide an explanation for both the biasing influence of stress illustrated during the signal detection task and the impact that stress has on proneness to auditory hallucinations. Chapter 4 details two further passive oddball tasks that were designed to assess the parameters of this goal-shielding effect. The results from these tasks supported the existence of the goal-shielding effect found in Chapter 3, and its restriction (for the purposes of the particular task used) to left ear stimuli. However these results also suggested that the goal-shielding effect may disappear when the perceptual system is exposed to high amounts of sensory information. Indeed in such circumstances the effect of stress may begin to take the form predicted by ACT (increased distraction by task-irrelevant information during stress).

Unique Findings

This project has provided a number of unique findings relating to the effect of stress on auditory perception. The signal detection study (Chapter 2) represents the first attempt to examine how situational stress affects the ability to detect emotionally neutral sensory signals. Indeed it appears to be the first signal detection study to vary the level of psychological stress within participants. Previous work has shown that more anxious participants are more likely to demonstrate a bias towards reporting the presence of threat related signals (Becker & Rinck, 2004; Windmann & Kruger, 1998). The signal detection study included in this thesis shows that situational stress can produce a bias towards reporting the presence of emotionally neutral signals in highly anxious individuals.

The crossmodal oddball task (Chapter 3) provided a non-replication of previous published results (Dominguez-Borras, et al., 2008a; Dominguez-Borras, et al., 2009) raising questions concerning whether the methodology used in these previous studies was effective at isolating the effect of emotion on auditory attention. The other passive oddball studies (Chapters 3 & 4) utilised a novel method for testing selective auditory attention. These studies provide the first demonstration that the goal-shielding effect of stress applies to auditory perception. They also provide behavioural evidence that this goal-shielding effect may be driven by a right hemisphere mechanism, in accordance with theories concerning the neural basis of negative emotions (e.g. Gainotti, 2012).

Although not found to be related to the influence of the stress manipulation, the signal detection study also contained a manipulation of the presence of predictive signals. While a previous auditory signal detection study had manipulated the *accuracy* of prediction via the congruence of the target word (Vercammen & Aleman, 2010) the signal detection task detailed in this thesis represents the first attempt to identify how the very presence of internal predictive perceptual signals might affect perception[34]. The results of this manipulation of expectation revealed that the existence of predictive signals biased perception towards reporting the presence of a signal, thus increasing false positive rate. This finding offers a new strand of evidence to support theories which suggest that signals of predictive perceptual input may act as generators of hallucinatory content (Behrendt, 2006; Nazimek, et al., 2012).

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[34] A previous signal detection study assessed how expectation affects visual perception using a semantic priming technique to manipulate expectation (Krol & El-Deredy, 2011). However as primes are unlikely to generate predictive signals, the study is of questionable relevance to the understanding of how predictive signalling may influence perception (see Chapter 2 discussion).

Implications for understanding the impact of stress on auditory perception

Attentional Control Theory

In addition to the aforementioned novel findings, the experimental work detailed in this thesis tested whether the predictions of ACT extend to the perception of emotionally neutral auditory stimuli. Although there is much empirical evidence which supports ACT (Derakshan & Eysenck, 2009; Eysenck & Derakshan, 2011; Eysenck, et al., 2007) almost none of this evidence relates to auditory perception. During the current thesis the predictions of ACT were not found to apply to the perception of emotionally neutral auditory stimuli. The decrement in attentional control predicted by ACT was not evident in reduced sensitivity (ability to distinguish signal from noise) during the signal detection task. This suggests that stress did not reduce the ability of the auditory perceptual mechanism to detect ambiguous sensory signals. The results from the passive oddball tasks also failed to show much evidence in favour of ACT. As described in Chapter 3, previous findings suggestive of strengthened stimulus-driven attention under stress using crossmodal auditory oddball paradigms (Dominguez-Borras, et al., 2008a; Dominguez-Borras, et al., 2009) were not replicated when the experimental design was improved to remove confounds relating to differences in task demands between conditions. Additionally, purely auditory passive oddball tasks involving both speech (Chapter 3) and tonal (Chapter 4) stimuli revealed the opposite effect to that predicted by ACT, with participants showing less distraction to task-irrelevant information during the stress condition, and more anxious participants showing a smaller level of distraction than less anxious individuals (tone task only).

The only evidence in favour of ACT during the entire project was found during the dichotic passive oddball task (Chapter 4) where participants were exposed to a high auditory perceptual load. In this task two types of deviants were presented; internal deviants, where an unexpected change in stimulation occurred within the task stimulus, and external deviants, where the unexpected change occurred in a non-task stimulus. The increase in error rate during internal deviant trials (when compared to standard trials) was greater in the stress condition. This result is in concordance with the prediction from ACT that stress will increase the ability of distracting stimulus to disrupt goal-directed attention. Furthermore the appearance of this effect only during a task with high perceptual load fits with the prediction from ACT that stress' impact on attentional control increases as the cognitive demands of the task increase (Eysenck, et al., 2007, p. 341). Indeed some visual attention studies have also found that the predictions of ACT are only confirmed at higher levels of perceptual load (Sadeh & Bredemeier, 2011; Sato, et al., 2012). Nevertheless the results of the dichotic task cannot be taken as unequivocal evidence in support of ACT for a number of reasons. Firstly ACT predicts that stress alters processing effectiveness (e.g. error rate) only in situations where extra effort, which causes a decrease in processing efficiency, is unable to overcome the reduction in attentional control induced by the stressor. Although the error rate data from the dichotic task suggest a reduction in processing effectiveness during stress, the reaction time data did not show a concordant reduction in processing efficiency during stress. Indeed the difference in reaction time between the internal deviant and standard trials was actually smaller during the stress condition, although not to a statistically significant extent. In addition, given a reduction in processing effectiveness under stress during a high load task, one would expect to see a reduction in processing efficiency under stress during the lower load tasks, reflecting the increased effort that is presumed to be exhausted during the higher load task. This was however not the case, with the reaction time data during the lower load tasks actually showing improved efficiency (lower increase in reaction time to deviant stimuli) during the stress condition. There is therefore no evidence to support the interpretation (inspired by ACT) that the increased error rate to internal deviants under stress was a result of the high perceptual load preventing extra effort from overcoming the effect of stress on processing effectiveness. Another reason to apply caution in interpreting the results of the dichotic task as supporting ACT is the fact that no statistically significant effect of stress was found for the external deviant trials, despite these deviant stimuli also being presented at a high perceptual load.

What can be concluded about ACT in response to the largely negative findings in relation to the theory during the current project? As already touched upon the low demands on cognitive resources during the speech and tone oddball tasks may explain the absence of evidence in support of ACT. It could be argued that as increased distraction was partially evident during the high perceptual load dichotic task, the other oddball tasks may not have been demanding enough to manifest evidence of ACT. However no evidence in support of the predictions of ACT was found during the crossmodal oddball task, which produced a similar error rate (11% during standard trials) to the dichotic task (13%). Likewise no evidence in favour of the (ACT inspired) prediction that stress decreases goal-directed attention was found during the signal detection task, even though this task was specifically designed to induce a sizeable error rate (19%). Furthermore, as discussed in the previous paragraph, the evidence in favour of ACT from the high load dichotic task was not particularly conclusive. Finally, low perceptual load tasks, such as the antisaccade task, have previously been used to demonstrate increased distraction to emotionally neutral stimuli under stress (Derakshan, et al., 2009) a finding which suggests that low perceptual load on its own cannot explain the negative findings relating to ACT in the current study.

An alternative explanation for the absence of support for the predictions of ACT during this thesis is that these predictions do not hold when (as is the case in the current thesis) the perception of emotionally neutral stimuli is assessed. The literature showing that more anxious individuals are liable to increased distraction by emotionally neutral stimuli is dominated by studies testing goal-directed attention during tasks involving higher-order cognitive functions (e.g. reading comprehension or working memory). When restricted to studies which specifically test perceptual performance, the literature illustrating support the predictions of ACT as regards emotionally neutral stimuli is relatively sparse (e.g. Moser, et al., 2012; Pacheco-Unguetti, et al., 2010; Pacheco-Unguetti, et al., 2011) and solely involves studies testing visual-spatial attention. Furthermore other studies exist (in addition to those contained in the current thesis) which fail to show that perceptual performance relating to emotionally neutral stimuli is disrupted during stress (e.g. Caparos & Linnell, 2012; Osinsky, et al., 2012). These studies include those involving tasks testing non-spatial visual attention, such as the Stroop task, which actually tend to show the opposite effect to that which would be predicted by ACT (e.g. Chajut & Algom, 2003). It would seem therefore that the influence of psychological stress on attentional mechanisms may be dependent on the characteristics of the task and the modality of the stimulus involved. Complex cognitive functions appear to be more vulnerable to disruption by emotionally neutral distracters during stress than basic perceptual processes. Similarly findings relating to visual perception may not be applicable to auditory perception (e.g. Gomes, et al., 2008). Regardless of the exact reasons for the contradictory findings within the research literature, it cannot be concluded from the current research that the predictions of ACT hold for the perception of emotionally neutral auditory stimuli.

Goal-shielding theory

The results of the oddball studies described in this thesis largely support the goal-shielding theory of stress. This theory suggests that during tasks involving selective attention stress causes an increased ability to ignore task-irrelevant information. The explanation for this effect is that stress causes a reduction in attentional capacity which disproportionately affects the processing of task-irrelevant information, thus producing an improvement in selective attention (Chajut & Algom, 2003). Although versions of this theory have a long history in empirical research (Easterbrook, 1959; Staal, 2005) there does not appear to have been any prior evidence to support this theory in relation to auditory perception. As reviewed in Chapter 1, the existing evidence on the impact of stress on the perception of emotionally neutral sounds appeared to point in the direction of ACT, although the relevant research evidence is sparse and equivocal. In retrospect some of this existing evidence can be interpreted in a way that potentially supports the goal-shielding theory. For example neuroimaging studies have found that stress enhances the neural response to attended sounds (Alexandrov, et al., 2007; Tartar, et al., 2012). Likewise behavioural studies have found that attended sounds are experienced as being louder during stressful situations (Asutay & Vastfjaill, 2012; Siegel & Stefanucci, 2011). Both these lines of evidence suggest that, in agreement with the goal-shielding theory, task relevant auditory processing might be prioritized during stress. However there is also neuroimaging evidence showing increased processing of task-irrelevant, emotionally neutral sounds during stress (Baas, et al., 2006; Brandao, et al., 2001) which would seem to conflict with the reduced processing of irrelevant information predicted by goal-shielding theory. It could however be argued that these neuroimaging studies have not tested selective attention, as they have not always included a particularly demanding (or indeed any) goal-directed task from which the sounds are supposed to compete for attention.

The results of the dichotic oddball task suggested that at high perceptual loads the goal-shielding effect may disappear. This is not dissimilar to the finding of Sato et al (2012) who demonstrated that social stress reduced the interference caused by incongruous stimuli during a visual-spatial task, but only when the perceptual load of the task was low. Sato et al's explanation for the disappearance of the goal-shielding effect during the higher load task was that the combined pressure of high load and stress on attentional resources caused a disruption of the 'task set' (in effect the inability to retain task instructions). An alternative explanation for this effect can be generated with reference to load theory (Lavie, 1995). Load theory suggests that increased perceptual load reduces attentional capacity, mirroring the effect that the goal-shielding theory attributes to stress. Stress and perceptual load could therefore be argued to negatively impact on the same attentional resource (Sato, et al., 2012). When stress alone is present, the reduced attentional capacity which results disproportionately affects the processing of task-irrelevant information, thus producing the goal-shielding effect. However when both stress and high load are present, the resultant reduction in attentional capacity might be such that even the processing of task-relevant information is affected, thus removing the improvement in selective attention seen when stress alone is present.

Also included within the dichotic task was an attempt to test whether the goal-shielding effect extends to reducing the processing of task-irrelevant information that occurs at a different location to that which is the focus of attention. This test was performed in recognition of the fact that almost all existing perceptual studies of the goal-shielding effect have used paradigms where the task-irrelevant information exists within the task stimulus, although both Lazar et al (2012) and Sato et al (2012) have found evidence of goal-shielding applying to visual distracters presented outside the focus of attention. The attempt to see whether the goal-shielding effect extends to auditory distracters that occur outside the focus of attention was inconclusive in the current thesis because the influence of distracter location could not be isolated from that of perceptual load given the task design and the results of the perceptual load manipulation. It therefore remains to be established whether auditory perceptual processing is also protected during stress from auditory distracters that occur away from the focus of attention.

Regardless of the type of sounds used, the auditory goal-shielding effect was only present for stimuli delivered to the left ear. This left-sided laterality may well be a bi-product of the particular selective attention task used, where stimuli were presented monaurally. This assertion would however need to be confirmed by future research. Given the contra-lateral arrangement of the cortical processing of sound, the fact that the auditory goal-shielding effect is strongest for the left ear suggests that the effect is driven by a right-brain mechanism.

State versus Trait manipulations of stress

Although ACT is assumed to apply equally to state and trait manipulation of stress (Eysenck, et al., 2007, p. 336) the majority of research supporting ACT has relied upon between-participant differences in trait anxiety (e.g. comparing the performance of highly anxious to less anxious participants). If ACT were to only actually be applicable to between-participant differences in anxiety, this might explain why the (within-participant) manipulations of the state of stress in the current thesis did not produce results consistent with ACT. However the level of trait anxiety also failed to predict performance in a manner consistent with ACT during any of the tasks detailed in this thesis. This suggests that ACT does not fully explain how even dispositional differences in anxiety affect auditory perception. Interestingly, in contrast to ACT, the majority of perceptual studies demonstrating goal-shielding effects utilise state manipulations of stress. Only Caparos & Linnell (2012) appear to have reported results in support of goal-shielding theories using a trait anxiety manipulation (i.e. that highly anxious individuals show greater selective attention than less anxious individuals). The apparent conflicting effects on perceptual performance, dependent on whether stress is varied within or between participants, suggests that trait and state manipulations of stress might have different and somewhat opposing effects on perceptual attention.

Pacheco-Unguetti et al (2010) assessed the separate effects of trait and state manipulations of stress by varying both during the performance of a visual attention task. They concluded that trait anxiety reflects differences in the ability to maintain top-down attentional control, while the state of stress increases the vulnerability to salient stimuli distracting attention in a ‘bottom-up’ fashion. This is in contrast to ACT which proposes that *either* trait or state manipulations will produce *both* these effects. The results of the current project do not however support the distinction suggested by Pacheco-Unguetti et al. For example the goal-shielding effect evident during the oddball tasks suggests that stress tends to protect task-processing from distraction, rather than making task performance more vulnerable to distraction (as suggested by Pacheco-Unguetti et al). Given that Pacheco-Unguetti et al (2010) utilised a visual task in their research, it is possible that (as with ACT) their predictions might not generalise to other perceptual modalities, or to tasks with different cognitive demands.

Implications for the understanding of auditory hallucinations

Two theories, inspired by ACT, were proposed in Chapter 1 to explain the state effect of stress on AH (see ‘Summary of findings’ section). Given the failure to find much support for the predictions of ACT in relation to the perception of emotionally neutral sounds during the project, it must be concluded that neither of these theories currently represent a viable explanation for the effect of stress on hallucination-proneness.

In Chapter 2 an alternative description of how stress might encourage AH was proposed based on the results of the signal detection task. It was suggested that the state of stress might bias perceptual systems towards reporting the presence of a signal, under the assumption that during periods of threat it is advantageous to adopt a liberal threshold for signal detection (Haselton & Nettle, 2006). However the extent to which this biasing effect takes hold in a stressful situation is dependent on the level of top-down control that the individual is able to exert, as indexed by their trait anxiety. In Chapter 3 it was discussed how the improvement in selective attention found under stress (the goal-shielding effect) might explain both the effect of stress on AH and the results of the signal detection task. From this discussion a tentative model of how psychological stress might encourage AH can be postulated.

A model of how stress encourages proneness to auditory hallucination

This ‘internal shielding’ model assumes that attention is already focussed inwards, towards endogenous neural signals and away from external sounds, before hallucinations start. Whether stress might itself encourage this inward focus is possible, given existing evidence that stressful situations encourage self-focussed attention such as rumination (Deiters, et al., 2013; Simonson, et al., 2012). Regardless, once attention is focussed towards the internal auditory milieu, the goal-shielding impact of stress on selective attention would result in an enhancement of the perceptual impact generated by the attended-to internal signals, through reduced processing of competing perceptual information. This could be considered the endogenous equivalent of the finding that stress enhances the perceived volume of attended sounds (Asutay & Vastfjaill, 2012; Siegel & Stefanucci, 2011). As this effect would make the perceptual impact of internal signals more similar to that which might be expected from external signals, it would serve to promote the perception of attended internal signals as if they were external. Those who exhibit general source monitoring deficits (such as hallucination-prone individuals: Waters, Woodward, et al., 2012) would be particularly vulnerable to mistaking stress-enhanced internal signals and external. Furthermore in instances of perceptual ambiguity the goal-shielding effect may encourage the perception of searched for sounds that do not in fact exist, through an increased propensity (during stress) to selectively attend to the elements of the auditory milieu that sound most like the searched-for signal. Considering the deficits in the processing of auditory information evident in psychotic individuals (McKay, et al., 2000; Sweet, et al., 2007; Vercammen, et al., 2008) stress is likely to be more successful in inducing false percepts in such individuals because their perceptual processing is presumably more prone to noise and ambiguity, and therefore more likely to be vulnerable to any top-down 'biasing' effects that stress induces.

The extent of this biasing of perception in the presence of stressor(s) is mediated by the anxiety profile of the individual. As more anxious individuals experience a greater emotional reactivity (as evidenced by their higher self-report ratings of stress during the current project) they are more prone to this biasing effect. Given that psychotic individuals (Horan, et al., 2008) and hallucination-prone healthy individuals (Allen, et al., 2005) report being more anxious than control populations, they are consequentially more likely to experience hallucinations during stressful situations. The assertion that trait anxiety determines the level of perceptual biasing explains the mediating impact that trait anxiety has on the effect of stressful experiences on the positive symptoms of psychosis (Docherty, et al., 2009). It also explains the relationship between trait anxiety and stress-induced response bias which was found during the signal detection study (Chapter 2).

Additional considerations

One facet of the goal-shielding effect demonstrated during this project that is worth mentioning in relation to the internal shielding model, is the finding that the goal-shielding effect disappeared when the oddball task had an increased perceptual load. Phenomenological data suggests that AH are worse when the sufferer is alone or not otherwise engaged in cognitively demanding activities (Delespaul, et al., 2002; Nayani & David, 1996; Slade, 1972). Likewise there is evidence that increasing auditory sensory load (e.g. through talking or listening to loud music) can attenuate the perceptual impact of AH (Hayashi, et al., 2007; Nayani & David, 1996). It could therefore be argued that the auditory perceptual 'load' is a mediating factor in the experience of AH. The fact that the instigation of increased auditory load has a similar impact on both the goal-shielding effect and the experience of AH (i.e. it reduces both) lends support to the adoption of the goal-shielding effect to explain the generation of AH.

Although promising, the internal shielding model of how stress acts to encourage AH can only be considered as extremely tentative until more data is gathered. It should also be noted that the model is not entirely consistent with the findings of the current project. For example trait anxiety did not predict the extent of the goal-shielding effect during the oddball studies, whereas in the internal shielding model the goal-shielding effect is assumed to cause the perceptual biasing which is predicted to be influenced by trait anxiety. Similarly, the fact that the goal-shielding effect has only been demonstrated for left ear stimuli needs to be considered, as this laterality is not addressed in the model (see discussion in 'Future Directions' section below). A final caveat in relation to the internal shielding model is the absence of a firm relationship between the impact of stress on auditory perceptual performance and self-report measures of positive schizotypy during the current project. The presence of a relationship between a behavioural effect and positive schizotypy in healthy populations is often taken as evidence as to the relevance of the behavioural effect to psychotic symptomatology. Scores on both the Launay-Slade Hallucination-Proneness Scale (LSHS: Laroi, et al., 2004) and the cognitive-perceptual sub factor of the Schizotypal Personality Questionnaire (SPQ_CP: Raine, et al., 1994) did demonstrate a marginally significant ($p<.1$) relationship with the size of the goal-shielding effect during the speech oddball task. The equivalent relationships were not however found to be significant during the tone oddball task. Furthermore no significant relationship was demonstrated between positive schizotypy and the impact of stress on response bias during the signal detection task[35]. However in each analysis the data was in the direction which would be predicted by the model (greater effect of stress in those reporting high positive schizotypy). While the data therefore indicates that the effects of stress on auditory perception found in the current project may be greater in those who are highly schizotypal, this

[35] Those scoring higher on the SPQ_CP did show a greater change in response bias under stress, but not at a level that is usually considered statistically significant ($p=.11$).

assertion requires further testing before it can be accepted.

As regards inferring the plausibility of the internal shielding model from self-report measures of positive schizotypy, it is important to consider that any such conclusions are prefaced on the assumption that psychotic symptoms exist on a continuum, and therefore that highly schizotypal healthy individuals are cognitively closer to psychotic individuals that less schizotypal individuals. The concept of a psychotic continuum has however recently been criticised (David, 2010; Kaymaz & van Os, 2010). For example there are clear phenomenological distinctions between psychotic symptoms and their (apparent) equivalents in healthy populations (Daalman, et al., 2010) suggesting that there must be some substantive aetiological distinction between psychosis and health. Indeed a recent review concluded that there is likely to be a latent categorical structure that underlies the apparent continuum in psychotic cognitive style (Linscott & van Os, 2010)[36]. It can also be argued that the variations in psychotic-like symptoms found within healthy populations is not necessarily evidence of a continuum, as such variations are inevitable given the measurement error inherent in self-report metrics, and the fact that these self-report measures largely seek reports on the healthy 'versions' of the relevant symptoms (David, 2010). The validity of inferring the relevance of an effect to psychotic symptomatology based on the effect's relationship with self-report measures of positive schizotypy is therefore questionable. On this topic it is interesting to note the surprising finding that the self-report measures of positive schizotypy failed to predict a participant's response bias during the signal detection study, or a participant's tendency towards being distracted by task-irrelevant information (i.e. the oddball effect) during the oddball tasks. These negative results occurred despite strong theoretical and empirical evidence that both these behavioural metrics (signal detection response bias and inability to inhibit distracting information) are abnormal in genuine psychotic populations (e.g. Vercammen, et al., 2008; Waters, et al., 2003). This suggests that, for whatever reason, the measures of schizotypy and hallucination-proneness used in the current study may not have been capable of distinguishing the presence of psychotic-like cognitive processes in healthy participants. The absence of a strong relationship between these self-report measures and the behavioural effects found in the current study should not therefore prevent a discussion as to how the behavioural effects might be relevant to psychotic symptomatology.

Even if it is concluded that the stress effects found in the current study are not accentuated in those with schizotypal traits (and therefore, by association, those with psychosis) this doesn't necessarily

[36] Meaning that subpopulations within the apparent 'continuum' are more at risk of developing psychosis than others, and thus that these subpopulations can be considered as a different 'category' to those not at risk.

negate the importance of these effects to the experience of AH. For example it could be argued that the effect of stress on auditory perceptual performance only become problematic (in terms of the generation of AH) when they interact with other processes whose severity *is* related to the presence of psychosis. Indeed the 'internal shielding' model detailed above proposes that cognitive deficiencies present in psychosis are necessary to explain the effect of stress on hallucination proneness. For example stress may make internal signals appear louder due to goal-shielding in all individuals to a roughly equal extent, but it is likely that it is individual differences in source monitoring which determine whether this effect results in hallucination. The internal shielding model of the stress effect on AH is not therefore invalidated by the absence of a consistent relationship between self-report measures of schizotypy and the effects of stress found in the current project.

How might this internal shielding model be understood in terms of existing theories of AH and psychosis? Attentional control is believed to be performed by the prefrontal cortex (Miller & Cohen 2001). The suggestion that maladaptive 'goal-shielding' leads to hallucinations would fit with the idea that disruption to the functioning of the prefrontal cortex underlies psychosis (Arnsten 2011). A dysregulation of the dopaminergic system is also commonly suggested as a cause positive psychotic symptoms, because such dysregulation is believed to upset the appraisal of the salience (e.g Howes & Kapur 2009) and also the functioning of the PFC. It could be posited that dysfunctional salience monitoring and the goal-shielding impact of stress might interact to generate hallucinatory experience. For example once an erroneous level of salience has been assigned to an anomalous percept, attention will naturally be placed upon that percept, allowing it to become the focus of the goal-shielding effect if the individual is experiencing stress. Alternatively if stress were to enhance the perceptual experience of minor perceptual disturbances via the goal-shielding effect, this might encourage the disturbance to be erroneously assigned salience by a dysfunctional salience monitoring mechanism.

Neurobiological models of AH which emphasise the importance of auditory cortical dysfunction to the appearance of AH (e.g. Behrendt 2006, Nazimek, et al., 2012) also fit well with the internal shielding model. Increased endogenous activity in the auditory cortex (e.g. Hunter et al., 2006) is a likely source of internal signals which might then become attended to and accentuated under stress to produce a hallucination (as suggested by the internal shielding model). However it is worth noting that alternative theories, such as those suggesting that failures in the mechanisms of inner speech cause AH, do not conflict with the internal shielding model, as the model is neutral as to the source of hallucinatory content. The internal shielding model merely explains how an internal signal, once attended to, might become more likely to be perceived as external during stress.

Therapeutic Implications

Although the internal shielding model discussed above can only be treated as a tentative description as to how stress might encourage AH, it is worth considering what the therapeutic consequences of this model might be were it to prove valid. Although the impact of psychological stress on positive psychotic symptoms is widely appreciated, a description as to how stress functions to encourage hallucinations may enable improved cognitive-behavioural therapies to be developed in order to counter this effect of stress. For example the potential for 'perceptual load' to undermine the goal-shielding effect might prompt a therapy whereby sufferers are encouraged to immediately focus on a genuine sound when they become stressed, or to create auditory input themselves in order to distract from the hallucinatory content. Alternatively merely having insight into the (putative) attentional changes triggered during stress might serve to lessen the subjective reality of hallucinatory sounds to the sufferer. The hallucinator might become better able to rationalise the appearance of hallucinatory content during times of stress if they can understand why such sounds are likely to appear. Finally the idea that stress-induced alterations in the functioning of attentional mechanisms might contribute to the production of AH could potentially lead to neurological treatments targeting the brain areas involved in attentional control. For example Transcranial Magnetic Stimuli (TMS) could be used to alter the excitability of the prefrontal areas which control the goal-shielding effect. Such a treatment would only be successful however if it were shown that the functioning of goal-shielding effect itself was abnormal in psychosis.

Future directions

The impact of stress on auditory perception

While the results of this thesis generally support goal-shielding theories of selective attention, it needs to be acknowledged that the research literature is by no means conclusive as regards the impact of stress on selective attention. In addition to the evidence cited in favour of the goal-shielding theory there are visual selective attention studies of emotionally neutral stimuli which show the opposing effect to that predicted by goal-shielding theory (e.g. Choi, et al., 2012). There is therefore a need to understand under what exact circumstances the goal-shielding theory applies (e.g. how task-characteristics determine whether the goal-shielding effect is found). Since the current research appears to be the first to suggest that the goal-shielding effect is applicable to auditory perception, this effect clearly needs to be replicated, preferably using alternative auditory selective attention paradigms to the one used during this thesis. For example given the use of monaural stimuli during the oddball tasks detailed in this thesis, it is important to confirm whether the goal-shielding effect can be replicated when auditory stimuli are presented binaurally.

Over and above understanding the parameters of the goal-shielding effect, there is a more general need to identify how the impact of stress on the perception of emotionally neutral stimuli differs depending on the sensory modality of the stimuli and the characteristics of the task used. As most studies concerning the impact of stress on perception use visual tasks, more research needs to focus on the effect of stress on auditory-perceptual performance. In terms of task characteristics, how perceptual load and attentional demands (e.g. selective attention vs. spatial attention) influence the impact of stress on auditory perception needs to be researched further. As an example, the goal-shielding effect is only predicted to apply in situations involving selective attention. It is still unclear how stress affects auditory perception during tasks not requiring selective attention. During the crossmodal oddball task stress was not found to alter auditory attention when distracter and task were not in direct competition. As this result was in contrast to both the predictions of ACT and previous oddball studies (e.g. Dominguez-Borras, et al., 2009) further research on this topic would be welcome.

As the goal-shielding effect was only evident for stimuli presented in the left ear during this thesis, further research should seek to understand whether (and under what circumstances) the goal-shielding effect can be demonstrated for right ear stimuli. It may also be of interest to perform a visual selective attention task where the stimuli are presented to one eye only. If a similar left-sided/right hemisphere laterality was to be evident for the visual goal-shielding effect this would further support the conclusion that this laterality is due to the stress response being controlled by a right-hemisphere mechanism.

Given the aforementioned interest in identifying whether manipulations of the state of stress and differences in trait anxiety have dissociable effects, future research could aim to manipulate both independently within the same paradigm. For example, separate samples of high and low trait anxious individuals could complete an auditory perceptual task which includes a stress manipulation. In particular during a selective attention task it would be of interest to see how the goal-shielding effect evident due to a state manipulation of stress might differ between individuals with extreme scores on trait anxiety. Less control over the allocation of the reduced attention resources that occur during stress might cause the goal-shielding effect to be lost in highly anxious individuals, due to their reduced cognitive control (Eysenck, et al., 2007; Pacheco-Unguetti, et al., 2010). Alternatively increased reactivity to the stressor might induce greater attentional resource loss in more anxious participants, thus enhancing the goal-shielding effect.

Relevance to auditory hallucinations

In terms of the relevance of the current results to understanding the impact of stress on AH, further research is needed to test the internal shielding model proposed in the preceding section. More specifically as the model suggests that the goal-shielding effect should enhance the perceptual impact of internal signals, it would be of interest to test whether internal auditory signals are experienced as louder during stressful conditions. This research goal is hampered by the difficulty in systematically controlling the appearance of internal auditory signals, although the sentence frame method utilised to manipulate predictive signalling during the signal detection task might prove to be a useful methodology in this regard[37]. Another facet of the model presented above that should be tested is the assertion that the stress-induced response bias is caused by the goal-shielding effect. As these two effects were achieved in separate studies during the current thesis, a direct link between them still needs to be confirmed. This could potentially be achieved by comparing the performance of the same set of participants during both an oddball and signal detection task. According to the internal shielding model those who experience a greater stress-induced change in response bias should also exhibit a greater goal-shielding effect.

Further research into the laterality of the goal-shielding effect evident in the current project might also provide evidence as to whether this effect is of relevance to AH. As many believe that AH arise from dysfunction in the left auditory cortex (e.g. Hugdahl, et al., 2008) one would expect that if the goal-shielding effect was responsible for generating AH, then such an effect should be evident for right-ear/left hemisphere stimuli. It is therefore of interest to identify why only left-ear/right hemisphere stimuli were subject to the effect in the current study. It could be argued that task responding was too quick during the oddball paradigms used in the current study for a right-brain stress mechanism to have an effect on stimuli processed in the left auditory cortex. If this were the case then increasing the cognitive demands of the goal-directed task should presumably cause the goal-shielding effect to manifest for stimuli presented in both ears.

[37] It could be argued that if internal signals appear louder during stress then during the signal detection task the expectation manipulation should have had more of an effect on response bias in the stress condition. A significant stress*expectation interaction for response bias was not found in the signal detection study, although the data was in the direction predicted (Figure 5B). It could also be argued that the main effect of expectation may have been so strong (r=.36) that it masked any mediating impact that stress may have had.

Regardless of whether the goal-shielding effect can also be demonstrated for right ear/left hemisphere stimuli, it would be of interest to further investigate how the apparent right-hemisphere dominance of the effect has a bearing on its relevance to AH. The right auditory cortex appears to be overactive in hallucinating individuals (Woodruff, et al., 1997). It is also activated during the experience of auditory hallucinations (Kompus, et al., 2011) and this activation may be related to the hallucination's emotional content (Sommer, et al., 2008). It is therefore possible that the right-hemisphere dominance of the goal-shielding effect may exacerbate a pre-existing tendency for abnormal levels of right auditory cortex activation in psychotic individuals. It would therefore be of interest to study the auditory goal-shielding effect in psychotic individuals to see how the laterality of the effect is related to both hallucinatory phenomenology and right auditory cortex activity. Taking this line of thought further, it must be acknowledged that the applicability of the internal shielding model to AH can only truly be resolved by testing auditory processing under stress in psychotic individuals. Given that trait anxiety has been found to mediate the impact of stress on both positive symptomatology in clinical samples (Docherty, et al., 2009) and auditory response bias in a healthy sample (Chapter 2) it would be of interest to repeat the signal detection study conducted in the current thesis with a clinical population. This would confirm whether a stress-induced change in response bias is likely to be related to hallucinatory experiences in psychotic populations, while also potentially elucidating how differences in trait anxiety between healthy and psychotic individuals affects signal detection. However it would be sensible to wait until more evidence is collected on the impact of stress on auditory perception in healthy individuals before such research is considered, given the existing uncertainties on this subject. In any case the ethical issues surrounding exposing psychotic individuals to a psychological stress manipulation would need to be seriously considered before any such research were undertaken. As an alternative, conducting such research on unaffected first-degree relatives of psychotic patients might represent an acceptable compromise.

A final area for further research concerns identifying whether the goal-shielding effect also applies to the processing of task-irrelevant auditory information that occurs at a different location to the focus of attention. Although reduced interference by non-task stimuli under stress has been demonstrated during visual selective attention tasks (e.g. Lazar, et al., 2012) an attempt to replicate this effect for auditory perception during the current project (via the dichotic task detailed in Chapter 4) proved inconclusive. If it could be demonstrated that stress reduces the processing of distracting auditory information which occurs at a different location to the attended stimulus, this would potentially allow the internal shielding model's explanation as to how stress encourages AH to be expanded. In addition to the mechanisms already described in the model, stress could be deemed to encourage AH by reducing the processing of genuine auditory stimuli during periods when attention is focussed on hallucinatory content.

Limitations

One potential limitation of the experiments conducted during this thesis is the method used to achieve the manipulation of psychological stress. Stress was manipulated through the sporadic presentation of aversive (vs. neutral) images between experimental trials. As detailed in Chapter 1, there is a significant amount of past research which supports the use of such stimuli to manipulate emotional state (e.g. Pereira, et al., 2006; Simmons, et al., 2004). Furthermore during the current project self-report ratings of stress taken after each experimental block suggested that this manipulation was successful in instigating the subjective experience of stress in participants. Skin conductance data, collected during the oddball tasks (Chapters 3 & 4) was also largely supportive of this conclusion. Nevertheless it must be considered whether this method is the most effective way of inducing stress. The individual response to a stressor such as aversive images is highly subjective. Many participants reported being minimally affected by the stress manipulation, whereas two participants actually withdrew from a study because of distress at the images used. This variation in the response of participants to the stressor may explain some of the between-participant variability in the effect of stress on task performance. For example the presence of the oddball effect (regardless of stress condition) was highly consistent across participants during all the oddball tasks, with very few participants showing quicker reaction times to deviant stimuli. In contrast, even during the speech oddball task where a main effect of stress was present, the impact of stress on the oddball effect varied widely between participants, with many demonstrating the opposite effect (increased distraction under stress) to that suggested by the results of the group analysis. This variability may explain the absence of a significant main effect of stress in all but one of the tasks detailed in this thesis. The research could perhaps therefore have benefited from using a stressor that is less vulnerable to variations in subjective experience. Threat of electric shock (e.g. Baas, et al., 2006; Hu, et al., 2012) is particularly useful in this regard, partly because the intensity of the stimulus can be adjusted so that its subjective unpleasantness is consistent across participants.

A lack of specificity regarding the emotional effect of the stress manipulation could also be highlighted as a weakness of the current research. Stress was assumed to be generated via the anticipatory anxiety provoked by the trepidation of being exposed to unpleasant stimuli during the stress blocks, rather than by the specific emotion generated by individuals stimuli themselves. On this basis a range of different aversive images were used during the stress manipulation, with the main selection criteria being that they produced strong negative affect (as determined by the IAPS ratings of valence and arousal for each image: Lang, et al., 2008). However as the nature of this negative affect is not specified, it is quite plausible that the aversive stimuli may have induced emotions other than stress in participants, such as disgust or sadness. Thus the stress manipulation cannot be considered to have exclusively induced stress, and therefore the effects attributed to it may not solely be due to stress. The research could therefore have been improved by enforcing a greater specificity regarding the emotional effect of the stress manipulation, or by measuring the effect of the stress manipulation on other emotions, and then factoring that into any analysis.

A further potential criticism of the stress induction procedure used was that any stress instigated during the stress blocks may have partially 'leaked' into the non-stress blocks, thus diluting the effectiveness of the manipulation. To assess this possibility the subset of participants who received a non-stress block first during Study 2 (Chapter 3) were isolated, and their ratings of their first non-stress block were compared with those for later non-stress blocks. As the first non-stress block for these participants was not preceded by any stress blocks, it cannot be contaminated by any 'leaking' of the effect of the aversive stimuli. In contrast if the emotional impact of the aversive images did 'leak' into other blocks, than this would presumably have an effect on the later non-stress blocks. The rating given to this first non-stress block was not found to differ from that given to subsequent non-stress blocks for these participants ($z=1.1$) suggesting that no such contamination of the stress manipulation occurred.

Finally the method used to assess the effectiveness of the stress induction procedure could have been improved. Although SCR data provided a physiological index of the success of the stress manipulation, it should be noted that SCR provides a measure physiological arousal, rather than of stress per se. The use of a physiological measure that is more specific to stress (such as salivary cortisol concentration) would have provided a better measure of the effectiveness of the stress manipulation used during the current project.

Another limitation of the current project concerns the utilisation of self-report measures. Participants were recruited randomly during each study. Although this method of sampling increases the likelihood of obtaining a representative sample, it tends to lead to only a modest range of scores on self-report measures, especially considering the sample sizes involved in the current project. While regression techniques can be used to identify relationships between psychometric scores and performance, they tend to lack power in the absence of large sample sizes. An experimental design where performance is compared between groups of participants pre-selected for their high/low scores on a relevant psychometric measure, may therefore have offered greater power in terms of testing the hypotheses concerning the self-report measures. Against this it could be argued that both trait and state anxiety were found to be significantly predictive of task performance at various points during the project, suggesting that the sample sizes used may have indeed provided sufficient power for the regression analyses. Pre-selecting participants based on extreme self-report scores also produces a sample that is not representative of the general population, potentially making the results of any such study harder to apply to the understanding of normal perception.

Conclusion

The major aim of this thesis was to identify a cognitive mechanism with the potential to explain the role that psychological stress plays in encouraging auditory hallucinations in those vulnerable to them. To this end a series of studies were conducted to assess the effect of stress on the perception of emotionally neutral sounds. Stress was found to improve participant's ability to selectively attend to the task-relevant aspects of an auditory stimulus. Stress was also found to instigate a response bias towards reporting the presence of auditory signals in highly anxious individuals. A tentative model of how stress might encourage auditory hallucinations in psychotic individuals was proposed on the basis of these results. This 'internal shielding' model suggests that the strengthening of selective attention under stress may bias perceptual processing so that the perceptual impact of endogenous auditory signals is enhanced, making those endogenous signals more likely to be misperceived as emanating from an external source in hallucination-prone individuals.

This thesis provides a significant contribution to scientific knowledge by adding to the sparse research literature concerning the impact of psychological stress on the perception of emotionally neutral auditory stimuli, including producing a number of unique findings on this topic. The thesis also provides a potential mechanism which might explain how psychological stress contributes to the generation of auditory hallucinations. The internal shielding model could be used as a basis for future research aimed at identifying the impact that psychological stress has on the pathophysiology of auditory hallucinations.

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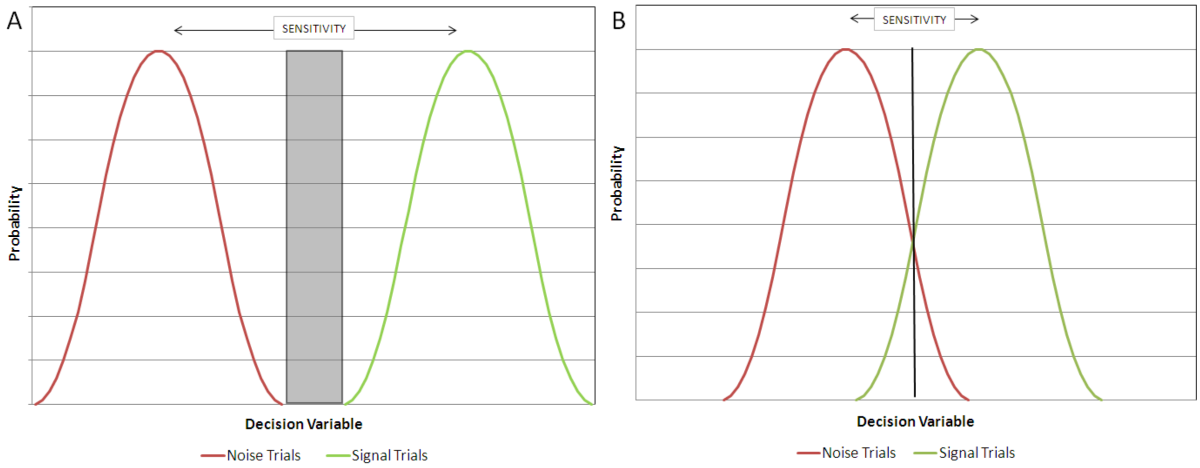
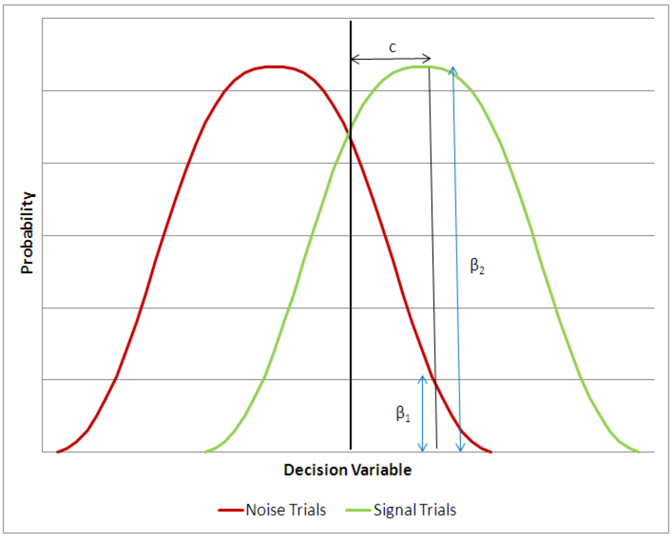
Appendix 1: Signal Detection Theory

Signal detection theory (SDT) provides two parameters that describe the performance of a system; sensitivity and response bias. Although SDT can be applied to data from any task where the participant has to make a binary decision of some sort, it is easiest to conceptualise sensitivity and response bias using the example of a standard perceptual signal detection task such as the speech in white noise task described at the start of Chapter 2. During such a task the participant's subjective experience of the target stimulus (i.e. the white noise stimulus) can be quantified using a theoretical variable called the 'decision variable', so called because it's value is what the participant uses to decide which response they are going to make. The higher the value of the decision variable, the more the perceptual experience resembles perceiving a signal. A participant's perceptual experience (and therefore the resulting decision variable) will naturally vary from trial to trial due to the influence that potentially any number of sensory and cognitive factors have on the efficiency of the perceptual system. Given this variability, separate probability distributions of the decision variable can theoretically be plotted for signal and noise trials. In a task where distinguishing signal from noise is relatively easy (e.g. hearing a fire alarm over the sound of a radio) the perceptual experience generated by signal and noise trials will be noticeably different. The plot of the decision variable experienced during the signal trials will therefore be separated by a large distance from the equivalent plot for the noise trials, despite the variations in the decision variable value within each type of trial (Appendix Figure 1A.). In situations where distinguishing between signal and noise is more difficult (e.g. understanding speech in a loud nightclub) the plots of the decision variable for signal and noise trails will be much closer together (Appendix Figure 1B.). Where mistakes (false positives and false negatives/misses) occur the two plots will overlap, as an overlap between the decision variable plots for signal and noise trials represents a situation where some signal trials are perceived as being less like signals than some noise trials and vice versa. It follows that the relative difficulty of a task is defined by the distance between the two plots. When different participants perform the same task (which is the case during signal detection studies) then the gap between the two plots represents a participant's relative ability to perform the task. Sensitivity is defined as the ability of the system (in this case a participant's auditory-perceptual mechanism) to distinguish between signal and noise. It equates to the distance between the plots of the decision variable for signal and noise trials. Participants who are better at a task will demonstrate a greater sensitivity, and therefore greater distance between the decision variable plots for signal and noise trials.



Appendix Figure 1. Theoretical representations of the distribution of the decision variable in signal and noise trials. When discrimination between signal and noise is simple, the distance between the mean value of the signal (green) and noise (red) trials is large (A). When the signal is ambiguous the distance between the means of the plots is much smaller, to the extent that the plots will overlap in situations where errors are made (B). The neutral point (black line) resides at the point where the two plots intersect.

A participant's sensitivity doesn't however solely determine their performance. A participant's exact performance is also dependent on the level of the decision variable above which they decide to report a signal as being present. In SDT it is assumed that the participant maintains a boundary of perceptual experience (i.e. a value of the decision variable) above which they will report a signal. This boundary value is referred to as the criterion, and its position is assumed to be maintained as long as the task conditions remain the same. Response bias is calculated as the distance between the participant's criterion value and the neural point; the point on the theoretical decision variable graph where neither response is favoured (Appendix Figure 1B). Response bias therefore equates to the participant's bias towards responding in a particular manner, quantifying as it does the direction and distance between the participant's boundary for responding and the point at which no bias would be present (Appendix Figure 2.). Where the criterion value is higher than the neutral point (in terms of the decision variable) a negative (or conservative) response bias is present, reflecting a situation where the participant is less likely to report a signal than would be the case if the neutral point were adopted. A criterion value that is lower that the neutral point equates to a positive (or liberal) response bias, where the participant is more likely to report a signal than would be the case if no bias were present. Where task conditions are identical, differences between different participants' criterion values can be taken to reflect differences in the characteristics of their perceptual systems (e.g. a relative bias towards responding positively or negatively). It should be noted that the criterion position a participant adopts (and therefore their response bias) is to some extent under conscious control. For example if a reward is available for detecting signals then a participant is likely to purposefully move their criterion towards a lower decision variable value, thus capturing as many signals as possible. Nevertheless where task conditions are controlled so that there are no explicit motivational factors favouring one response over the other, it is assumed that the position of the criterion will largely be determined by unconscious internal biases in information processing.



Appendix Figure 2. An illustration of the principle of response bias. The participant's criterion (thin black line) is higher than the neutral point (thick black line) reflecting a negative response bias where correct detection of the signal is sacrificed to avoid false positives. Response bias can either be calculated by computing the distance (c) between the neutral point and the criterion, or by taking the ratio of the likelihood of signal trials and noise trials at the criterion (β [which equals β2 / β1]).

Both sensitivity and response bias are calculated using both hit rate (H: the proportion of signal trials where a signal was detected) and false positive rate (F: the proportion of noise trials where a signal was erroneously detected). Exactly how sensitivity and response bias are calculated depends on what assumptions are made concerning the distribution of the decision variable (see Stanislaw & Todorov, 1999 for an excellent review of these calculations). The crucial point to appreciate is that if the relevant assumptions are met, the resulting measures of response bias and sensitivity will be independent of each other. This can be appreciated by considering that on the putative decision variable graph (e.g. Appendix Figures 1/2) the criterion value can be placed independently of the position of the two decision variable plots.

Appendix 2: Sentence frames and targets nouns used during the signal detection task

Expectancy Prompt	Percent	Most frequent answer	Syl	Words	Duration (ms)
The relay team dropped the	97%	baton	6	5	1,880
The shepherd herded the	97%	sheep	6	4	1,630
The jockey rode the	97%	horse	5	4	1,710
The person dried their hands on the	97%	towel	8	7	2,000
The visitor knocked on the	97%	door	7	5	1,780
The squirrel ate a	97%	nut	5	4	1,560
The web was spun by a	97%	spider	6	6	1,950
The referee blew the	97%	whistle	6	4	1,710
The farmer milked the	97%	cow	5	4	1,520
The hole was dug with a	94%	Spade	6	6	1,690
The pilot flew the	94%	plane	5	4	1,490
The photo was taken with a	94%	camera	8	6	1,990
The vain person looked in the	94%	mirror	7	6	2,000
The waiter placed food on the	94%	table	7	6	1,930
The rockstar strummed their	94%	guitar	5	4	1,870
The person ate soup with a	94%	spoon	7	6	2,000
The campers put up their	94%	tent	6	5	1,840
The picture hung on the	94%	wall	6	5	1,730
The bike had a flat	94%	tyre	5	5	1,730
The rubbish was put in the	94%	bin	7	6	1,820
The tourists stayed at a	90%	hotel	6	5	2,000
The apple fell from the	90%	tree	6	5	1,780
The bird flew back to its	90%	nest	6	6	1,990
The child picked petals from a	87%	flower	7	6	1,990
The lock was opened with a	87%	key	7	6	2,000
The unicycle had one	87%	wheel	7	4	1,810
The gambler flipped a	87%	coin	5	4	1,640
The child washed their hands in the	87%	sink	7	7	2,000
The child walked their	87%	dog	4	4	1,590
The rowers climbed aboard their	87%	boat	7	5	1,940
The milk was kept in the	84%	fridge	6	6	1,770
The teacher worked at a	84%	school	6	5	1,900
The juggler dropped a	84%	ball	5	4	1,650
The receptionist answered the	84%	phone	8	4	1,880
The chef baked a	84%	cake	4	4	1,540
The librarian picked up a	81%	book	8	5	2,000
AVERAGES	**91%**		**6.17**	**5.06**	**1,814**
VARIANCES			**1.17**	**0.91**	**26,585**

Non-expectancy prompt	Percent	Most frequent answer(s)	Syl	Words	Duration (ms)
The expert identified the	19%	Problem	8	4	2,000
The person spoke about the	19%	event	6	5	1,850
The meeting was about a	19%	project	6	5	1,880
The car drove past the	19%	house/shop	5	5	1,840
The person walked towards the	19%	door(way)	7	5	2,000
The family talked about the	19%	holiday	6	5	1,930
The person remembered the	16%	Date	7	4	1,780
The person ignored the	16%	sign	6	4	1,680
The person learnt about the	16%	subject	6	5	1,930
The child took a photo of the	16%	flower	7	7	2,000
The person bought a	16%	car	5	4	1,500
The person acquired a	13%	skill	6	4	1,760
The person was confused by the	13%	question	8	6	2,000
The shopkeeper sold a	13%	newspaper/paper	6	4	1,560
The person thought about the	13%	past	6	5	1,840
The group discussed the	13%	problem	5	4	1,610
The children looked at the	13%	picture	6	5	1,540
The person asked about the	13%	price/time	6	5	1,900
The person knew about the	13%	secret	6	5	1,880
The picture showed a	13%	landscape	5	4	1,550
The story was about a	13%	boy	6	5	1,860
The person was impressed by the	13%	size	8	6	2,000
The children examined the	10%	dog/insect/toy	7	4	1,740
The question was about the	10%	weather	6	5	1,730
The child was told about the	10%	danger	6	6	1,860
The person measured the	10%	length/distance	6	4	1,660
The person dreamt about the	10%	sea	6	5	1,770
The person touched the	10%	tree/wall	5	4	1,620
The child heard about the	10%	story	5	5	1,650
The letter concerned a	10%	person/bill	6	4	1,850
The person imagined the	6%	future/scene	7	4	1,760
The project was about a	6%	book/disease/place	6	5	2,000
The report was about a	6%	child/death/person/school/theft	6	5	1,940
The child could barely see the	6%	tree/insect	7	6	1,930
The children read about the	6%	princess/dog/animal	7	5	1,670
The person described the	6%	house/room/scene/weather	6	4	1,750
AVERAGES	**13%**		**6.19**	**4.78**	**1,801**
VARIANCES			**0.68**	**0.58**	**22,388**

Appendix Figure 3: Sentence frames and associated target nouns used in the signal detection task. Those listed on the left relate to the high constraint (expectation) condition and those on the right relate to the low constraint condition. The 'Percent' column gives the constraint of the frame, calculated as the percentage of participants who responded with the most frequently given answer during the pilot study. Duration relates to the length in ms of the audio file created for the frame.

Appendix 3: Ratings for IAPS images used during the signal detection task

Aversive Images				Neutral Images			
IAPS Ref	Description	Valence	Arousal	IAPS Ref	Description	Valence	Arousal
3064	Mutilation	1.45	6.41	7030	Iron	4.69	2.99
3080	Mutilation	1.48	7.22	7150	Umbrella	4.72	2.61
3015	Accident	1.52	5.9	7130	Truck	4.77	3.35
3120	DeadBody	1.56	6.84	7038	Shoes	4.82	3.01
3130	Mutilation	1.58	6.97	7175	Lamp	4.87	1.72
3000	Mutilation	1.59	7.34	7006	Bowl	4.88	2.33
3100	BurnVictim	1.6	6.49	7055	Lightbulb	4.9	3.02
3069	Mutilation	1.7	7.03	7009	Mug	4.93	3.01
3010	Mutilation	1.71	7.16	7050	HairDryer	4.93	2.75
3110	BurnVictim	1.79	6.7	7059	Keyring	4.93	2.73
3060	Mutilation	1.79	7.12	7950	Tissue	4.94	2.28
3068	Mutilation	1.8	6.77	7020	Fan	4.97	2.17
3261	Tumor	1.82	5.75	7185	AbstractArt	4.97	2.64
3225	Mutilation	1.82	5.95	7041	Baskets	4.99	2.6
9405	SlicedHand	1.83	6.08	7000	RollingPin	5	2.42
3071	Mutilation	1.88	6.86	7056	Tool	5.07	3.07
3030	Mutilation	1.91	6.76	6150	Outlet	5.08	3.22
9571	Cat	1.96	5.64	7233	Plate	5.09	2.77
9301	Toilet	2.26	5.28	5471	Satellite	5.21	3.26
9300	Dirty	2.26	6	7547	Bridge	5.21	3.18
3150	Mutilation	2.26	6.55	7053	Candlestick	5.22	2.95
3181	BatteredFem	2.3	5.06	7080	Fork	5.27	2.32
3051	Mutilation	2.3	5.62	7057	Coffeecup	5.35	3.39
3400	SeveredHand	2.35	6.91	7710	Bed	5.42	3.44

Appendix Figure 4: IAPS images used during the signal detection task (Chapter 2) along with associated mean valence and arousal ratings (taken from Lang, et al., 2008).

Appendix 4: Calculation of Signal Detection Parameters

Parametric model of signal detection

The most common method for calculating sensitivity and response bias relies on a model of signal detection which assumes that the decision variable is normally distributed in both signal and noise trials, with each distribution also having an equal variance. These assumptions are normally referred to as parametric assumptions. If these assumptions are met then signal detection parameters can be attained from the Hit Rate (H) and False Alarm Rate (F) as calculated from the response to the Yes/No question. As H and F effectively represent probabilities (of detecting a signal when it is and is not present respectively) then, given the aforementioned assumptions relating to normality and equality of variance, they can validly be converted into z-scores. Sensitivity (d') is then simply difference between the z-score of the hit rate and the z-score of the false alarm rate, while response bias is the average of these two z-scores multiplied by -1 (Stanislaw & Todorov, 1999). However if these parametric assumptions are not met then alternative, 'distribution-free' signal detection parameters can be attained (e.g. Kornbrot, 2006).

Testing assumptions of parametric SDT

The validity of the assumptions of the parametric model of signal detection can be assessed by analysing the rating data collected immediately after the Yes/No response. Taking a rating of the certainty of a yes/no response in effect forces the participant to adopt several different criterion levels, one to differentiate between each pair of potential responses (e.g. between a 'yes' with a certainty of 2 and a 'yes' with a certainty of 3). The number of criterion values the participant has to adopt equals 1 less than the number of points on the rating scale. These multiple criterion values reflect different points on the theoretical decision variable plot (Appendix Figure 2). Therefore the distribution of the decision variable during signal and noise trials can be ascertained by plotting performance for each type of trial for each of the criterion values. To achieve this, values of H and F are calculated for each criterion level provided by the scale. In the context of the current signal detection study this required the 4-point certainty scale used for both the 'yes' and 'no' responses to be amalgamated into an 8-point scale (running from the most certain 'no' response [4] through to the least certain 'no' response [1] then the least certain 'yes' response [1] to the most certain 'yes' response [4] – Appendix Figure 5.). H and F values can then be calculated for each criterion point by treating all responses that represents less certainty (than the criterion point) of a signal as 'no' responses, and all responses that represent a greater certainty as 'yes' responses. For example to calculate H and F for the first criterion all responses of '1' (on the 8-point scale) were treated as No, and every other response was treated as 'Yes'. For the next criterion, responses of '1' and '2' on the 8-point scale are treated as 'No' and everything else is treated as 'Yes' and so forth.

Amalgamation of responses into one scale

Response Y/N	N	N	N	N	Y	Y	Y	Y
Response (certainty)	4	3	2	1	1	2	3	4
Amalgamated Scale	1	2	3	4	5	6	7	8

Calculation of ROC points from amalgamated scale

First Criterion	N	Y	Y	Y	Y	Y	Y	Y
Second Criterion	N	N	Y	Y	Y	Y	Y	Y
Third Criterion	N	N	N	Y	Y	Y	Y	Y
Fourth Criterion	N	N	N	N	Y	Y	Y	Y
Fifth Criterion	N	N	N	N	N	Y	Y	Y
Sixth Criterion	N	N	N	N	N	N	Y	Y
Seventh Criterion	N	N	N	N	N	N	N	Y

Appendix Figure 5: Calculation of the ROC[38] curve from the rating data. Top Panel: The rating data (1=least certain, 4=most certain) is amalgamated in a logical way to produce one scale relating to the certainty that there is a signal (1=least certain). Hit and false alarm rates can then be calculated for the criterions used to distinguish between each point on the rating scale, by treating all points before each criterion as 'no' responses and all points after it as 'yes' responses (bottom panel).

To test how closely the distribution of the response variable matches the normal distribution, the resulting H and F values are converted in z-scores before being plotted against each other. As H is calculated solely from signal trials and F solely from noise trials a plot of their z-values against each other at different criterion levels should result in a straight line if the decision variable distributions for both are Gaussian. Furthermore the ratio of the variances between the signal and noise trials is reflected in the gradient of this line, with a gradient of 1 equating to equal variance between the two plots. The assumptions of parametric signal detection theory is therefore tested by assessing these characteristics of the graph of H against F. The slope of this graph can be assessed by performing two linear regressions, one which attempts to predict H from F, and one which attempts to predict F from H. The average of the first slope and the reciprocal of the second slope give an unbiased estimate of the slope of this graph (Stanislaw & Todorov, 1999)[39].

[38] These are referred to as ROC points because they can be used to calculate ROC Curves (see 'Distribution free measures...' section below).

[39] Performing just one regression would produce a biased result because the ordinary least squares method only attempts to reduce the errors associated with predicting the dependent variable, whereas the variance

A one-sample t-test of the slope estimates taken from the data generated during Chapter 2 revealed that the slope was significantly different from 1 ($t(69) = -10.4$, $p<0.001$) thereby suggesting that the variances of the signal and noise distributions were not equal. Given this, distribution-free versions of sensitivity and response bias were calculated.

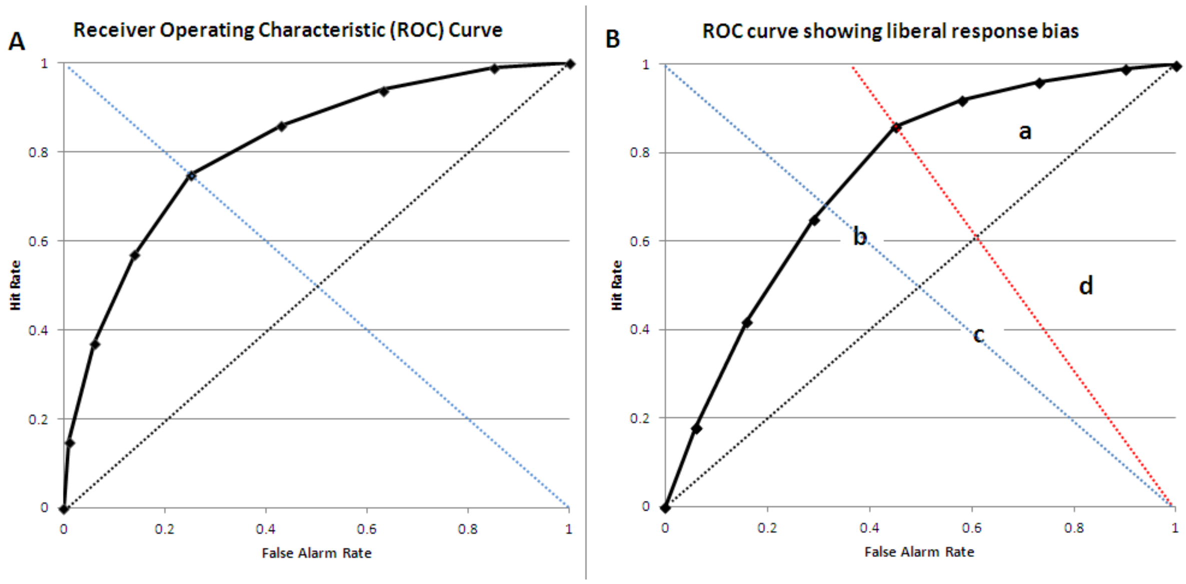
Distribution-free measures of signal detection parameters: The ROC Curve

Certain alternatives to the parametric signal detection measures can be calculated solely from the yes/no response (so called 'single point measures': Verde, et al., 2006) but as these are generally considered to be prone to bias (Macmillan & Creelman, 1996) they were not used in the current study. More valid, distribution-free measures of signal detection parameters can be calculated using a receiver operating characteristic (ROC) chart. The ROC chart involves plotting the H and F probabilities attained from the rating scale data outside of Z-space, with F on the x-axis. On such plots the data for the first criterion value will appear closest to the top right of the graph as, by definition, the values of H and F will be highest for this criterion because it is calculated by attributing most of the scale points to 'Yes' (Appendix Figure 5.). As further criterion values are plotted both values of H and F will fall as fewer responses are treated as 'Yes', resulting in the points on the ROC chart moving progressively towards the bottom left. Above chance performance will see the value of H (where the 'Yes' responses are correct) fall slower than the value of F (where 'Yes' responses are incorrect) and thus the plot will take the form of a curve (known as the ROC Curve) which arcs toward the top-left of the graph (Appendix Figure 6A/B.).

Perfect performance in a signal detection task would be reflected in all signal trials being rated at the highest level of certainty that there is a signal (8 on the scale utilised in the current study) and all noise trials being rated as the lowest certainty (in this case 1). This scenario would produce H values of 100% and F values of 0% for every criterion. The ROC Curve for perfect performance would therefore be represented by a single point at the top left of the chart. Technically in addition to the H and F values calculated from the data, two extra points (herein referred to as 'boundary values') relating to a situation where all responses are treated as 'yes' (H=100, F=100) and all responses are treated as 'no' (H=0, F=0) can be included in the graph, thus 'completing' the curve. When these boundary values are included, a plot of perfect performance would take the form of a line moving up the y-axis, through the point at the top left of the chart and then across the top of the graph. In

associated with both H and F need to be taken into account when determining the slope of the graph (Stanislaw & Todorov, 1999).

contrast, chance performance would be reflected by a situation where the distribution of signal and noise trials does not vary between the different points of the rating scale (because the participant is completely unable to distinguish between signal and noise trials and therefore responses would be assigned randomly against each rating scale value). This would result in values of H and F being identical for each criterion value (i.e. falling in tandem as you travel 'up' the criterion values) and therefore would be represented by the major diagonal on the ROC chart (Appendix Figure 6A). Following the same logic, the worst possible performance (H=0, F=100 for each criterion value) would be plotted as a point at the bottom right of the chart, or a line running along the x-axis and then up the right side of the chart, once the boundary values are added. From this it follows that a measure of sensitivity can be calculated from the area under (to the right) of the ROC curve, a measure referred to as A_{ROC}. An A_{ROC} value of 0.5 reflects chance performance (area under major diagonal) whereas an A_{ROC} value of 1 reflects perfect performance (i.e. the entire area of the graph, given that the maximum value of x and y are 1).



Appendix Figure 6: Example ROC curves (thick line). The major diagonal (black dotted line) represents chance level performance. The minor diagonal (blue dotted line) connects the points of maximum (top left) and minimum (bottom right) performance. A) Example ROC curve without response bias, the minor diagonal bisects the midpoint criterion value (representing the change between a 'yes' and 'no' response). B) ROC curve showing performance with a liberal response bias, reflected in the relative sizes of areas a and b. The midpoint criterion value (red dotted line) is shifted from the minor diagonal. Sensitivity (A_{ROC}) equals the total area under the ROC curve (a+b+c+d). Response bias (β_k) equals the ratio of area between the ROC curve and the major diagonal that is either side of the midpoint criterion (b/a).

Assuming that the rating scale is balanced (such that there are an equal number of points on the scale that relate to responses relating to the signal being perceived as present and absent) then the middle point on the ROC curve will represent the criterion that is used to separates positive and negative responses (i.e. that separates the 'no' responses from the 'yes' responses; identical to the criterion that would be evident if just the Yes/No responses were used). A liberal response bias (i.e. toward responding 'yes') will result in high values of H and F being maintained across the criterion values scale (as both H and F increase with more 'yes' responses). This will in turn cause the ROC curve to stay closer to the maximum value of both axis and will therefore cause the points on the curve to 'bunch up' towards the top right of the graph (Appendix Figure 6B). The opposite will be true if there is a conservative response bias. The values of H and F will drop more quickly than when there is a no response bias, bunching the points on the ROC curve towards the bottom left. When there is no response bias the ROC curve should be symmetrical either side of the midpoint criterion (the point which separates 'Yes' from 'No' responses). In effect the midpoint criterion will sit on the minor diagonal (Appendix Figure 6B.). It follows that a measure of response bias (β_k) can be taken by calculating the ratio of area between the ROC curve and major diagonal; that is above and below the midpoint criterion value (Kornbrot, 2006).

The aforementioned calculations of sensitivity and response bias are termed "distribution-free" measures because they do not assume a shape for the distribution of the decision variable. The derivation of the various areas under the ROC curve can be achieved via geometric principles (Kornbrot, 2006) using the formulas shown in Appendix Figure 7. (taken from Fleming, et al., 2010). Sensitivity is then simply the sum of these areas ($K_A + K_B$), whereas response bias is the natural logarithm of their ratio ($\ln[K_A/K_B]$).

$$K_A = \frac{1}{4}\sum_{k=1}^{k=\frac{1}{2}i}[(h_{k+1} - f_k)^2 - (h_k - f_{k+1})^2]$$

$$K_B = \frac{1}{4}\sum_{k=\frac{1}{2}i}^{k=i}[(h_{k+1} - f_k)^2 - (h_k - f_{k+1})^2]$$

Appendix Figure 7. Derivations of the areas which lie between the ROC Curve and the major diagonal and which are either below (K_A represented by 'b' on Appendix Figure 6) or above (K_B

represent by 'a' on Appendix Figure 6) the midpoint criterion . For each criterion value (k) a hit rate (h) and false alarm rate (f) are calculated as described in Appendix Figure 5.). These h and f values equate to the points which are used to plot the ROC curve. The formula shown in effect calculates the area between the ROC curve and the major diagonal by splitting it into (polygon) sections that cover the distance between one criterion point (k) and the next (k+1). These polygons areas are the summed for each criterion (k) before and after the midpoint criterion ($\frac{1}{2}i$, with *i* representing the total number of criterion).

Appendix 5: Audio-visual stimuli used during the oddball studies.

Aversive Audio-Visual stimuli

Image_Desc	IAPS_Nbr	Valence	Arousal	Sentence	Words	Sylables
Mutilation	3071	1.88	6.86	Throat wounds sever crucial arteries	5	9
Mutilation	3051	2.3	5.62	People are sometimes attacked for no reason	7	11
DeadBody	3120	1.56	6.84	Some people have died during surgery	6	10
Mutilation	3225	1.82	5.95	Disfigurement is usually permanent	5	11
Mutilation	3000	1.59	7.34	Physical attacks often target the face	6	11
BatteredFem	3181	2.3	5.06	People can be abused by those they love	8	10
Mutilation	3010	1.71	7.16	Gun shot wounds are often fatal	6	8
Dirty	9300	2.26	6	Untreated Faeces can harbour disease	5	10
Mutilation	3060	1.79	7.12	Eye sockets are vulnerable to damage	7	11
Toilet	9301	2.26	5.28	Diahorrea is extremely unpleasant	4	11
SlicedHand	9405	1.83	6.08	open wounds can become infected	5	9
Cat	9571	1.96	5.64	Many pets are killed on the road	7	8
Mutilation	3030	1.91	6.76	A single blow could kill anyone	6	9
BurnVictim	3100	1.6	6.49	Severe Burns are extremely painful	5	9
Mutilation	3068	1.8	6.77	People have been killed while they sleep	8	8
Tumor	3261	1.82	5.75	Cancerous tumours can be deadly	5	9
Mutilation	3064	1.45	6.41	Millions have died in civil wars	6	9
BurnVictim	3110	1.79	6.7	human flesh can be easily burnt	6	9
Mutilation	3150	2.26	6.55	Fingers are often lost in accidents	6	10
Mutilation	3069	1.7	7.03	The skull is fragile to trauma	6	8
SeveredHand	3400	2.35	6.91	A severed hand cannot be reattached	6	11
Accident	3015	1.52	5.9	Many have died in Traffic accidents	6	10
Mutilation	3080	1.48	7.22	Often injured people cannot be saved	6	10
Mutilation	3130	1.58	6.97	Severe blood loss can cause death	6	7
Dog	9570	1.68	6.14	Stray dogs are often killed	5	6
StarvingChild	9040	1.67	5.82	Millions have died through starvation	5	9
DeadMan	9433	1.84	5.89	Murders are common in some countries	6	9
Injury	3550	2.54	5.92	Blood loss can cause people to panic	7	9
EyeDisease	3160	2.63	5.35	Eyes can easily become infected	5	10
DeadCows	9181	2.26	5.39	many animals starve to death	5	8
CryingBoy	2900	2.45	5.09	children find funerals traumatic	4	9
Assault	9254	2.03	6.04	Terrorism has caused many deaths	5	9
DuckInOil	9560	2.12	5.5	Animals suffocate in oil spills	5	9
HungMan	9265	2.6	4.34	Hanging kills by constricting the neck	6	9
Vomit	9320	2.65	4.93	Vomit can contain blood and bile	6	8
SickKitty	9561	2.68	4.79	injured pets often have to be put to sleep	9	11
DisabledChild	3300	2.74	4.55	Some children are born with disabilities	6	11
Attack	6370	2.7	6.44	Violent Criminals often mask their faces	6	11
StickThruLip	9042	3.15	5.78	Large incisions to the lip are painful	7	10
NativeBoy	2730	2.45	6.8	Close contact with animals is unhealthy	6	11
Mutilation	3168	1.56	6	The face is vulnerable to disfigurement	6	12
Mutilation	3016	1.9	5.82	Violent attacks can occur during the day	7	11
BurntFace	3101	1.91	5.6	Flesh can be burnt by chemical agents	7	10
Toenail	N/A	N/A	N/A	Toenails can separate from the skin	6	9
Puss	N/A	N/A	N/A	Pus is the result of infection	7	9
Headburn	N/A	N/A	N/A	Severe sunburn damages the skin	5	9
HandInjury	N/A	N/A	N/A	Open wounds should be treated quickly	6	9
Disfigureation	N/A	N/A	N/A	Chemicals can disfigure the skin	5	9
MissingToes	N/A	N/A	N/A	Toes sometimes need to be amputated	6	10
Toe Stitches	N/A	N/A	N/A	Blood often clots around stitches	5	7
Sliced Foot	N/A	N/A	N/A	Cuts to the sole are difficult to repair	8	11
ExposedNail	N/A	N/A	N/A	Infected nails are often removed	5	9
Skull wound	N/A	N/A	N/A	The skull can easily be penetrated	6	9
Deformed Face	N/A	N/A	N/A	Severe deformity is hard to live with	7	11

Neutral Audio-Visual stimuli

Image_Desc	IAPS_Nbr	Valence	Arousal	Sentence	Words	Sylables
Satellite	5471	5.21	3.26	Satellites are used for communication	5	11
Outlet	6150	5.08	3.22	Electrical sockets are commonplace	4	10
RollingPin	7000	5	2.42	Rolling pins are used to flatten dough	8	9
Bowl	7006	4.88	2.33	People have breakfast in the mornings	6	9
Mug	7009	4.93	3.01	mugs are used to hold beverages	6	8
Fan	7020	4.97	2.17	Fans are used for climate control	6	8
Iron	7030	4.69	2.99	some clothes require ironing	4	6
Shoes	7038	4.82	3.01	Walking boots are heavier than shoes	7	9
Baskets	7041	4.99	2.6	Wood has a multitude of uses	6	9
HairDryer	7050	4.93	2.75	Hairdryers can be noisy	4	7
Candlestick	7053	5.22	2.95	Glass objects are usually breakable	5	10
Lightbulb	7055	4.9	3.02	There are different types of lightbulb	6	9
Tool	7056	5.07	3.07	Many tools have multiple uses	5	9
Coffeecup	7057	5.35	3.39	Coffee normally contains caffeine	4	9
Keyring	7059	4.93	2.73	Metal can be moulded into loops	6	9
Fork	7080	5.27	2.32	Cutlery is used to eat food	6	8
Truck	7130	4.77	3.35	Lorries are used to transport cargo	6	10
Umbrella	7150	4.72	2.61	Umbrellas can be used to stay dry	6	9
Lamp	7175	4.87	1.72	Most lamps are powered by electricity	6	11
Bed	7710	5.42	3.44	Pillows support the head during sleep	6	9
AbstractArt	7185	4.97	2.64	Art can be used to decorate walls	7	9
Plate	7233	5.09	2.77	Plates are often decorated with patterns	6	11
Bridge	7547	5.21	3.18	Bridges can be used to cross rivers	7	9
Tissue	7950	4.94	2.28	Tissues are made from paper pulp	6	8
Boat	5390	5.59	2.88	Rowing is a form of exercise	6	9
Bus	7140	5.5	2.92	Coaches are used for long distance travel	7	10
Clothespins	7052	5.33	3.01	Pegs can be made out of wood or plastic	9	10
Book	7090	5.19	2.61	Books can have hard or soft covers	6	8
Window	7490	5.52	2.42	Exterior walls can be painted	5	9
Flowers	5731	5.39	2.74	Gardening is a common pasttime	5	9
Rug	7179	5.06	2.88	Carpets are often made from nylon	6	9
Building	7491	4.82	2.39	Buildings come in many different shapes	6	9
Pole	7161	4.98	2.98	Floor tiles can often become cracked	6	8
Basket	7010	4.94	1.76	Baskets are usually made from wicker	6	10
FireHydrant	7100	5.24	2.89	Fire hydrants provide a source of water	7	10
Shadow	2880	5.18	2.96	Shadows occur when light is obstructed	6	10
Shipyard	7036	4.88	3.32	Goods are regularly transported by ship	6	11
Towel	7002	4.97	3.16	Towels are designed to be absorbant	6	10
Chess	2840	4.91	2.43	A chess board has sixty four squares	7	8
Shopping	2745.1	5.31	3.26	Supermarkets sell many different products	5	11
Mushroom	5520	5.33	2.95	Mushrooms are a type of fungus.	6	8
Rain	9210	4.53	3.08	Frequent rain is vital for life on earth	8	10
Hammer	7034	4.95	3.06	Claw Hammers are used to extract nails	7	9
Spoon	7004	5.04	2	Spoons are used for the consumption of food	7	10
Chair	7235	4.96	2.83	A Chair normally has four legs	6	8
NeuWoman	2038	5.09	2.94	Laptops allow mobile computing	4	9
NeuMan	2102	5.16	3.03	Most newspapers are printed daily	5	9
Man	2190	4.83	2.41	Flat caps are often made of tweed	7	8
Secretary	2383	4.72	3.41	Many companies employ secretaries	4	11
Factoryworker	2393	4.87	2.93	Many people are employed in factories	6	11
Tourist	2850	5.22	3	Many economies rely on tourism.	6	12
Teenager	2870	5.31	3.01	Modern cars have inbuilt radios	5	9
Plant	5740	5.21	2.59	Plants grow in a variety of locations	7	12
Man	7493	5.35	3.39	Many streets are paved with stone	6	7

Appendix Figure 8: Details of the images and sentences used for the audio-visual stimuli during the tasks detailed in Chapters 3 and 4. Ratings of arousal and valence are provided for the IAPS images.

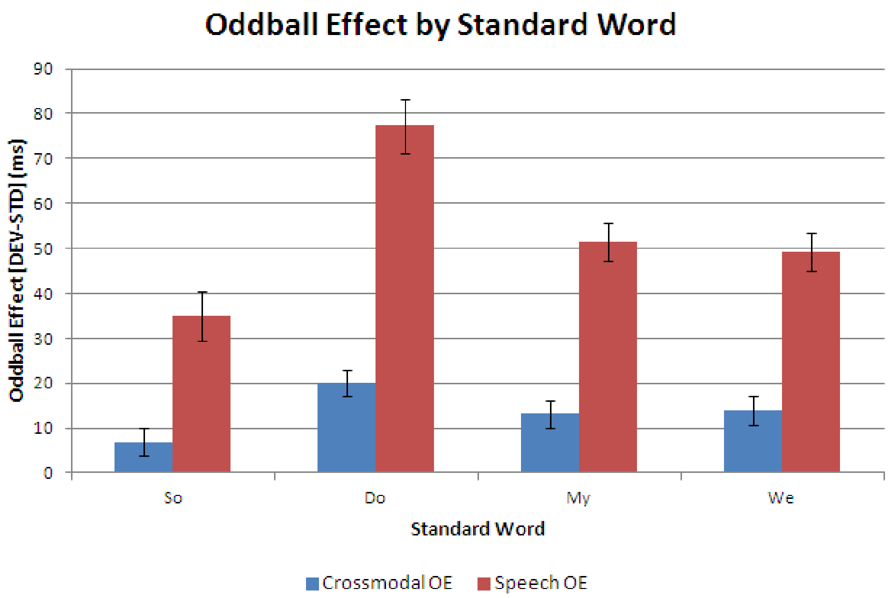
Appendix 6: Words used as auditory stimuli during oddball trials.

Word	Type (Freq)	Homophone (Freq)	Total Freq
So	Qualifier (932) Adverb (574) Conjunction (479)	Sew (6)	1991
Do	Verb (1350)		1350
My	Pronoun (1366)		1366
We	Pronoun (2654)	Wee (3)	2657

Appendix Figure 9: Words used as auditory oddball stimuli during the oddball tasks detailed in chapters 3 and 4. Word types and frequencies taken from Francis et al (1982)

Appendix 7: Analysis of the impact of standard word type on the oddball effect

Four different word stimuli were used in both oddball tasks during the oddball study detailed in Chapter 3, with each word taking the role as the standard in 2 of the 8 blocks (see Task Design section). Although this design counterbalanced any potential standard word*stress interaction within the data, we nevertheless ran a 2*2*4 repeated-measures ANOVA with stress, trial type and standard word (Do, We, So and My) as the factors for both tasks. The 3-way interaction, and the 2-way stress*standard word interaction were non-significant for both tasks ($p>.2$) suggesting that the nature of the words used in each task did not alter the impact of the stress manipulation. Interestingly however there was a 2-way standard word*trial type interaction in both tasks. Post-hoc analyses revealed that in the speech task the oddball effect when the word 'Do' was the standard was larger than for all the other words, and that the oddball effect for the word 'So' was smaller than that for all the other words. The data was in the same direction for the crossmodal task although only the direct contrast of the oddball effects for 'So' and 'Do' reached significance once the data had been corrected for multiple comparisons (Appendix Figure 10.).



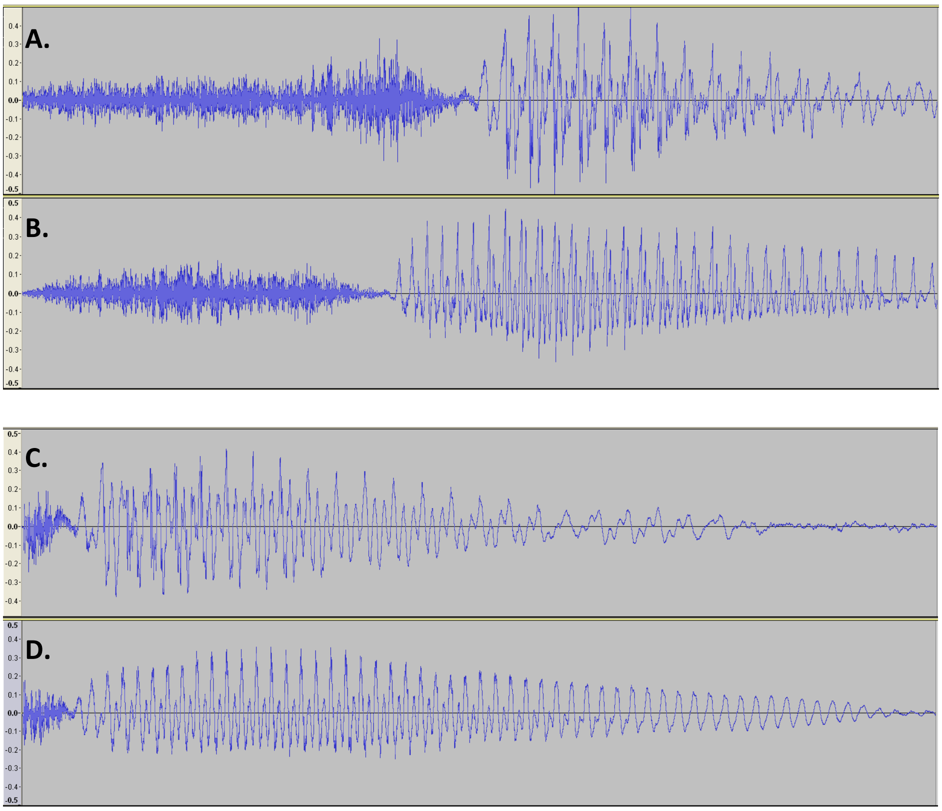
Appendix Figure 10: Oddball Effect (difference in reaction time between deviant and standard trials) for the speech and crossmodal oddball tasks, split by the word that was used as the standard oddball stimulus.

Appendix 8: Reaction times during the speech oddball task

	N	Range	Minimum	Maximum	Mean	Std. Deviation
Non-Stress Deviant	49	277.93	356.61	634.54	466.22	64.56
Non-Stress Standard	49	353.40	299.91	653.31	409.99	71.22
Stress Deviant	49	306.11	327.37	633.48	465.83	66.73
Stress Standard	49	352.48	294.62	647.10	415.54	69.61

Appendix Figure 11: Descriptive statistics concerning reaction times during the speech oddball task

Appendix 9: Waveforms for the speech stimuli used during dichotic oddball trials.



Appendix Figure 12: Wave forms showing the recordings of the auditory oddball speech stimulus used in the dichotic task (Chapter 4.). Top 2 plots show the word 'So' recorded in a male (A) and female (B) voice. Bottom 2 plots show the word 'Do' recorded in a male (C) and female (D) voice.