Investigating Misperceptions of visuotactile information,

Somatosensory Amplification and Illusory Tactile Sensations

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Abstract

This thesis investigated the underlying mechanisms of illusory tactile sensations that are generated by visuotactile cross-modal manipulations in healthy individuals using the Somatic Signal Detection Task (SSDT) as well as a modified version of the task known as Somatic Signal Discrimination Task (SSDiT). To investigate how the presence of light can result in an illusory report of tactile intensity (i.e., False Alarms), a series of behavioural experiments were conducted using the SSDT and SSDiT paradigms. Further experiments measured the underlying neural processing using EEG and MIRAGE augmented reality system. Behavioural findings indicate that simultaneous presentation of light with a tactile pulse created an illusory tactile enhancement effect (greater false alarms). EEG results indicate that there are two underlying mechanisms that are present during the SSDiT, an early sensory mechanism (EEG components P120 and P160) and a later discrimination mechanism (P360 and P400). Additionally, the SSDiT MIRAGE investigation found that participants were affected by bottom-up visual information they perceived, as fewer false alarms were observed during light present trials during the visual manipulated conditions (no sight and pixilated view). This implies that the level of external focus participants have can affect their susceptibility to experience these illusory sensations; more specifically, bottom-up sensory information can be affected by top-down expectations.

The findings from the current investigations suggest that these illusory mechanisms occur as a result of hyper awareness to ambiguous extra-bodily stimulus that is misinterpreted subjectively as being an actual stimulus sensation when it is not. The individual's ability to 'filter' out non-essential sensory noise causes disruptions to the mechanisms that mediate sensory information processing (e.g., the ability to distinguish threatening stimulus from non-threatening). The findings of this thesis can be used to help improve the treatment of patients with Medically Unexplained Symptoms (MUS) by focusing on improving patients' interpretation and perception of sensory signals.

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Chapter one

Introduction

The focus of this thesis is to provide a deeper understanding of the processes underlying somatic misperceptions by observing visuo-tactile illusory sensations reported by healthy participants. Previous research has shown that the presence of a light has resulted in individuals reporting that they felt a tactile sensation when no stimulation was present, and it has also resulted in an enhancement effect of near threshold tactile stimuli. Additionally, this thesis aimed to investigate the cognitive factors that may modify these experiences as well as to understand the temporal nature of these illusory sensations. This chapter will first touch briefly on medically unexplained symptoms (MUS) and the theories that seek to explain it. Although this thesis did not investigate patients with MUS, it is important to understand how illusory sensations can impact health. The chapter will then move on to discuss cross-modal illusions and then focus on research related to the Somatic Signal Detection Task (SSDT) and Somatic Signal Discrimination Task (SSDiT).

Somatic Misperceptions and Medically Unexplained Symptoms

We perceive the environment around us in many different ways, and the brain also holds concepts and beliefs about the self. At times these beliefs can become distorted in a way that feel subjectively real, these are called somatic misperceptions. These misperceptions can be expressed as unpleasant symptoms that cause distress to the individuals, with no medical explanations to their cause. Medically Unexplained Symptoms (MUS) are examples of somatoform dissociation and connected phenomena, such as amnesia and identity disturbance (Nijenhuis, 2004). These MUS occur when individuals experience convincing physical symptoms in the absence of any physical abnormality (DSM-IV,* American Psychiatric Association, 1994). In primary care, MUS are commonly seen in the form of sensory loss, amnesia, paralysis, gait disturbance, tremor, pseudo-hallucination, convulsive and non-convulsive pseudo-seizures. These symptoms can be exhibited on a short-term or long-term basis, with 20% of the general population having occurrences of MUS lasting constantly or on a regular basis for six months or longer (Faravelli et al., 1997). MUS can be a considerable strain on resources for primary health care units (Kroenke, Spitzer, Williams, 2002). Patients with MUS account for one third more hospitalisations than patients without MUS. Additionally, patients with MUS account for one-third more of outpatient costs. GPs receive little formal training with the assessment and management of patients with MUS and do not have the resources available to refer patients with MUS to

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* The DSM-IV was updated to the fifth edition (DSM-V) during the course of this thesis; therefore, the DSM-IV classification for somatoform disorders has changed to Somatic Symptom Disorders (SSD) and related disorders. SSDs are characterised by somatic symptoms that are very distressing or result in significant disruption of daily life and must be accompanied by excessive and disproportionate thoughts, feelings and behaviours relating to the symptoms. An individual would be diagnosis as SSD if they have persistently been symptomatic, for at least six months. The SSD diagnosis no longer requires that somatic symptoms are MUS, as it is not appropriate to diagnose individuals with a mental disorder solely because a medical cause cannot be demonstrated.

relevant health care services and professionals (Morriss & Gask, 2006). Treatment of MUS varies and consists mainly of cognitive behaviour therapy (CBT; e.g., Speckens et al., 1995, Sumathipala, 2007) short-term group therapy (e.g., Kashner, 1995) and psychodynamic psychotherapy. The reason for the occurrences of MUS is very much debated. There are three main theories that attempt to explain the cause of MUS: dissociation theory, conversion theory and somatisation theory.

Dissociation theory

Dissociation theory state that the expression of MUS is due to a narrowing of attention when exposed to traumatic events, which lead to dissociate traumatic memories (Janet, 1889). This narrowing of attention reduces the amount of sensory information that can be focused on at once. Therefore, individuals may develop a habit of concentrating on a few sensory modalities while ignoring the remaining, leading to the loss of attentive control over the ignored channels. The information from the unattended modality is still processed outside of conscious awareness (Janet, 1889). Janet (1907) stated that these symptoms may occur due to the activation of memories that have become dissociated from what they actually were as their attention is focused to a specific single modality. This would mean they cannot integrate new memories with their existing knowledge of self. Therefore, an inability to integrate new sensory information leads to misinterpretation, and new memories are processed as perceptions rather than recollections. The emotional and mental state of an individual would affect their ability to process the sensory stimulus, as it would affect top-down (internal models/perceptions held by the body) processing of the bottom-up (incoming sensory data) sensory information.

Similarly, Ludwif (1972) also proposed that MUS is the result of a deficit in attention. This dysfunction is a process of inhibition, which generates a dissociation between attention and the source of stimulation, that prevents the integration of sensory information with that of the individuals' conscious awareness.

Conversion Theory

Conversion theory state that the brain attempts to balance the conscious experience of negative affects by unconsciously repressing the memories linked with a specific trauma (Breuer & Freud, 1991). According to the conversion model, unexplained symptoms are a form of defence mechanism. This notion is similar to Janet (1889, 1907) whereby the unexplained phenomena are created due to the conversion of psychological distress into physiological symptoms. In support of this theory, studies have found that patients who have experienced extreme trauma exhibit distress with physiological symptoms (e.g., Brown et al., 2005).

Somatisation Theory

Although, there are similarities between somatisation and conversion theories, the somatisation theory emphasises on the underlying processes of normal somatic perception and looks at the connection between experiencing physical and mental illness from a biopsychosocial context (Lipowski, 1968). The body monitors many different sensations (e.g., illness, emotional arousal and everyday physiological sensations) and provides different levels of attention to each sensation. These can be moderated by different mechanisms and can be affected by dispositional factors such as previous illness experience, illness worry, attention, response of others, individual differences in personality, coping mechanisms and autonomic reactivity (Kirmayer & Robbins, 1991).

Each of these three models have valid points in trying to provide an explanation of MUS; however, these are general descriptions of possible causes for MUS which are not always precise and may cause confusion about the source of dissociation (Frankel, 1994). These models also emphasise the roles of the individuals' emotional and motivational factors (Ron, 1994). Brown (2004) put forward a theory called the integrative conceptual model of MUS that incorporates aspects of the dissociation and conversion models. This model theorises that MUS are an illusory somatosensory phenomenon that is subjectively real to the people reporting the symptoms. Brown's (2004) model supports the dissociation theory of Janet (1889), suggesting that these symptoms are caused by the disruption between conscious and preconscious processing of stored information in the cognitive system. Brown's (2004) integrative conceptual model of MUS also takes aspects of the conversion and somatisation theories by stating that these processes are often a defensive reaction to reduce the exposure to a traumatic affect; furthermore, this model identifies that symptom-focused attention is a key component of the creation of and the maintenance of MUS. To help the treatment of patients with MUS, one needs to understand how and why patients with MUS experience illusory somatosensory sensations.

Cross-modal Sensory Illusions

Illusory somatosensory sensations have been created in healthy participants by cross-modal manipulations. This is when illusory experiences are brought on by manipulation of one sensory modality affecting the perception of another sense (e.g. visual stimulus to induce illusory tactile sensations) making it a cross-modal stimulus effect (e.g. Botvinick and Cohen, 1998; Ramachandran, Rogers-Ramachandran & Cobb, 1995; Ro, Hsu, Yasar, Elmore, Beauchamp, 2009).

It is common to use signal detection analysis in cross-modal investigations as it uses participants' actual responses to the task stimuli, which helps to understand the extent to which participants were actually responding to the task at hand rather than guessing. Signal detection analysis enables us to determine whether participants were able to distinguish between task signals and noise. Signal detection terminologies would be applied to the participants' responses: a 'yes' response to stimulus present trials would be a 'hit'; a 'yes' response to stimulus absent trials would be a 'false alarm; a 'no' response to a stimulus present trial would be a 'miss'; and a 'no' response for stimulus absent trial would be a 'correct rejection'. Signal detection analysis uses this information to then calculate Hit and False Alarm rates, sensitivity indices (*d'*) and response bias (*c*). Sensitivity indices (*d'*) indicates how much the two signals (e.g., task stimuli and noise) differed within the task. This would also indication how difficult participants found the task. Response bias (*c*) is an indicator of the strategy that participants adopt in order to gauge how to make their judgement. A positive response bias (*c*) would indicate a conservative (less liberal) approach; a negative response bias (*c*) would indicate a more liberal approach.

Examples of cross-modal illusory sensations include that of Lovelace, Stein, Wallace (2003) who investigated how multisensory information/cross-modal interactions can enhance stimulus detection; low-intensity sound detection could be influenced by the simultaneous presentation of a task irrelevant light. Lovelace et al. (2003) conducted two experiments that asked participants to indicate the presence or absence of a brief low-intensity sound that was either presented alone or paired with a simultaneous light (central LED) in a signal detection task. Lovelace et al. (2009) found that during experiment 1, the task-irrelevant light did enhance the detection of the sound, and also increased participants' response bias (*c*; willingness to report the presence of a sound). Lovelace et al. (2009) designed experiment 2 to remove this response bias and found that there was also an enhancement in participants' ability to detect the audible stimuli, without affecting the participants' response bias (*c*). Lovelace et al. (2009) conclude that their findings suggest that the enhancement of detection seen can be due to changes in activity at early stages of sensory information processing.

Cross-modal investigations identified that focusing on the site of stimulation results in an enhancement of detection and discrimination of stimuli (task relevant) (Kennett, Taylor-Clarke, Haggard, 2001; Taylor-Clarke et al., 2002; Lloyd et al., 2008; Mirams et al., 2010). These enhancements in tactile detection are thought to result due to the cross-modal effect of vision influencing small tactile receptive fields, via feedback to the early somatosensory cortex (Kennett et al., 2001). Functional imaging data has shown that tactile events do change unimodal visual processing areas of the brain (Kennett, Eimer, Spence, Driver., 2001). An increase in accuracy would be the result of an adapted unimodal sense of touch to gather more information from the visually relevant sight of the skin due to an increase in feedback to unimodal somatosensory areas (Kennett, Taylor-Clarke, Haggard, 2001; Kennett, Eimer, Spence, Driver., 2001).

This type of feedback processing consists of multimodal systems working simultaneously; processing internal and external sensory information. The ability to react to the environment must require a representation of the body (the body schema) and the space immediately around the body (peripersonal space; Rizzolatti, 1997; Holmes and Spence, 2004). Peripersonal space is the area immediately around the body where objects can be directly interacted with or reacted to. Objects within the peripersonal space do not require movement to be interacted with; conversely, objects outside this space (i.e., extrapersonal space) would require movement towards the objects or for objects to be moved closer. A review of body schema and peripersonal space by Holmes and Spence (2004) indicates that viewing one's direct body, or body part in mirrors or computer screen and using tools might modulate representations of peripersonal space and body schema. These representations are dynamic interactive properties between multisensory neural regions. Separate representations must exist for close objects and those further from the body. The neural representations of peripersonal space are thought to be built from multi cortical regions. A peripersonal body-centred representation would consist of a reference for the entire surface of the body, which could be held within the primary somatosensory cortex and several other brain areas. In order to process visual space around the body the specific part of the body's somatotopic representation would become active after visual detection of the respective body sites were detected (Holmes and Spence, 2004). This can enhance tactile perception by amplifying responses to tactile stimuli in the somatosensory cortex (Burton & Sinclair, 2000). Attending to the body can increase awareness of bodily sensations, however interoceptive (awareness of stimulus from within one's body) accuracy would not improve detection of tactile stimulus. Interoceptive ability was accessed by participants counting their heartbeat during the trials, greater accuracy in counting would indicate greater interoceptive awareness (Mirams, Poliakoff, Brown, Lloyd., 2012). Conversely, focusing attention to interoceptive information can result in perceptual errors occurring (illusory reports), such as reporting the presence of a physical sensations that do not exist (similar to that of MUS patients) or reporting sensations that are greater than the level presented (enhancement effect). The perceptual relationship between peripersonal and extrapersonal space have been explored using cross-modal sensory modulation to understand how illusory sensations can arise.

Both animal and human studies have found that for any illusory cross-modal enhancements to occur, the stimuli of both modalities (e.g. tactile and visual) have to be presented in the same or in very close proximity to each other (Meredith and Stein, 1986; Avillac, Ben Hamed, & Duhamel, 2007) and is also found in human studies where participants have viewed the site of stimulation (Lloyd et al., 2008; McKenzie et al., 2010; Poliakoff et al., in prep; Taylor-Clark et al., 2001, 2002). Perception of external stimuli occurs in different ways, a stimulus that is far from the body would be interpreted a different way to those closer to the body. A major factor that affects perception of close objects (within peripersonal space) is the ability to be able to directly interact/react to these stimuli.

Longo, Musli, Haggard (2012) conducted an ERP investigation into visuo-tactile integration in peripersonal space (the skin). Participants were seated at a table and had a mirror placed along their midline, with both arms placed at equal distance on either side. The mirror could be turned at a slight angle to either provide a leftward or rightward viewing angle. The middle and ring finger on both hands were attached to stimulus array. When viewing the hand in the mirror it would appear to be in the same location as the real limb behind the mirror. Participants were asked to make verbal reports of which finger they saw touched in the mirror and which finger they felt touched behind the mirror. There were four experimental conditions, the fingers of the hand behind the mirror (middle or ring) and the mirror image fingers. To account for subjective experiences of the mirror box a questionnaire was verbally delivered after each block. Longo et al. (2012) did find connections between both visual and tactile judgements of whichever finger on the left hand had been touched; this was not found for right hand judgements. ERP component analysis found P200 was greater and the N2 was reduced over congruent stimulus trials on the left hand, but not the right. A large contralateral P300 component was found over parietal areas for congruent stimuli on both hands. Longo et al. (2010) conclude that their findings provide evidence for highly precise spatial matching of multi-sensory signals originating in personal space. Internal and external factors do contribute to the illusory effects of cross-modal integration. The sensory information from peripersonal space (bottom-up) must affect the body schema (top-down information) to a certain degree; enough to cause misperceptions of external stimuli (e.g. illusory enhancement of touch).

Talsma (2015) put forward the unified theory of bodily self, which helps explain how sensory data (bottom up) and internal held models (top-down; e.g. body schema) can interact and how misperceptions could occur. The unified theory of bodily self states that bottom-up data is constantly being compared with top-down data held by the body. The integration between sensory systems occurs due to top-down information actively maintaining a mental model of the environment based on the concepts of environmental probabilities (Talsma, 2015). These estimated predictions would be about how environmental factors can affect the body. Prediction errors occur when the incoming data does not match the internally held predictions. The brain must be able to minimize these prediction errors, or unexpected events (surprises) over all sensory mechanisms to maintain a stable representation of the self. A dynamic evaluation mechanism must be working to adjust predictions of the self, based on the actual sensory information, which would also adjust initial sensory processing (Talsma, 2015). This dynamic mechanism of feedback and adjustments must learn and provide the best model of prediction to maintain optimum operation of the body. This would mean that the image held of the bodily self would also need to be flexible (Seth & Critchley, 2013; Seth, 2013; Apps & Tsakiris, 2014; Talsma, 2015; Tsakiris, 2017). The individual's sensory information is processed in a probabilistic manner, by adapting a model that best fits the image of the self, which is most likely to be 'me' (Seth & Critchley, 2013; Seth, 2013; Apps & Tsakiris, 2014).

Integration of top-down (estimated predictions of the body) with uni-modal bottom-up (prediction errors) would create the probabilistic representations of self (Apps & Tsakiris, 2014; Moutoussis, Fearon, El-Deredy, Dolan, & Friston, 2014; Tsakiris, 2017). The model of self is a multimodal concept, thought to be a hierarchical construct, consisting of higher level (top-down) beliefs and attitudes and lower level (bottom-up) bodily representations (Seth, 2013; Moutoussis et al., 2014; Tsakiris, 2017). The self would be distributed and underpinned by different types of information from different modalities across this hierarchical model. The signals and predictions from different modalities would be utilised to reduce/account for errors detected in another modality, such as amodal assumptions (predictions). This hierarchical model would therefore, integrate interoceptive and exteroceptive pathways for there to be a body self representation (Seth, 2013; Moutoussis et al., 2014). Predictive coding model would see continuous interaction in the form of prediction errors at each level of perceptual representation (via uni-modal processing and bottom-up data). Unexplained errors would need to be processed at a higher level within the hierarchy. Data processing within this hierarchal model uses continuous evaluative and updating processing (through active inference, a feedback and feed forward mechanism) between the internal predictions of stimuli from different modalities (top-down) and early uni-modal (bottom-up) sensory processing of self constructs (Kennett, Taylor-Clarke, Haggard, 2001; Taylor-Clarke, Kennett, & Haggard, 2002; Busse, Roberts, Crist, Weissman, Woldorff, 2005; Lloyd et al., 2008; Mirams et al.

2010; Van der Burg, Talsma, Olivers, Hickey, Theeuwes, 2011; Seth, 2013; Moutoussis et al., 2014; Talsma, 2015; Tsakiris, 2017). Predictions already held (and subsequent prediction errors) or newly modified predictions would vary in their level or reliability depending on the quality of incoming sensory signals (bottom-up). Sensory signals compatible with few potential predictions would have high precision and would consist of low noise (higher reliability). The opposite would apply if sensory signals were compatible with many predictions, they would be deemed as being composed of less reliable (greater noise) information or imprecise prediction errors and would be inhibited by a more reliable prediction (Apps & Tsakiris, 2014; Tsakiris, 2017).

Studies that have shown that changes to perceptual beliefs brought on by a modified external image of self or a combination of visual and internal focus can affect an individual's perception of external stimuli (e.g. Botvinick and Cohen, 1998; Jousmaki and Hari, 1998; Ramachandran et al., 1995). Newport, Preston, Pearce, Holton (2009) investigated this aspect while examining the after effects of prism lens (PL) adaption. PLs shift light entering the visual fields of the eye at an angle, displacing the wearers' visual field to the left or depending on the angle of the PL. When worn PLs initially cause participants to misreach targets, their reach is offset in the direction of the visual displacement. After a short while participants become accurate at aiming to the visual targets. However, when the PLs were removed, participants made target-reaching errors in the opposite direction, a residual effect of the PL adaption. Newport et al. (2009) aimed to understand the process that occurs during the PL adaption process to further the understanding of visual neglect patients. Neglect is a neuropsychological condition that is caused by right hemisphere stokes, and results in the patient to not respond to stimuli to their left side.

The established methods of measuring the aftereffects were not able to fully distinguish between the influences of visual error feedback and eye movements during the adaption period. Newport et al. (2009) created a novel way to present realistic moving visual depictions of participants' own hands, which allows for a variety of visual manipulations to create illusory visual effects, such as stretching participants' finger to double its length, and making it appear as though it has become detached form the hand (see chapter 2 Methods, for more details information about the MIRAGE). Newport et al.'s (2009) method enabled them to separate the eye movement and manual error reduction to subjective straight ahead (SSA, where participants point out along their midline with their eyes closed) by either shifting the eye alone, the hand alone or both together. They found that shifting the hand did contribute to SSA realignment, however eye rotation alone did not.

Newport, Pearce, Preston (2010) utilised low and high level measurements of ownership to investigate whether synchronous active stroking can inform low level motor responses (body schema) as well as high level perceptual judgements of ownership (body image). They used an augmented reality system to manipulate live dynamic video image of participants' own real hand in the same location as their real unseen hand (Newport, Preston, Pearce, & Holton, 2009). The dynamic nature of this task could facilitate participants' incorporating not their real limb locations into their action based body schema. The view of participants' hand was manipulated to show two additional virtual hands, to the left or right of the true location of their real hand. Participants were not informed if the hand they were viewing was in the same location as their actual real hand. In the experimental condition two simultaneous representations of their left hand were presented. Three visual feedback manipulations were applied. Participants were then required to make an open-loop pointing movement towards a target that was directly positioned ahead of the real unseen hand. Participants were also asked to verbally complete questionnaires (adapted from Botvinik and Cohen, 1998) to determine the level of ownership and indicate whether the limb(s) had been incorporated into the body image and body schema. They found that participants claimed a sense of ownership over two limbs and no difference was observed between the distractor and no distractor task in the both hand synchronous conditions. The two simultaneous limb presentations can be assimilated into the body image, however only one can be incorporated into the body schema (Newport et al., 2010). The MIRAGE system provides a means to distort body representations and can be utilised as a tool to research body image representations and body schemas. Further studies using the MIRAGE system have successfully shown the distinction between body image and body schema (Newport, Preston, 2011); how different fake limbs were simultaneously incorporated into the body image and the body schema (clinical population: Preston, Newport, 2011a); evidence from MIRAGE study is in favour of multiple and dissociable body representations in the brain (Preston, Newport, 2011b); and provide an insight into disorders of body ownership, which also outlines the importance of bottom-up processing of normal body sensory functions (Newport and Gilpin, 2011).

The Somatic Signal Detection Task

In order to explore cross-modal illusory sensations, Lloyd, Mason, Brown, Poliakoff (2008) developed a paradigm that creates a robust illusory effect within healthy participants in a laboratory setting while the individuals are not consciously aware that they are experiencing an illusory effect. Lloyd et al. (2008) developed an experimental paradigm (the Somatic Signal Detection Task (SSDT) to investigate the creation and maintenance of illusory tactile sensations within a laboratory setting. This technique measures changes in tactile sensitivity and response bias and the paradigm is based on the findings of Johnson, Burton, Ro (2006).

Johnson et al. (2006) conducted five experiments to investigate if non-informative light stimulus paired with a tactile pulse could increase near threshold tactile perception in neurologically healthy participants, by affecting their response biases. All the participants were threshold before starting experiments; this was to find the lowest point at which the participants' could detect a pulse. Participants' finger was fixed to an electric stimulator that also had an LED mounted to it. Participants were asked to look at their hand and only report tactile sensations not any visual stimuli. The first experiment investigated if non-informative information affected touch detection. The second experiment investigated if there would be any improvements in detection with the shifts in response criteria. Third experiment was conducted to see if the addition of instructions resulted in the same bias for reporting a tactile sensation across all conditions. The fourth experiment was a discrimination task between visual and tactile stimuli to left middle and index fingers. The fifth experiment was similar to the fourth, except the left and right index fingers were used. Correctly reporting the stimulated finger or reporting none during light only trials was considered as correct responses; reports of touch on light only trials or for the opposite finger to the true site of tactile stimulation were taken as a False alarm during the fourth and fifth experiments. Jonhson et al.'s (2006) findings from the five experiments indicated that non-informative simultaneous presentation of light with tactile stimuli did increased participants' report of sensitivity to touch. The presence of light also affected participants' response biases for reporting touch with vision, even with the absence of tactile stimuli.

Building on from Johnson et al. (2006), Lloyd et al. (2008) asked participants to judge whether or not they detected a weak tactile pulse, presented alone or simultaneously with a light emitting diode (LED) flash. The stimulus array consisted of a polystyrene block with a vibrotactile bone conductor (this is a modified bone conducting hearing system's processor) with an LED mounted in it. The participants' left index finger was then fixed to the bone conductor and it was not touching the LED. There were four conditions light (light present and light absent) and tactile pulse (present and absent). Firstly, they found the participants threshold, this is finding the lowest point at which they can feel a tactile sensation, which was when the participant reported feeling a tactile pulse in roughly 50% of the trials. The beginning of each trial was cued by the mounted LED. Participants were then asked to verbally report if they had felt a pulse or not. For the light present trials the same LED as the prompt flashed for 200ms. Participants were unaware of the significance of the light stimuli and were instructed to only report if they perceived a tactile sensation. They found that the presence of a light significantly improved participants detection of the tactile stimulus, as well as increasing the number 'false alarms' reported (where participants reported feeling a pulse when none were present). The illusory sensations reported from Lloyd et al. (2008) may, as Brown (2004) integrative model suggests, because of activation of a tactile representation in memory induced by a non-tactile stimulus.

Lloyd et al.'s (2008) study may demonstrate how illusory effect can be greater when participants' focus on their body part which is the site of stimulation. Haggard, Christakou, Serino (2007) investigated how top–down factors affect tactile discrimination performance. They indicate that performance on tactile discrimination task would be affected by the size of the somatosensory cortex (SI) receptive field. SI is located in the Parietal lobe, posterior to the central sulcus, the postcentral gyrus has a somatotopic map of the entire surface of the body; and is the region of the brain that receives all sensory information. The receptors in the skin differ in the level of tactile information they supply; fingers and lips have many receptors with small receptive fields thus increasing their acuity, as compared with the forehead (Brown, Koerber, Millecchia, 2004; Haggard et al., 2007; Serino, Haggard, 2010). Haggard et al. (2007) conducted a spatial discrimination task between two touch locations on the forearm. Participants could view their arm or had their view obscured by a non-informative object. Vibrotactile masks were also placed at two equal distances on either side of the tactile target location. Performance was improved when participants saw their forearm compared to viewing a neutral object in the same location. This enhanced effect was not present during trials with restricted view of their arm, therefore sight of actual body part is important. Furthermore, the masking impaired the discrimination, also viewing the body reduced the effect of distant masks but enhanced closer mask in comparison to viewing the neutral object. Haggard et al., (2007) conclude that viewing the body improved touch detection by increasing acuity of tactile receptive fields, which maybe the result of top-down modulation of early sensory areas. Haggard et al., (2007) further state that their results indicate that visual enhancement of touch is a perceptual effect.

Serino and Haggard (2010) put forward an analytical model of how bottom-up (tactile) sensory information interacts with top-down information (mental body representations). They described four interactions of how this could happen: the connection between skin and receptive fields in the primary somatosensory cortex (SI), the contribution of SI information to mental body representations, a feedback pathway from these higher representations back to SI for tactile processing, and modulation of tactile perception by mental body representations. Serino and Haggard's (2010) model can also account for illusory multisensory symptoms and can strengthen the connection between mental body representations and how they contribute to the modulation of tactile perception.

Mirams, Poliakoff, Brown, Lloyd (2010) investigated the effect of viewing the body during the SSDT. They conducted the SSDT (as Lloyd et al., 2008) but had manipulated vision of the stimulated hand. There were two visual conditions that all participants undertook while maintaining their gaze towards their left hand: the vision condition participants had clear view of their hand and site of stimulation (but could not see the tactile stimulation); the second non-vision condition consisted of covering the entire left arm, hand and finger but the LED was visible.

Mirams et al. (2010) found that False Alarm rates were significantly greater in light trials when the hand was visible. However, vision of the hand did not affect participants' hit rates, sensitivity indices (*d'*) and response bias (*c*). The presence of light may have increased participants' tactile attention towards the hand when it was visible; as a result, participants mistakenly detect this external factor as an internal sensation.

To understand the effect of external factors on internal sensations, Mirams, Poliakoff, Brown, Lloyd (2012) investigated whether interoceptive (awareness of stimulus from within one's body) and exteroceptive (awareness of stimulus from outside of one's body, from the environment) attention would affect the tendency to report feeling this ambiguous external tactile stimulation using the SSDT. They conducted two experiments; the first was to investigate how sensory noise in the fingertip contributes to false alarms during the SSDT, and how prior performance of an interoceptive task affects preceding decision making during the SSDT. They used a mental tracking task, heartbeat sensation (HBS) task where participants concentrated on internal heartbeat pulses they felt in their fingertip. The HBS task was expected to increase interoceptive awareness, and this was expected to have a carryover effect on the performance of the preceding SSDT. This was expected to cause confusion between the internal pulse and the vibration. Participants were more likely to report feeling a touch sensation in the light absent trials during the HBS task. However, the HBS task did not affect the number of touch reports in the light absent trials and it did not affect the accuracy of tactile perception. These findings are consistent with the proposed notion of excessive focus on bodily sensations in MUS patients as proposed by Brown (2004).

For the second experiment Mirams et al. (2012) investigated the effect an exteroceptive task would have on SSDT performance. They used a grating orientation task (a tactile sensory task) to focus attention to external tactile stimulation. Participants report the orientation they feel on each trial. The researchers chose this task as it involves spatial discrimination and not just detection of tactile stimuli. This task was expected to increase sensitivity on the SSDT and increase correct touch reports, and also increased participants' confidence in their responses. They found that the grating orientation task did not affect sensitivity but did lead to participants being less likely to report feeling a touch after the task and lowered confidence in touch reports. Their response criterions (this is the participants' own willingness to respond with 'yes' they felt something) were stricter, and participants were less likely to report feeling a touch after the grating orientation task. This was evident as lower hit rates and false alarm rates were recorded across light condition. The grating orientation task was thought to have reduced levels of sensory noise by increasing awareness to the same sensory modality as the SSDT, increasing the awareness to tactile sensation of the SSDT stimuli, and by decreasing interference from distracting stimuli.

McKenzie, Poliakoff, Brown, Lloyd (2010) further investigated the illusory effects of SSDT, they had two aims: experiment 1, was to use the SSDT to investigate how strong the tendency to experience illusory touch sensations was, by comparing false alarm reports between experiment 1 and 2; experiment 2 investigated whether the modality in which trials were cued affects performance on the SSDT, Lloyd et al. (2008) used the same fixed LED to present both the start cue for the target stimulus and the task-irrelevant light stimulus. McKenzie et al.

(2010) suggested that the visual start cue used by Lloyd et al. (2008) may have drawn attention to the visual modality and this would have enhanced attention to the non-important visual stimuli, causing an increase in the Hit and False Alarm rates during light present trials. They also suggested that the participants might have been visually cued to the bodily location of the target by the proximity of the finger to the LED, which could have altered the tactile sensitivity. McKenzie et al.'s (2010) experiment 1 had participants doing the SSDT but with two different start cues, either visual or an auditory cue. The cues were presented away from the participants' left (stimulated) hand, although both cues did draw participants' attention to the stimulated hand. The visual cue was presented on a screen behind the stimulus array, a green arrow that pointed down to the participants' left hand, and the auditory cue was a tone delivered to the left ear. Each participants' threshold was found using the staircase method (Cornsweet, 1962; see Chapter 2.1.3, SSDiT thresholding for more details), this is the lowest intensity at which point participants report feeing a tactile pulse in roughly 50% of the trials. The start of trials (light (present, absent); tactile pulse (present, absent) was signalled either by the green arrow (visual cue) or a tone (auditory cue). McKenzie et al. (2010) further hypothesised that a tactile trial start cue delivered in the same modality, as the stimuli would impact more on performance on the SSDT. Therefore experiment 2 compared a vibratory tactile cue and a light flash cue as a visual cue, this would then be similar to the tactile stimuli and the task irrelevant LED. Experiment 2 was conducted in the same manner as the first, but the visual and auditory cues (green arrow and tone) being replaced by the second stimuli array comprising of an orange LED fixed to the top of a bone conductor. McKenzie et al.

(2010) found that the concurrent light did result in a higher number of illusory touch reports (similar findings as Johnson et al 2006; Lloyd et al., 2008; Mirams et al., 2010), they had also found that the trial start cue did not affect participants' responses and that response biases were steady over time. The presence of the illusory sensations were found to be quite strong as the researchers found there to be a positive relationship between the response rate of illusory sensations and the experimental sessions. The findings from McKenzie et al. (2010) second experiment also argue against a stimulus-priming effect. The tendency to report false alarms was robust in three sessions over five weeks, with those participants who reported high numbers of false alarms and those who reported low numbers continuing to do so throughout the experimental sessions.

Brown, Brunt, Poliakoff & Lloyd (2010) investigated the role of tactile perception in the development of somatoform dissociative symptoms by using the SSDT. They also aimed to understand the extent to which how the frequency of illusory touch on the SSDT varies according to the activation of tactile representations in memory (Brown, 2004; Lloyd et al., 2008). Prior to starting the experimental session participants were asked to fill out four questionnaires. The Somatoform Dissociation Questionnaire (SDQ-20; Nijenhuis et al., 1996), used to measure the tendency of experiencing pesudoneurological symptoms. The State-Trait Anxiety Inventory (STAI-T; Spielberger et al., 1983) to control for the effects of negative affectivity, which changes with medically unexplained symptoms. The Somatosensory Amplification Scale (SSAS; Barsky et al., 1988), to measures the tendency to notice and experience normal sensory events as unpleasant. Finally, the Depression Anxiety Stress Scale (DASS-21) depression subscale was used to control for individual differences in depressive symptoms, which have also been found to change in relation to medically unexplained symptoms. A memory task was used to produce low (minimal) or high (maximal) levels of activation of tactile representations in memory. Before starting the SSDT, all participants had to undertake a training phase then completed a recall task. For the latter, participants were presented with a selection of training picture stimuli and were asked to identify those that had been previously presented with a vibration during the training task. Participants were prompted to think back to the training phase and recall if the picture was paired with a vibration. If a vibration had been reported for that picture, participants were asked to imagine as vividly as they could what the vibration felt like. They were then asked to indicate the duration and the frequency of the vibration, and asked to describe how the vibration felt, as well as rate the vividness of their recollection. If participants said that the picture was not paired with a vibration, they were asked to spend 5 seconds imagining how the picture looked, and then asked a probing question about the picture to describe it and rate the vividness of their recollection. Brown et al. (2010) changed the frequency of the vibration present stimuli during the recall phase to turn vary the activation of vibration related memories. They found that participants in the high SDQ-20 group had a larger response criterion (*c*, is an individual's overall tendency to respond positively regardless of what stimulus is presented) than those scoring low on the SDQ-20, the higher SDQ-20 group also had a larger number of False Alarm Rates, but they did not show an increase in Hit Rates.

A related study by Brown, Skehan, Chapman, Perry, McKenzie, Lloyd, Babbs, Paine & Poliakoff (2012) proposed a link between physical symptom reporting and the somatic distortion on the SSDT. They conducted two experiments: the first of which evaluated the relationship between SSDT performance and somatisation in a nonclinical sample. To account for symptom reporting they used a series of questionnaires as measures to control for depression, trait anxiety, and state anxiety. They used the Patient Health Questionnaire (PHQ-15; Kroenke et al., 2002) used to assess physical symptom reporting. Depression was assessed by the Patient Health Questionnaire (PHQ-9; Kroenke et al., 2001) which consists of nine common symptoms of depression and participants indicate the degree to which they have been bothered by each symptom. State-Trait Anxiety Inventory (STAI-T; Spielberger, 1983) was used to measure trait anxiety, participants indicated how they generally feel. The state anxiety scale (STAI-S) was used to measure current anxiety, participants respond and rate how they feel right now, in the exact moment. Brown et al. (2012) found a significant positive relationship between false alarm rate in the light present condition and PHQ-15 score, controlling for trait anxiety and depression anxiety. Experiment 1 provides evidence of somatisation in a nonclinical population and indicates a relationship of somatic distortion on the SSDT. Brown et al. (2012) further investigated this within a clinical population; experiment 2 grouped the participants as having medically explained or unexplained symptoms. In addition to the questionnaires from experiment 1, participants also reported somatosensory amplification and hypochondriacal worry, which were included as additional factors. Anxiety and depression were assessed using the Hospital Anxiety and Depression Scale (HADS; Zigmond et al., 1983). Somatosensory Amplification Scale (SSAS; Barsky et al., 1990) was used to measure individual differences in the tendency to experience discomforting physical sensations and identifies them as symptoms of illness. The findings of the second experiment were the same as that of experiment 1; a significant positive relationship between false alarm rate and PHQ-15 was seen with the light present condition and for light absent condition. The significance was observed with light absent trials when the self-reported SSAS and hypochondriacal worry were used as additional factors. These findings support the notion that a relationship exists between symptom reporting and tendency to experience somatosensory distortion.

Poliakoff, Puntis, McKenzie, Lawrence, Brown & Lloyd (Submitted) investigated how tactile strength judgements are affected by a simultaneous light with a modified SSDT. They conducted three experiments: experiment 1 participants were threshold for both parts of the experiment, they detected and then discriminated between weak and strong tactile pulses, this occurred with or without a simultaneous light presentation. Participants received weak tactile pulse, stronger tactile pulse or no tactile pulse and carried out a detection judgement (did they feel anything, 'Yes' or 'No') if 'Yes' participants were then asked to class the pulse they felt (i.e. 'weak' or 'strong'). They found that the simultaneous light improved participants' ability to discriminate the weak from the strong tactile pulse, and also produced a bias to reporting any tactile stimulus as 'strong'.

Experiment 2 aimed to investigate if the presence of a light led to a reduced bias to classify stimuli as 'weak' in experiment 1 because large number of strong stimuli were detected. This was a simplified version of experiment 1 and participants only had to discriminate between weak and strong tactile pulses, they received a tactile pulse on every trial (weak or strong), they did not threshold participants for this experiment. They also used a visual start cue and not an auditory start cue. They found that the light led to a bias in classifying the weak and strong tactile pulses as ‘strong’, signifying that the light bias seen in experiment 1 was not likely to be produced by participants detecting more strong tactile pulses. They also found that participants had a bias towards responding weak to tactile stimuli during light absent conditions and a bias of responding strong to tactile stimuli during the light present conditions. Experiment 1 showed a small bias to respond ‘weak’ even in the light present conditions; they claim that this difference may have been due to the different number of strong tactile pulses in the two experiments. Participants may have found the discrimination between the weak and strong pulses too easy as Poliakoff et al.(submitted) found much higher *d′* than that of experiment 1, this was due to them not thresholding participants prior to testing. They found that the light led to more ‘strong’ responses when it was present, and that the light influenced tactile judgment only when the tactile signal was ambiguous. The researchers also found that the effect of light on bias was not dependent on how sensitivity participants were at distinguishing between tactile pulses.

Experiment 3 aimed to understand if the light affects judgements of strength for both weak and strong stimuli, from experiment 2. It was not known if strong pulses were already classified as ‘strong’ in the light absent condition and therefore, did not know if the perceived strength would increase with the light present condition. Each participants’ tactile threshold was found prior to testing. Participants felt two tactile pulses (weak, strong) and had to rate the strength of each stimulus on a 6 point scale. When a light was simultaneously presented with a tactile pulse participants rated both weak and strong tactile pulses higher on magnitude ratings, participants also rated strong tactile stimuli as ‘stronger’ than weak stimuli in light present and absent conditions. Poliakoff et al. (submitted) also found that participants were more biased towards rating tactile stimuli as strong (one of the three magnitude options) in light present trials than those without light. Interestingly they also found that the light did not affect participants’ sensitivity to the difference between strong and weak stimuli. However, presence of the light influenced participants to rate tactile stimuli as feeling stronger than at the same strength without light, surprisingly they found that mean rating for light present weak stimuli was slightly above that of the strong stimuli without light. Poliakoff et al. (submitted) conclude that experiment 3 indicates that the light produces a stronger subjective experience of tactile stimuli. Overall Poliakoff et al.’s (submitted) findings indicate that a simultaneous light does increase accuracy of tactile intensity reports and subjective intensity of tactile targets.

The outlined research has demonstrated that SSDT and SSDiT is a suitable tool to investigate somatoform dissociation, as the procedure minimises the effects of expectation and bias on the participant by obtaining perceptual reports from participants who are unaware that their somatic experience is in fact a misperception (Lloyd, McKenzie, Brown, Poliakoff, 2011). Lloyd et al. (2011) were the first to use neuroimaging techniques to investigate neural generators of somatic misperception on the SSDT. A modified version of the SSDT was used in to make the stimuli compatible with magnetic resonance imaging (MRI). They were able to replicate the behavioural data of past SSDT studies, in that participants made greater number of false alarms in light present trials. They also found that both light present and light absent false alarms activated regions of the medial parietal and medial prefrontal cortex: more specifically the precuneus, posterior cingulate and the paracingulate cortex. However, Lloyd et al. (2011) found no significant increase in the primary somatosensory cortex (SI) when measuring responses to false alarm vs. correct rejection trials. This finding differs from past neuroimaging studies into illusory tactile phenomena, which found activation in the SI with no actual stimulation, which was similar to when real tactile stimulation was presented. The authors concluded that their results provided evidence for the role of top-down processes in somatic misperception, consistent with findings from studies in humans and non-human primates.

McKenzie and Newport (2015) investigated whether individuals with MUS traits would be susceptible to visual illusions inducing tactile sensations on the skin when none are presented. Participants were seated and placed their hands into the MIRAGE augmented system where they viewed a real time video of their own hand with one of three different visual conditions: a normal live video view of their hand; a digitally altered live view of their hand with darker luminance mask over it; or they saw a live video of their hand with a pixilation mask on it (crawling skin illusion). McKenzie and Newport (2015) recorded participants' subjective reports strength for the physical sensations during each of the visual conditions on a numerical scale and compared their subjective reports to their individual measure of somatoform dissociation (SDQ-20). They found that participants who had higher SDQ-20 scores were more susceptible to somatic sensations across all visual conditions and felt less ownership towards their viewed hand. These findings suggest that high scoring SDQ-20 individuals would report more False Alarm Rates

(Nijenhuis et. al., 1996; Brown et al., 2010; Poliakoff et al., Submitted; Chapter 5). McKenzie and Newport (2015) analysed their data further by removing the reports of the higher SDQ-20 participants during the crawling skin condition. They found that during the baseline no visual manipulation condition also had higher ratings of illusory sensations. This may be due to these participants having a greater baseline sensitivity level due to interceptive noise being misinterpreted and reporting false feelings of sensations. The researchers concluded that their findings do strengthen the notion that MUS occurs due to increased reliance on top-down processing when interpreting bottom-up sensory information (McKenzie et al., 2014; Mirams et al., 2010. Brown, 2004).

Temporal effects and Somatoform Dissociation

Electroencephalography (EEG) investigations help understand what processing is occurring during somatosensory tasks (like those mentioned in the previous section). EEG recordings of event related potentials (ERP) from these tasks provides information about which form of processing was occurring during the task. This would in turn indicate what role bottom-up processing (early sensory processing) and later top-down processing has in the task. Taylor-Clarke, Kennett, Haggard (2002) conducted an investigation using EEG to see whether vision modulates cortical processing of tactile stimuli via back projections from multimodal cortical areas. They also investigated if viewing the stimulated body site would improve tactile discrimination. Taylor-Clarke et al. (2002) used Event-related potential (ERP, see methods chapter for further ERP details) while measuring tactile acuity using a two-point discrimination threshold with non-clinical participants. They used two tests (number of taps and type of frequency) and two conditions (view arm and view object). Participants had to judge if they felt one or two distinct taps, after hearing a tone at a specific frequency. The researchers concluded that viewing the stimulated body site improved performance on tactile discrimination and detection task and also enhanced tactile acuity. The ERP results showed a significant interaction between visual condition and task type. Visual modulation is not presented in the form of the P50 component, this is an early ERP component with a positive peak around 50ms from stimulus on set and reflects early sensory processing from primary sensory input. Visual modulation was however seen to be reflected in the later N80 component, this is a negative peak at 80ms after stimulus onset. The N80 component was localised to the scalp area around SI (Taylor-Clarke et al., 2000). The researchers conclude that their results strengthen the hypothesis that vision modulates cortical processing of tactile stimuli via back-projections from multimodal cortical areas. Taylor-Clark et al.'s (2000) findings also demonstrate how modulation of spatial and tactile attention with visual cue can direct affect primary (SI) and secondary (SII) somatosensory cortices. Furthermore, the researchers concluded that their findings indicate that areas of the brain, which were normally thought to process unimodal somatosensory events, may only do so in terms of early direct sensory projections.

Hernandez-Peon et al.'s (1963) findings along with those observed by Taylor-Clarke et al. (2000) for the early P50 and N80 components indicate that these illusory effects occur at an early processing stage before conscious processing. They also help strengthen Brown (2004) integrative model of MUS and also complement Lloyd et al. (2011) findings. Early bottom-up sensory information maybe initially processed by unimodal SI regions, however due to a later feedback mechanism for secondary sensory processing may cause the illusory symptoms present with MUS patients and with cross-modal studies with neurologically healthy participants.

ERP investigation of cross-modal links to internal spatial attention between vision and touch found early somatosensory ERP components when tactile stimuli were relevant (Eimer and Driver, 2000). This would be indicative of connections in spatial attention from touch to vision affecting early stages of visual processing (Eimer and Driver, 2000). These findings strengthen the theory that the early sensory ERP components could arise from feedback projections from multimodal neurons to the unimodal neurons at an early processing mechanism (Eimer and Driver, 2000).

Popovich and Staines (2014) investigated how bottom-up sensory information and top-down attention (task relevance) can influence early somatosensory processing. They used a cross-modal sensory integration task where participants were required to respond to the amplitude of tactile and visual stimuli they perceived. Popovich and Staines (2014) found that somatosensory ERP components P50 and P100 were modulated by the timing of the cross-modal interactions and the relevance of the behaviour required by the task and the attended stimuli. The researchers found that relevant visual and tactile inputs can enhance attentional processing at early stages to complete goal orientated behaviour. Popovich and Stains (2014) found modulation of early ERP components

(< 100ms), especially when the condition was incongruent between visual and tactile presentations.

There has been strong evidence that attending to the site of stimulation has an enhancement of tactile stimuli. Eimer and Forster (2003) investigated how spatial attention affects somatosensory processing in an ERP investigation. Eimer and Forster's (2003) findings indicate that sustained and brief attention affect different somatosensory areas. The sustained attention could be filtering out sensory noise from attended stimuli in the primary somatosensory cortex (SI). Whereas the transient attention could be showing evidence of shifts in tactile attention due to visuo-spatial cues in other somatosensory processing areas (such as secondary somatosensory cortex, SII; Eimer and Forster, 2003).

Implications

People experience somatic sensations (e.g. pain) for a variety of reasons, the rational as to the cause is usually one of something happened to or within the body for it to occur. There are, however, many clinical cases where one's somatic experience does not show to be the result of any medically known reason but appears to be a misrepresentation of bodily events (e.g. phantom limb, Ramachandran and Hirstein, 1998). Experimental studies have demonstrated it is possible to safely create illusory sensations with neurologically healthy participants. Research has also indicated that there are several factors contributing to somatic experiences; they are not only shaped by events in the body but are also affected by sensory inputs from different modalities and different cognitive factors (e.g. attention and memory).

The goal for this thesis is to provide a deeper understanding of the processes underlying somatic misperceptions. Experimental studies have demonstrated that the SSDT and SSDiT are robust tools to use to recreate tactile illusory sensations with neurologically healthy people. The presented thesis aimed to investigate the timing and maintenance of the illusory sensations as well as the possible somatic amplification of these sensations in normal, healthy individuals using the SSDiT. The thesis also aimed to investigate the cognitive factors that may modify these experiences. There is evidence from Brown (2004) about a relationship between internalised negative thoughts influencing one's perception or misperception of external stimuli. The previous literature outlined in this chapter has indicated that by understanding the temporal nature of such illusory somatic experiences can help understand what the underlying mechanisms are working to generate and maintain these illusory sensations. ERP combined with SSDiT would help understand what underlying mechanisms are occurring during the task that elicits the illusory sensations. ERP will provide millisecond precision in recording to when these illusory effects are formed, do they form at an early sensory processing stage or whether they occur later during decision making stage of sensory processing? Furthermore, there is evidence that viewing the site of stimulus presentation can affect individuals' body schema by cross-modal manipulations, which could result in incorrectly adapting their body schema and top-down predictions. Using predictive coding to explain the internal representation of the self provides evidence of an integrated relationship between exteroceptive (bottom-up) and interoceptive (top-down) processes. As exteroceptive (bottom-up) data can be used to reduce prediction errors during the creation of and maintenance of the bodily self via a form of active inference and probability predictions (Seth, 2013; Moutoussis et al., 2014; Tsakiris, 2017). The weight given to the evaluation of exteroceptive and interoceptive data across all modalities must be learnt over time to ensure that the outcomes reduce prediction errors and increase precision of predictions. The MIRAGE augmented reality system will be used to determine how the SSDiT affects an individuals' body schema and the role peripersonal space during the SSDiT. The MIRAGE system is a robust technique that enables the real time manipulation of dynamic video image of participants' real hands and not fake objects (the RHI, Botvinick and Cohen, 1998). Manipulating sight of stimulation using the MIRAGE system should help clearly understand the effect of bottom-up and top-down factors in the SSDiT.

There is extensive research that has investigated misperceptions and illusory affects brought about by cross-modal sensory manipulations. However, the research outlined in this thesis utilised several investigative methodologies that have never been used together before to further extend our understanding of somatosensory illusory effects of the SSDiT: EEG/ERP (chapter 5), this is a very exploratory experiment where we would expect to find two distinct timeframes, early (80ms – 180ms) and late components (300ms – 450ms) of interest; SSDiT (chapters 3, 5 & 6), we would expect to find light presence to result in greater false alarm rates; and the MIRAGE system (chapter 6), we would expect visual distortions to result in fewer false alarm rates during light present trials. Furthermore, a modified SSDiT was used to understand the effects of order of judgement on the discrimination of tactile pulses and the effects on illusory reports (chapter 4).

General Methods

2.1. Somatic Signal Detection Task (SSDT) and Somatic Signal Discrimination Task (SSDiT) Equipment

The TactAmp 4.2 (see figure.2.1.1: Dancer Design) is a bespoke four-channel amplifier unit capable of driving tactor vibrotactile stimulators as well as four light emitting diodes (LEDs).

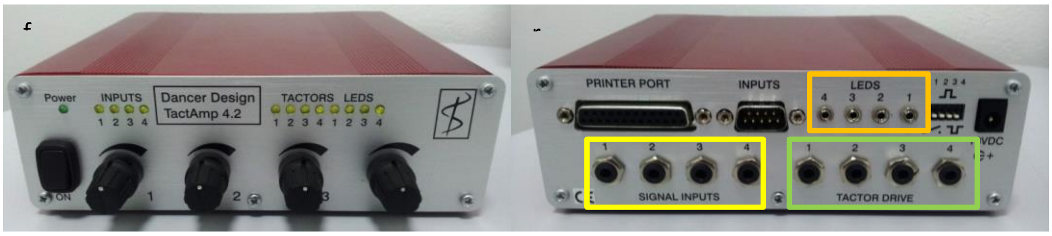


Figure.2.1.1. Front (f) and rear (r) view of TactAmp.

Each numbered dial corresponds to an output Tactor (figure 2.1.1.r green highlight). This design is useful for investigations where a static tactile pulse needs to be delivered to the skin. Each amplifier is a DC-coupled audio frequency amplifier capable of delivering 1.35 watts (RMS sine wave) into an 18-ohm load. The output current of each amplifier is limited to 500 mA by a self-resetting fuse inside the TactAmp. The signal inputs (outlined in yellow in figure.2.1.1r) and Tactor driver (outlined in green in figure.2.1.1r) connectors are 3.5mm mono jack sockets; the tactor lead is fitted with 3.5mm mono jack male connector. The Tactor is an electromagnetic solenoid measuring in total 12mm (h) x 19mm (w) (figure.2.1.2).

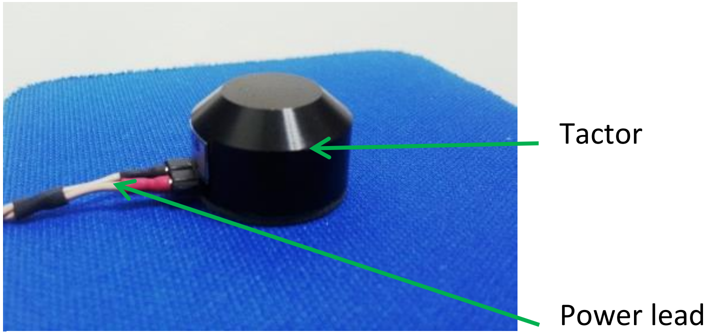


Figure. 2.1.2. A close up view of the Tactor

A 10mm red LED was used and was powered by the TactAmp (see figure.2.1.3. for image of a wired LED; LED output ports outlined in orange in figure.2.1.1).

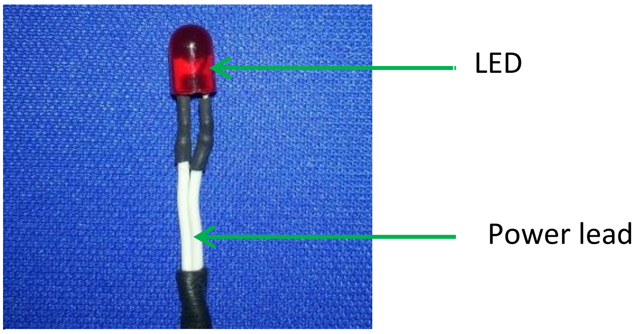


Figure.2.1.3. LED

For all SSDT and SSDiT experiments (Chapters 3, 4, 5, and 6) the analogue source input was used, and the input signal was provided by the output of the sound card from a desktop pc via a 'Y' cable - stereo 3.5mm plug to 2x mono 3.5mm plug cable into the TactAmp inputs (outlined in yellow in figure.2.1.1).

The SSDT, SSDiT and all thresholding tasks were created and controlled within E-Prime 2.0 by Psychology Software Tools (Psychology Software Tools, Inc, Pittsburg, PA); all participants' responses were also recorded within E-Prime. This experimental set up enables full control over stimuli onset and durations to the millisecond (i.e. 20ms) as well as record any delays of onsets.

The Tactor and LED were embedded in a foam wedge during all thresholding and experimental trials. An affixed foam wedge was used as it could maintain a consistent location of the Tactor and the distance of the LED from the participant’s finger. A firm base was also required for the Tactor to be able to create a tactile sensation; the foam material produced a viable material to enable this. All wires and connectors were securely taped down and were not exposed to participants, (see figure 2.1.4 and 2.1.3.1 for the stimulus array). The stimulus array was 25mm (w) x 75mm (l) x 35mm (height at raised end). The experimental set up only called for one Tactor and one LED to be driven by the TactAmp (see figure.2.1.2).

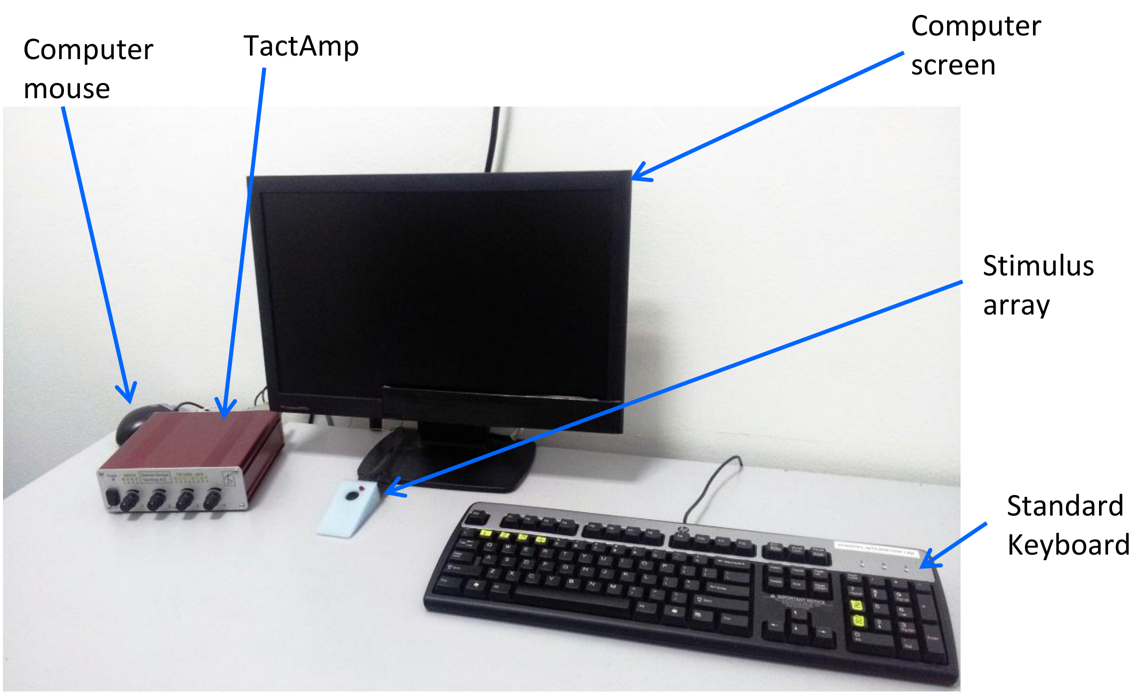


Figure.2.1.4. Experimental set up

2.1.1. Questionnaires

To account for the strong relationship between sensitivity of experiencing bodily symptoms with reports of False Alarm (Brown et al., 2005, 2006, 2010, 2012; Katzer et al., 2011; Poliakoff et al., in prep), several questionnaires were used to determine each participants' level of sensitivity to internal and external factors. The scores from these questionnaires were used as covariates to determine if the results found could be attributed to individual differences of sensitivity. Each experimental chapter will outline which questionnaires were used. The questionnaires used within the experiments were:

The Health Anxiety Inventory short (HAIs, Salkovskis et al., 2002) is a self-rated scale of health anxiety that is sensitive across the full range of intensity, which is a reliable measure to indicate if participants are suffering from a range of health anxieties including symptoms characteristic of clinical hypochondriasis. Each question consists of a group of four statements. Participants had to select the statement which best describes their feelings over the past six months (i.e.(a) I do not worry about my health; (b) I occasionally worry about my health; (c) I spend much of my time worrying about my health; (d) I spend most of my time worrying about my health.

Somatoform Dissociation Questionnaire 20 (SDQ-20; Nijenhuis et.al., 1996) measures an individual's tendency to experience pseudo-neurological symptoms. The questionnaire consists of 20 statements describing a symptom (i.e. ‘My body, or a part of it, feels numb’) and were asked if these were applicable to them for the past year. Participants responded on a five point Likert scale, with 1 (not at all) to 5 (extremely). Non clinical population scores of ≤ 22 would be deemed low and scores ≥ 28 were taken as high.

Patient Health Questionnaire 15 (PHQ-15; Kroenke et al., 2002) provides a means to ascertain the severity of individuals somatosensory symptoms and comprises of 15 physical symptoms (i.e. Stomach pain, Back pain, Headaches, Dizziness) which people rate the degree to which they have been bothered by each symptom in the last 4 weeks on a 3-point scale ranging from 0 (not bothered at all) to 2 (bothered a lot).

The Somatosensory Amplification Scale (SSAS, Barsky et al., 1988) measures the tendency to notice and experience vague sensory events as unpleasant. Participants rate 10 statements (i.e. When someone else coughs, it makes me cough too) on a five point Likert scale to what extent the statement applies to them from 1 (not at all true) to 5 (extremely true). Higher total score indicates greater symptom amplification (score range of 10 to 50).

State-Trait Anxiety Inventory (STAI, Spielberger et al., 1983) is used to measure the level of anxiety and internal self-thoughts individual’s hold of themselves. It contains statements such as ‘I feel calm’, ‘I feel frightened’ and asks participants to rate these statements according to how they generally feel, on a scale of 1 (not at all) to 4 (very much so). The State scale of the STAI (STAI-S) was used to measure current anxiety, in which respondents’ rate how they feel right now; the Trait scale (STAI-T) was used to control for the effects of negative affectivity, which has been found to relate with MUS.

Private Body Consciousness Subscale (PBCS; Miller et al., 1981), is a good indicator of an individual’s awareness of their internal bodily sensations. Participants rated five statements (i.e. ‘I'm very aware of changes in my body temperature’) on a five point Likert scale, with 1 (extremely uncharacteristic) to 5 (extremely characteristic); scoring range between 14 to 50, the higher the score, the greater the participants’ body awareness/body competence.

Participants were also given two questionnaires in the MIRAGE experiment in chapter 6, an adapted version of the Acclimatisation questionnaire (Newport et al. 2010) was used, which consisted of six items asking questions such as ‘It seemed like the image of the hand was my own’ and ‘It seemed like the image of the hand belonged to me’. Participants provided verbal feedback which the experimenter noted and was used to assess the extent a participant believed the live video image they saw was truly their actual real hand and was not further analysed.

All participants were screened to determine their handedness by using the Edinburgh Handedness Inventory (Oldfield, 1971) and only right hand dominant participants were used during all experiments. This is because previous studies found that the non-dominant hand has increased sensitivity to vibrotactile and somatosensory stimuli as compared to the dominant hand (Goldblatt 1956; Ghent 1961; Rhodes and Schwartz 1981).

2.1.2 Experimental Stimuli for the SSDT and SSDiT

Tactile stimuli were composed of a single 20 millisecond 100Hz square wave; the sound file was manipulated and created with Audacity (Audacity Team Version 1.3.14-beta http://audacity.sourceforge.net). When the tactile pulse was presented, this sound file was initiated and was output from the desktop pc into the TactAmp 4.01, which then drove the Tactor to provide the tactile stimulation (TactAmp 4.01 and Tactor are of Dancer Studio Designs, Merseyside, United Kingdom). All tactile stimuli for the SSDT were presented at the individual participants' specific threshold level determined by the participants' lowest tactile threshold level which was determined during the thresholding procedure (described below) prior to the main experiment. The tactile stimuli intensity for the SSDiT 'Weak' stimuli was determined by the thresholding procedure (described below) and the 'Strong' tactile pulse was 50% above their threshold. The Light conditions were triggered by the experimental script and consisted of Light present [trigger on, duration 20 milliseconds, stop] or Light absent [wait 20 milliseconds, this would not trigger the LED]. When the 'LED on' script was triggered, a signal from computer would be sent to the corresponding LED circuit via the serial printer port/cable from the computer to the TactAmp, which would result in the LED illuminating for 20 milliseconds; the Light absent condition would not have any LED illumination.

2.1.3 Thresholding procedures

Prior to starting the main (either the SSDT or SSDiT), participants were required to undergo thresholding to determine their lowest level of detecting tactile stimulus. This was adapted from Cornsweet (1962; see below for a detailed description). Participants were presented with a tactile pulse and asked to respond to if they felt anything, if they respond 'Yes' (they did feel it) this first pulse then the next stimulus would be less intense and if participants' respond 'No' the stimulus presentation is made more intense. If the participants' respond 'Yes' to the second stimulus the intensity of the third presentation is then based on what participants felt during the second presentation, if they reported 'No' then the intensity would be increased, if 'Yes' the intensity would be decreased. This procedure of slightly increasing or decreasing intensity is continued until a predetermined number of trials are reached (e.g. 30), the level of being threshold was to be taken by the mean value of the 'Yes' responses from all the trials of these 30 trials. Cornsweet (1962) identified a limitation with this method, as participants would become aware of the stimuli order and procedure over the duration of the task. A double staircase method was proposed to reduce any interdependencies and to reduce the bias in participants' responses.

Cornsweet (1962) outlined that the double staircase method would be a better method. During this, two series of the single staircase methods would be presented simultaneously. Two starting intensities are chosen, the first stimulus is presented at one of these levels and participants' responses are recorded. The next trial is presented at the second predetermined level and responses are recorded. The third pulse intensity is adjusted by what participants responded to the first stimuli, if 'Yes' then the intensity is lowered or if 'No' the intensity is increased for the third trial. The intensity for the fourth trial is then determined by participants' response to the second trial and adjusted accordingly. Therefore, it is as though there are two staircases, one with even (A) and the other on odd (B) numbered trials. These two data series that initially started at separate start positions would eventually become closer, this would mean participants' threshold value (mean) would have reduced interdependency bias to the stimuli. Cornsweet (1962) further outlined that the presentation of A and B can be randomly presented, and the data can be taken as one thresholding procedure from which participants' threshold level can be determined. Lloyd, Brown et al., (2012; and subsequent SSDT studies outlined in the Introduction) used an adapted version of Cornsweet's (1962) staircase method, therefore it was adopted by the investigations in this thesis.

For all thresholding and experimental sessions participants sat in a light attenuated room approximately 60cm in front of a computer monitor, stimulus array and keyboard, for the duration of the thresholding and main experimental tasks. All indicators lights on the monitor and keyboard were covered as to not cause any visual noise during the task. During all thresholding and experimental trials, participants listened to white noise through a digital audio player (iPod Nano) with Philips SHP 1900 stereo over ear headphones; this was to mask the sound of the Tactor and any background or experimentally informative noises. Participants were asked if they could hear any external noise while the white noise played, if they did the volume was increased slightly until they could not hear any ambient sounds. The white noise was turned off during breaks. This experimental setup was the same for all SSDT and SSDiT experiments, any differences in setup will be outlined within that experimental Chapter (see figure 2.1.3.1, for a depiction of the experimental set up).

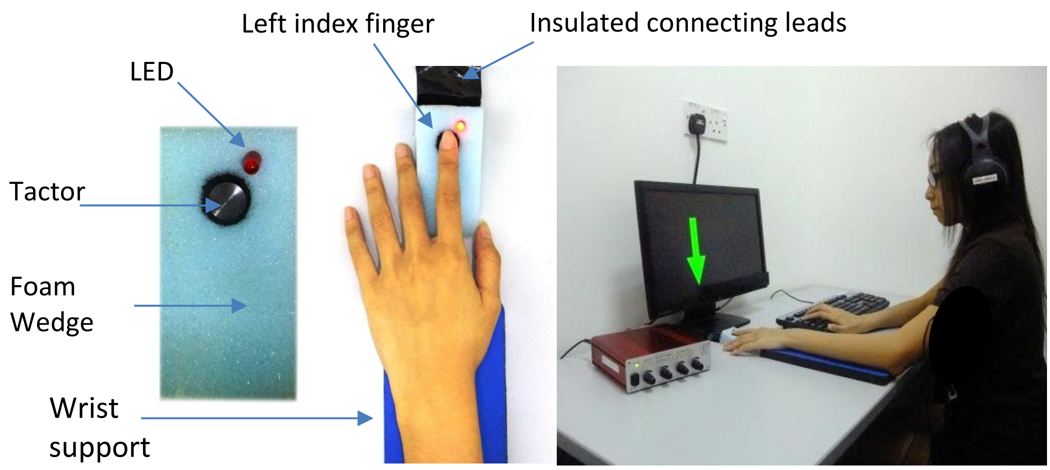


Figure.2.1.3.1. SSDiT experimental set up.

Thresholding procedure consisted of participants being presented with a block of 13 trials, consisting of 10 tactile (touch) present and 3 touch absent randomly presented trials, with each trial lasting 1020ms. The participants' left index finger was attached to the Tactor using a double-sided adhesive circle, this was to minimise movement during the experiment. An onscreen green arrow cue indicated the start of each trial, prompting the participant to look at their left index finger. There was a 500ms wait before the onset of stimuli from the cue: during touch present trials a 20ms tactile stimulus was delivered to the participants' left index finger, followed by a 500ms wait; touch absent trials were the same as touch present trials except there was no tactile stimuli presentation during the 20ms and an empty trial was presented lasting the same duration of 1020ms. After each of these trials participants were prompted on the monitor to indicate whether they had felt a tactile pulse by pressing one of two keys on the number pad of the keyboard, "Y" for yes and "N" for no. Stickers with these letters printed on were placed on number '1' and '4' to denote the 'Yes' and 'No' response; the keyboard was rotated by 90 degrees from the normal functional orientation to make it easier for participants to press these keys. At the end of each block the experimenter was presented with the total correct (yes) responses and the tactile intensity was adjusted according to the staircase method described above. Participants had to responded 'Yes' on 40% to 60% of touch present trials during a thresholding block, if they failed to report the desired number of touch present trials the intensity of the tactile stimulus was adjusted by turning the Tactor dial at the front of the TactAmp in small increments to change the amplitude of the output signal in the Tactor; clockwise to increase and anticlockwise to decrease amplitude after which a new threshold block would commence. Participants were required to respond 'Yes' on 40% to 60% of touch present trials during three consecutive thresholding blocks to be considered as having found their 50% threshold level. Participants only progressed to the main experimental blocks after they had met these thresholding requirements. Over course of the experimental session the threshold level for a participant can change due to fatigue and tactile drift (McKenzie et al., 2010). Therefore, a further thresholding procedure was used at the mid-point of each experiment to make sure that participants were within the 50% threshold level. Participants would have a short rest halfway through the experiment and the thresholding task would be conducted again to assess participants' threshold levels. The original thresholding procedure for the SSDiT was only used during the experiment outlined in Chapter 3. The SSDiT experiment outlined in Chapter 4 was modified to a two forced-choice discrimination task.

2.1.4 SSDiT Experimental Procedure

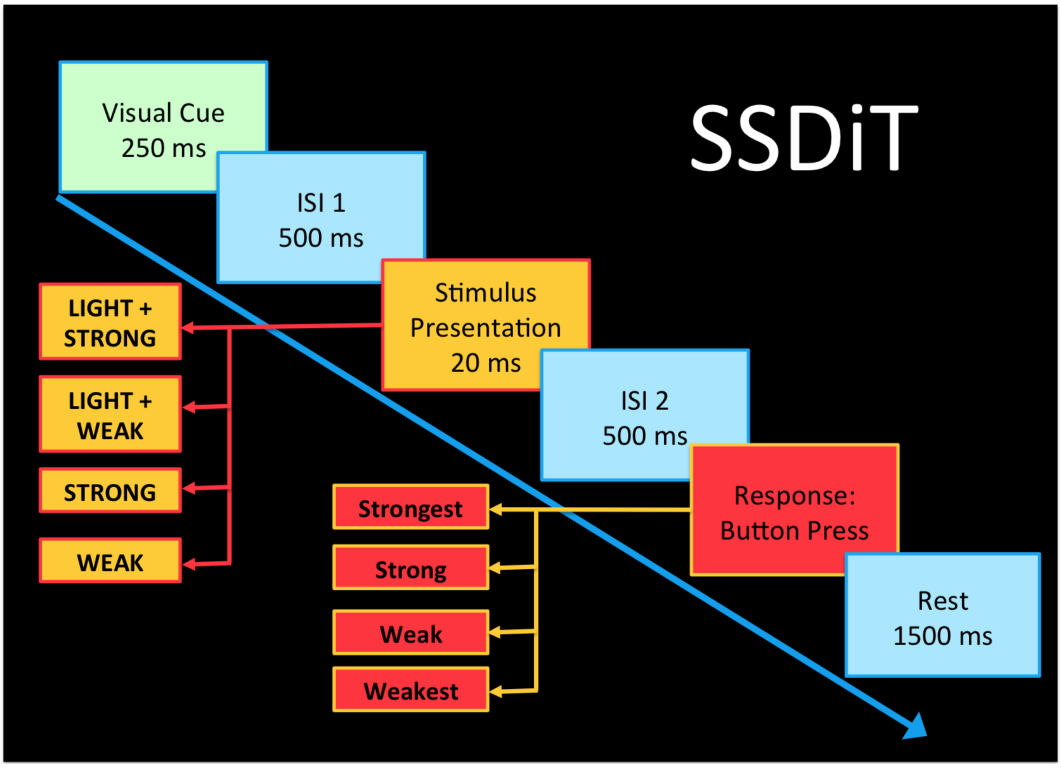


Figure.2.1.4.1. Experimental design of the SSDiT. Stimuli consisted of one of condition from 2 Tactile Strengths (Strong, Weak) and Light (present or absent) being presented for 20ms before participants responded with one key response out of the four possible choices (Strongest, Strong, Weak, Weakest).

The equipment was set up as shown in Figure 2.1.3.1. The SSDiT experiment consisted of a total of 360 trials, split over four experimental blocks, each block consisted of 80 trials, 20 of each of the four conditions: tactile stimulus Strength (strong/weak) x Light (present/absent) which were presented in a pseudo-randomised order. Participants were asked to report the intensity of the tactile pulse they felt by pressing one of the corresponding keys on the keyboard: ‘Strongest; ‘Strong; ‘Weak; ‘Weakest. All SSDiT experimental designs followed the standard outline shown in figure 2.1.4.1, any variations will be specified within that experimental chapter.

The SSDT has been shown to be a reliable method to induce cross-modal illusory effects, previous research showed no evidence of learning behaviour or any carry over effect from prolonged exposure over multiple SSDT trials (McKenzie et al., 2010; McKenzie, Lloyd, Brown et al., 2012) causing the illusory effects.

2.2. Electroencephalography (EEG)

2.2.1. Neural basis of EEG signal

The human male brain consists of an average of 86.1 billion neurons in the brain (Azevedo, Carvalho, Grinberg, Farfel, Ferretti, Leite, Filho, Lent, Herculano-Houzel, 2009), each of these generate an electrical current. The voltage during this electrical activity is very small and is measured in millivolts (mV). There are two kinds of voltage spikes during this electrical activity, action potentials and postsynaptic potentials. Action potentials occur when information needs to be transmitted over a relatively long distances. These nerve impulses (voltage spikes) spread through a neuronal axon by specific voltage-gated ion channels in the membrane of the axon.

A single neuron can have multiple 'incoming' connections (synapses) with adjacent neurons; multiple postsynaptic potentials can occur. This makes it difficult to record a single neuron's postsynaptic potential as the signal is mixed with adjacent signals. Non-invasive scalp electrodes cannot detect action potentials due to the arrangement of the axons and the timings of the action potential (Luck 2014). The current flows into a neuron and the action potential is only generated at one point, this current then flows in microseconds along the axon and into the next neuron and continues along until it reaches the end. If the action potentials were occurring close together and at the same time their signals would summate and would be detectable on the scalp surface. However, the action potentials occur quite fast and the orientation of axons would not create summation therefore the signal of one action potential is too week to detect on the scalp surface. EEG studies from the scalp usually detect summated signals from postsynaptic potentials.

It is widely thought that postsynaptic signals recorded on the surface scalp with EEG are generated from pyramidal cells. The pyramidal cells of in the neocortex follow the many convolutions of the brain, resulting in the cells being aligned but with their polarity not aligning; as some cells would have their apical dendrites pointing out directly towards the scalp, some could be pointing inwards or across to another point on the scalp. When these pyramidal cells are active it would result in many dipoles being generated; a dipole occurs when the distance separating a pair of positive and negative electrical charges is small, there will be a slight pull towards one side than another. Scalp recordings would not be able to detect the dipole of single neurons; the voltage of the summation of millions of neurons' dipoles would need to be recorded on the scalp. This is what EEG records, the surface voltage of these summated dipoles. The position and orientation of these summated dipoles would determine what polarity (positive or negative) is recorded at the scalp surface; this is due to the fact that not all polarity within the cells aligns with the surface of the skull and convolutions of the cortex also changes the cell alignments. These dipoles have a magnetic field that travels around it. Only the dipoles that are slightly parallel to the skull and that are close to the surface of the skull can be detected.

EEG is a useful tool for measuring and investigating brain activity. However, due to the summation of the dipoles, the EEG signal is composed of multiple sources of activity that makes it difficult to isolate specific cognitive processes. The amalgamation of the postsynaptic potentials within the EEG signal makes it difficult to isolate these individual cognitive processes. The temporal acuity of EEG is very high (to the millisecond) though its spatial acuity is low (ability to identify exactly where the signal source is). However, embedded within the EEG signals are the neural responses that are associated with specific sensory, cognitive and motor events.

2.2.2. Event Related Potentials

These electric potentials that relate to specific neural events are known as event-related potentials (ERPs) and can be extracted from the overall EEG signal by using a time-locked averaging technique. To obtain ERPs the neurons must have a similar orientation to one another with their postsynaptic potentials arising from the same part of the neuron. These detected dipoles create the voltage waveforms (components) and are composed of many different dipoles merging together to contribute to an electrodes source waveform (recorded voltage output for a given electrode). The surface source waveform shows the time course of continuous voltage components (positive and negative voltage spikes). It is therefore not easy to identify where the ERP waveforms lie amongst the general EEG waveform.

Each scalp electrode (referred to as a channel) would generate its own source waveform. As explained earlier, the summated postsynaptic dipole is what is detected on the scalp electrodes. The generators of these dipoles would propagate a certain percentage of their signal to several scalp electrodes. Therefore, contributing to the generation of different source waveforms at different electrode sites. The degree to which these generators contribute the source component depends on the position and orientation of the generator in relation to the electrode and the level of resistance to that electrode (Luck 2014). One cannot assume the source waveform from at a given electrode is the result of underlying neural activity; the source signal could have propagated from the opposite side.

The ERP components would be too small (microvolts, µV) to identify within the EEG, therefore they need to be isolated by marking the EEG recording with event codes. Event codes are used to time lock specific events at the precise time they occur, such as the stimuli onset. These time locks codes would then be used extract the segments of the EEG that contain the specific ERPs. These segments would then undergo processing, which includes averaging all same trials from each participant together to help amplify the ERP components for the task at hand. The process of averaging reduces the signal to noise ratio and the remaining components would be related to the task (the event) that occurred.

Many researches refer to the latency position of the peak: a positive peak at 100ms after stimulus onset would be P100 and a negative peak around 400ms after stimulus onset would be N400. EEG research into cross-modal mechanisms utilised somatosensory evoked potentials, (ERPs that are the result of tasks pertaining to a sensory modality), found early peaks from around 50ms to 140ms after stimulus onset and later positive peaks around 300ms – 400ms are also present. Earlier components are also believed to be sensitive to attention, with attended stimuli generating larger P100 components (Eimer and Forster, 2003; See chapter 5 for further literature on somatosensory ERP investigations).

2.2.3. EEG equipment and parameters used

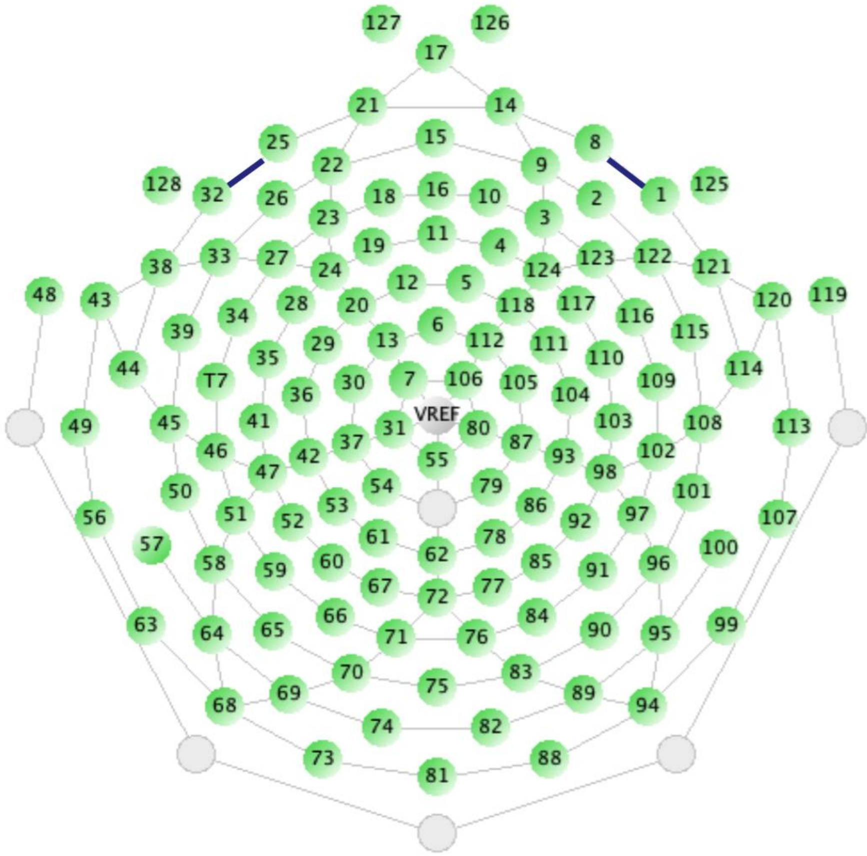


Figure.2.2.3.1. Showing a map of the HydroCel Geodesic Sensor placement; image from EGI NetStation Technical Manual, 2006).

The EEG signal was continuously recorded from a 128-channel HydroCel Geodesic Sensor Net (HGSN, see figure 2.2.3.1 for electrode arrangement on the nets and figure 2.2.3.3 of HGSN placement on participant) with the Net Amp 300 (Electrical Geodesics Inc. [EGI], Eugene, Oregon). Impedances were kept below 50 KΩ. The EEG signal was digitized online from all 128 electrodes at 4KHz and band-pass filtered between 500 and 1000 Hz. The ground electrode was positioned at the vertex (along the midline, CZ [VREF]).

HGSN's design makes for an abrasion free electrode sensor placement, with each sensor being held in place with radial compression, this enables the net to fit each person easily and properly without causing pain or discomfort. Each electrode is imbedded within a sponge that is held in by a small plastic well. The sponges would have saturated with the electrolyte solution prior to placement on participants' head (see figure 2.2.3.2 for a cross section diagram of a single electrode).

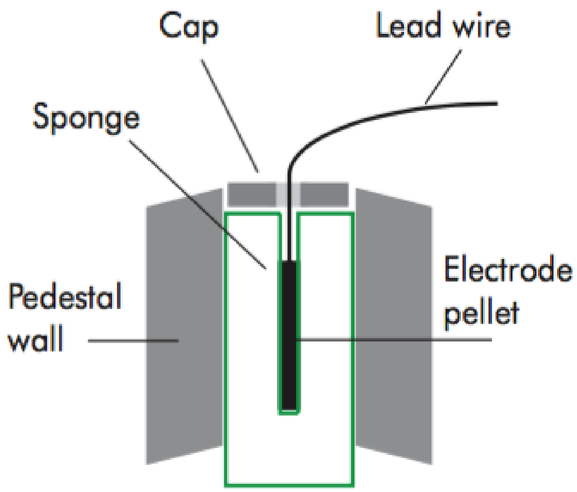


Figure.2.2.3.2. Cross section diagram of a single electrode from the HGSN *(image from EGI NetStation Technical Manual 2006).*

Three different sizes of nets were available to fit onto participants' head, based on the circumferences of their head (Small, 54-56 cm; Medium, 56-58 cm; Large, 58 cm and above). After the appropriate net was choses it was soaked in a simple electrolyte solution (distiller water, potassium chloride and small amount of Johnson's Baby Shampoo), to ensure that the electrodes of the net conduct and transmit the electric potentials from the scalp to the EEG system. Small amount of shampoo was used to help break down any oils on the scalp that would cause any resistance (impedance) between the electrode and the scalp surface, making for a stronger contact to help conductance of the signal. During this time the participants' vertex (central point on top of their head) was found. To do this the midpoint was found between the nasion (the lower depression between the eyebrows, at the top of the bridge of the nose; electrode 17 in figure 2.2.3.1) and the inion (the small bump at the back of the head; electrode 81 figure 2.2.3.1) and the midpoint between the left and right preauricular points (the depression just in front of the ear, near where the lower jaw joint is; near electrodes 43 & 120 on figure 2.2.3.1). Where these two midpoints intersected marked the participants' vertex and placement marker was made using a wax pencil. The now electrolyte saturated HGSN would be placed onto the participants' head, ensuring that the vertex marker lined up with the central reference electrode (VREF on in figure 2.2.3.1). The HGSN was held in place with radial compression. This enables the net to fit each person properly and easily without causing pain or discomfort (see figure 2.2.3.3 for image of HGSN placement on the head.

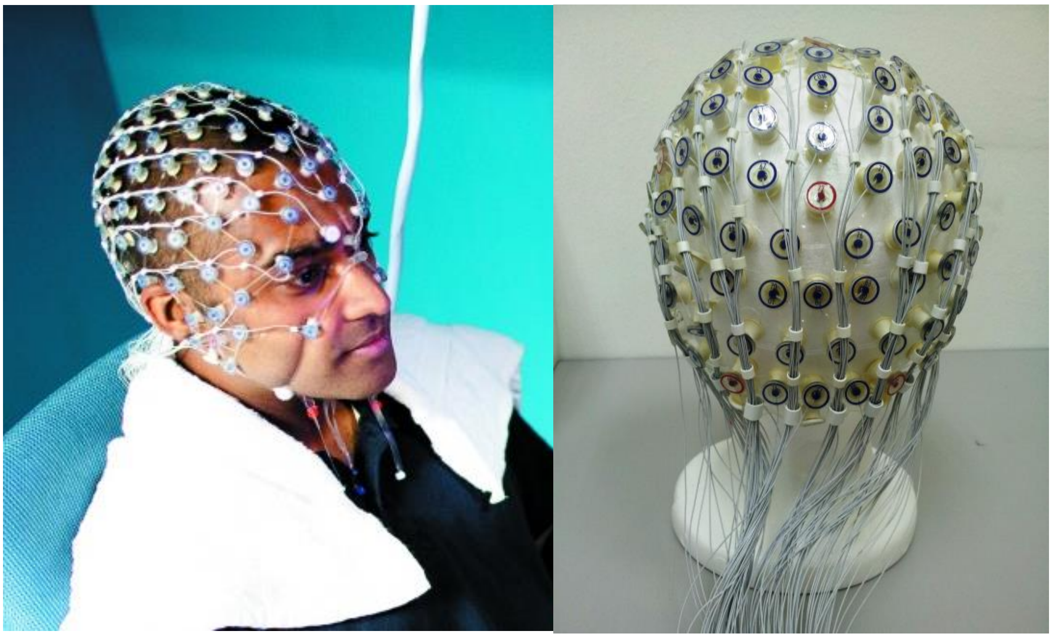


Figure.2.2.3.3. A profile view and a rear view of how the 128 channel HydroCel Geodesic Sensor Net would be placed on a participant's head.

Each of the electrodes lead wire would be routed to the amplifier through the HGSN's umbilical cord and then to the signal amplifier via an articulated arm. The signal amplifier, The Net Amp 300 (EGI, USA; see figure 2.2.3.4 showing the signal amplifier and articulated arm's base connection) is a low noise amplifier that amplifies and digitises the raw EEG signals from the HGSN and transfers them to the data acquisition computer in real time.

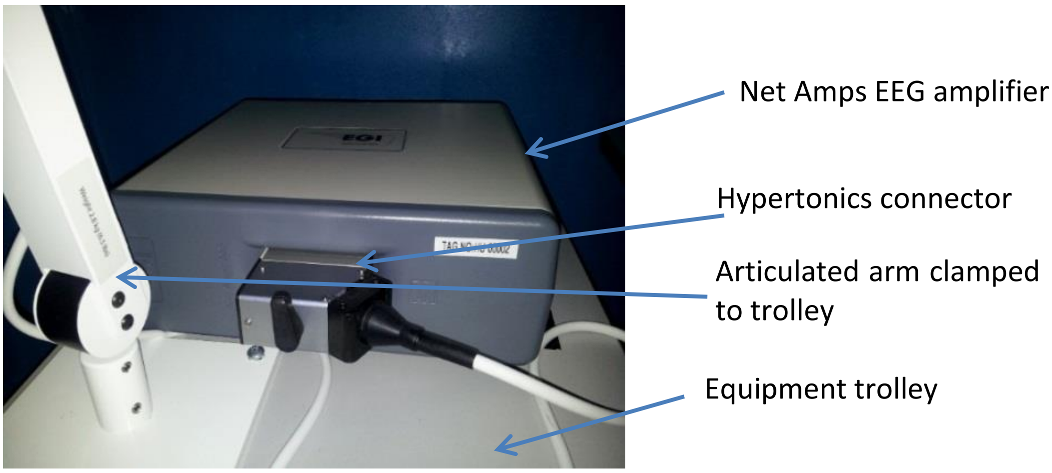


Figure.2.2.3.4. EGI Signal Amplifier 300 and the connection from the HGSN umbilical cord via the articulated arm.

The NetStation amp and HGSN were set up inside a Faraday cage made of steel meshing embedded in MDF. The Faraday cage provides electromagnetic shielding form ambient electromagnetic fields, which could be detected by the HSGN and recorded on the EEG data as noise. The data acquisition and stimulus presentation computer were placed outside of the faraday cage, as was the SSDiT TactAmp. The EEG acquisition computer was an Apple Mac Pro, situated outside of the faraday cage. The participant display was a 19" LCD display and was set up as a secondary screen from the stimulus control computer (this computer was the same as that described in the SSDiT subsection of this chapter). Participants sat in a chair in the light attenuated Faraday cage approximately 60cm in front of a computer monitor, the SSDiT stimulus array and response box (see figure 2.2.3.5 for experimental setup). Long cables were run into the Faraday cage from the TactAmp to the SSDiT tactor/stimulus array. The SSDiT experimental equipment was set up in the same manner as outlined in the previous subsection (SSDiT equipment set up) Participants wore earplugs at this point to ensure that no ambient sound would be processed as noise in the EEG signal.

Figure.2.2.3.5. Participant seated within the Faraday cage, at the stimulus array for the SSDiT EEG.

Impedance checks were then carried out to make sure the level of resistance across all 128 channels was less than 50 kΩ, if they were not a pipet was used to saturate the electrode sponge with electrolyte solution and moved around to ensure the sensor made contact with the participants' scalp; this process varied in time depending on the participants' initial impedance readings, in some instances it took up to 15 minutes. After all electrode impedances were checked, the participants' left index finger was fixed to the SSDiT Tactor and they were instructed not move their head or left hand for the duration of the experiment; as it would cause noise in the EEG signal. All visible indicator lights on the monitor were covered to reduce any visual noise during the task. The thresholding procedure for the SSDiT was then conducted. As the thresholding procedure took up to 15 minutes, there was a chance that the electrodes could have dried out, so the impedances were quickly checked again before the main experiment was conducted. Halfway through the experiment, participants underwent the thresholding procedure and impedance checks again. The impedance was checked again to ensure a cleaner EEG signal is obtained, as the electrodes would have started to dry out again in the room.

2.3. MIRAGE Augmented Reality system

The MIRAGE system was developed by Newport et al. (2009) to present realistic moving visual depictions of participants' own hands and allows for a variety of visual manipulations to create illusory visual effects; such as stretching participants' finger to double its length, to making it appear as though it has become detached form the hand. This is possible due to real-time video manipulations that can be applied via the MIRAGE systems bespoke software (created in LabView, National Instruments 2012 www.ni.com/data-acquisition). To achieve these illusory effects the MIRAGE uses a combination of a high performance camera, infrared (IR) light, bespoke programming, mirrors and a computer system. The MIRAGE is rectangular in shape measuring 720(w) x 550(h) x 500mm(d) (see figure 2.3.1.).

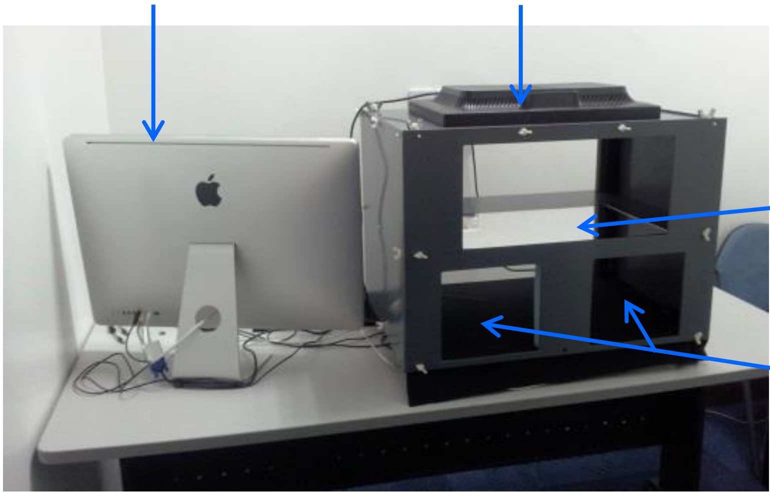


Figure.2.3.1. The MIRAGE equipment setup. The experimenter sits on the opposite side to the participant at the control computer.

It has three levels, the top level has an inverted computer screen mounted to it, the screen is a 22 inch NEC MultiSync E222W-BK liquid crystal display monitor operating at 60Hz. Directly below this screen is the second level which is the viewing area (see figure.2.3.2), where participants look down onto a smooth polished mirror and see a transposed video image of their hands in real time in the same location as their actual hands via the mounted screen above the mirror.

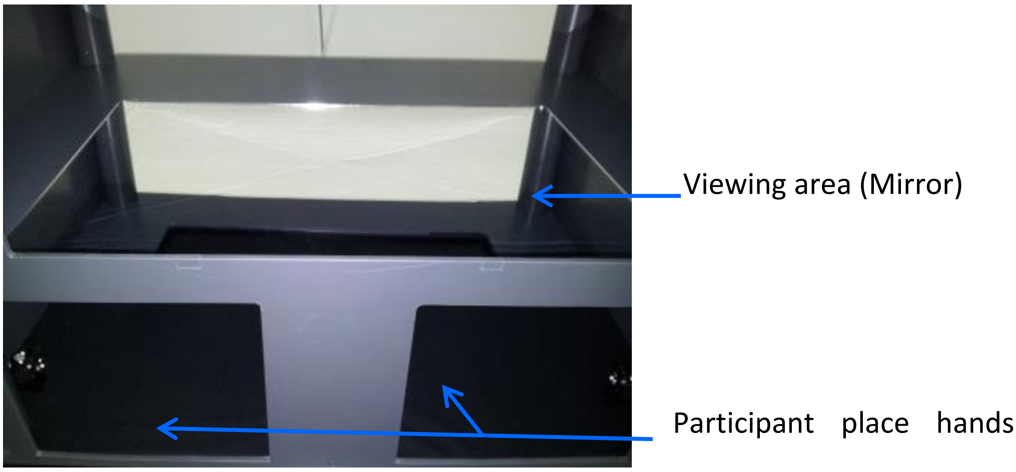


Figure.2.3.2. Participant view when at the MIRAGE.

The video is captured using a Basler A601F at 60 frames a second with a 659 x 493mm mono progressive scan COMS sensor with a Tamaron 1/2 4-12mm F/1.2 IR camera with an aspherical varifocal lenses attached. The angle, focus and magnification of the camera are adjusted to produce an image with the same proportion as the participants' real hands on the viewing mirror. The camera is connected to the control computer via a FireWire 400 cable.

Participants are seated in a height adjustable chair and place their hands into the lower section of the MIRAGE, as indicated by Figure.2.3.1 and Figure 2.3.2. Once the live video image is captured, it goes through the control computer and undergoes processing via National Instruments LabVIEW 2010 v.10.0.1 (National Instruments 2012 www.ni.com/data-acquisition). The latency from image capture to processing and presentation to the participant viewing screen is up to 20ms (Newport et al., 2009; 2010), there is no behaviourally-detectable lag in motion of the video image.

Chapter three

Somatic Signal Detection versus Discrimination: An intra-individual comparison between tasks

Many different techniques have been used to help understand how illusory tactile sensations are generated and maintained. They have provided new understanding of how cross modal links that might result in illusory effects. Manipulating one modality can induce a sensation in another sensory modality (Botvinick and Cohen, 1998; Ramachandran et al., 1995; Lloyd et al., 2008; Taylor-Clarke et al., 2000). The Somatic Signal Detection Task (SSDT, Lloyed et al., 2008) has shown that when a tactile stimulus is presented with a simultaneous light flash, individuals have an increased sensitivity to tactile stimuli and also tend to report feeling a tactile sensation as present when one was not present. This bias does vary between individuals; however, it remains constant over time within an individual (McKenzie, Poliakoff, Brown and Lloyd, 2010).

The SSDT was developed to help understand how medically unexplainable symptoms (MUS) can occur in individuals by conducting cross-modal investigations with neurologically healthy participants. Brown's (2004) integrated conceptual model theorised that individuals subjectively experience and report these illusory sensations as real because they are hyperfocused on external stimuli that they then internalise and misinterpret, all of which occurs unconsciously. A modified version of the SSDT (a tactile stimulus discrimination task), the Somatic

Signal Discrimination Task (SSDiT) has shown that simultaneous light presentation led to a significant improvement in people's ability to discriminate 'weak' tactile stimuli from 'strong' ones, as well as a bias towards reporting any tactile stimulus as 'strong' (Poliakoff, Puntis, McKenzie, Lawrence, Brown & Lloyd, submitted).

Early investigations into somatoform symptoms (Brown et al., 2005, 2006, 2010, 2012; Katzer et al., 2011; Poliakoff et al., in prep) used a range of questionnaires (see Chapter 2, SSDiT questionnaires subsection for more details about these) to investigate how an individuals' introspective understanding/knowledge of the happenings within them and the 'world' around them can affect their susceptibility to experience these illusory sensations. Brown et al. (2010) found participants' who scored higher in the SDQ-20 questionnaire had greater response criterion (*c*) and False Alarm rates than those scoring low on the questionnaire.

This study aimed to investigate whether the False Alarm rates on the SSDiT relate to the False Alarm rates on the SSDT. More specifically, this study aimed to determine whether participants' ability to discriminate between different tactile strengths (SSDiT) is related to their ability to detect a tactile stimuli (SSDT). Previous investigations have shown that the False Alarm rates were greater during Light present condition; therefore, it is expected that the False Alarm rates would be greater during both tasks with the light present conditions. Furthermore, it is predicted that the False Alarm rates between the two tasks would have a significant relationship with the Light present conditions, as the sensory processing involved in both tasks would be the same. The only difference between the two tasks is the type of judgement the participants make (i.e., discrimination versus detection). The SDQ-20, PBCS and SSAS questionnaires (see Chapter 2, SSDiT 2.1.2 Questionnaires for further information) will provide a subjective account of participants' susceptibility to experience somatoform sensation (illusory sensations). It is predicted that high SDQ-20 scorers would have greater False Alarm rates than low scorers. This would provide a stronger understanding of how the bias to feel cross-modal illusory enhancement in tactile stimuli is affected by tactile strength. Further providing a deeper understanding as to why certain people are more susceptible to feeling somatoform symptoms. The data is expected to replicate that of previous findings (Lloyd et al., 2008; and subsequent SSDT studies, see Chapter 1) that tactile stimuli presentation accompanied by an LED flash would result in more confident reports of touch (during the SSDT). We would also expect the sensation of tactile stimuli to be enhanced when it is accompanied with a simultaneous LED flash (during the SSDiT). Greater False Alarm rates are expected during Light present trials than Light absent trials during both experiments.

Method

Design

A repeated measures design was used, and the same participants took part in the SSDT and SSDiT:

SSDT

> A 2[Light (present/absent)] x2 [Tactile strength (strong/weak)] repeated measures design was used, and participants were asked to report of they felt a tactile pulse by pressing the appropriate key [Response (Definitely Yes, Maybe Yes, Maybe No, Definitely No)].

SSDiT

> A 2 [Light (present/absent)] x2 [Tactile strength (strong/weak)] repeated measures design was used, with participants rating the intensity of the tactile stimuli they perceived [Response (Weakest, Weak, Strong, Strongest)].

All trials were pseudo randomised within the SSDT and SSDiT with key presses being rotated between the thresholding task (number pad on keyboard) and the experimental task (number row above letter keys).

Participants

26 participants (8 males), aged between 18 and 30 years old (M = 20.23 years, SD = 3.66). All participants were right-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). Full informed consent was obtained from each participant, after written and verbal explanations of the tasks were provided. The University of Nottingham Malaysia Campus Research Ethics Committee approved all procedures. Participants were recruited from the University of Nottingham Malaysia Campus, as requirement of course one course credit and RM10.

To help provide a subjective account of participants' susceptibility to experience somatoform sensations (illusory sensations) the following questionnaires were used (see table 3.1 for the mean scores): the Somatoform Dissociation Questionnaire-20 (SDQ-20; Nijenhuis et.al., 1996); Patient Health Questionnaire 15 (PHQ-15; Kroenke et al., 2002); Somatosensory Amplification Scale (SSAS; Barsky et al., 1988); these were used as covariates during analysis (Brown et al., 2010; McKenzie et al., 2010; Katzer et al., 2011; McKenzie et al., 2012; Poliakoff et al., submitted), See Chapter 2, 2.1.2 Questionnaires, for more information about these.

Table.3.1. Mean and range of scores across all questionnaires (± 1 SD).

	SDQ-20	SSAS	PBCS
Mean	26.62	26.23	15.88
(SD)	(6.65)	(6.06)	(3.43)
Range	20 – 43	17 – 39	8 – 25

Stimulus and Materials

Tactile stimuli were composed of a single 20 millisecond 100Hz square wave; the sound file was manipulated and created with Audacity (Audacity Team Version 1.3.14-beta http://audacity.sourceforge.net). When the tactile pulse was presented, this sound file was initiated and was output from the desktop pc into the TactAmp 4.01, which then drove the Tactor to provide the tactile stimulation (TactAmp 4.01 and Tactor are of Dancer Studio Designs, Merseyside, United Kingdom). All tactile stimuli for the SSDT and SSDiT were presented at the individual participants' specific threshold level determined by their lowest tactile threshold level, which was determined during the thresholding procedure (described below) prior to the main experiment. The tactile stimuli intensity for the SSDiT 'Weak' stimuli was determined by the thresholding procedure and the 'Strong' tactile pulse was 50% above their threshold. The Light conditions were triggered by the experimental script and consisted of Light present [trigger on, duration 20 milliseconds, stop] or Light absent [wait 20 milliseconds, this would not trigger the LED]. When the 'LED on' script was triggered, a signal from computer would be sent to the corresponding LED circuit via the serial printer port/cable from the computer to the TactAmp, which would result in the LED illuminating for 20 milliseconds; the Light absent condition would not have any LED illumination. See Chapter 2.1, for detailed SSSDT/SSDiT equipment information. See figure 3.1 below for the experimental set up with the SSDiT stimulus array.

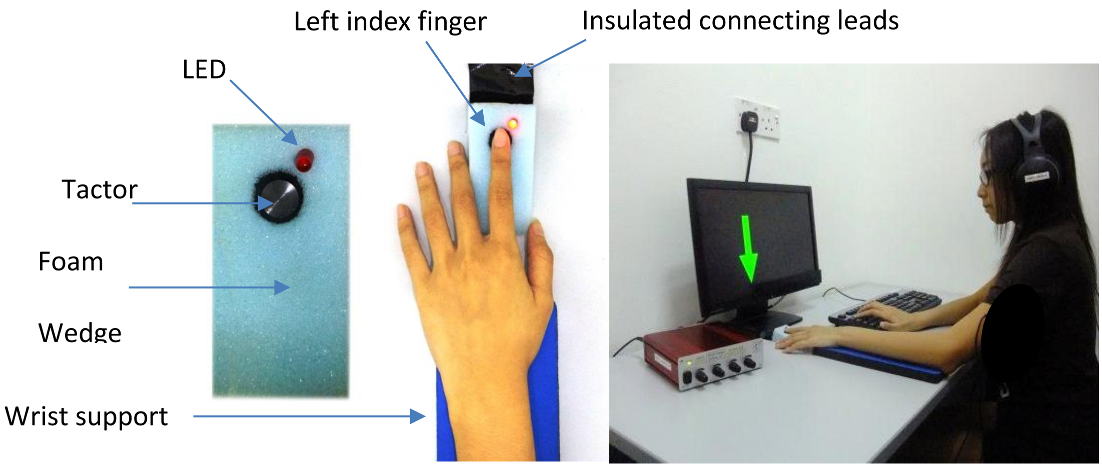


Figure.3.1. SSDT and SSDiT experimental set up.

Procedure

Participants took part in both the SSDT and SSDiT with each experimental session conducted on two separate days, seven days apart and at the same time. This was to ensure participants were not fatigued by taking part in both experimental sessions too close together. The time of the experimental session for each participant was also kept consistent to try and match the participants' state of mind prior to the experimental session starting. The order in which participants did the two tasks was randomised (i.e. SSDT first and SSDiT second or SSDiT first and SSDT second). The response keys were rotated between the thresholding procedures and the main task for all. All experimental sessions took place in the same light attenuated room with the same experimental setup (see figure 3.1 for experimental setup). The SSDT and SSDiT procedures will be described separately below and were the same for all participants.

Somatic Signal Detection Task (SSDT)

Thresholding

Prior to starting the main experiment, participants were thresholded. The thresholding procedure consisted of participants being presented with a block of 13 trials, consisting of 10 tactile (touch) present and 3 touch absent randomly presented trials, with each trial lasting 1020ms. The participants' left index finger was attached to the Tactor. An on screen green arrow cue (136 x 320 pixels in width and height; the point of the arrow is located pixel at 493 x 623 coordinates) indicated the start of each trial, prompting the participant to look at their left index finger. There was a 500ms wait before the onset of stimuli from the cue: during touch present trials a 20ms tactile stimulus was delivered to the participants' left index finger, followed by a 500ms wait; touch absent trials were the same as touch present trials except there was no tactile stimuli presentation during the 20ms and an empty trial was presented lasting the same duration of 1020ms. After each of these trials participants were prompted on the monitor to indicate whether they had felt a tactile pulse by pressing one of two keys on the number pad of the keyboard, "Y" for yes and "N" for no. Stickers with these letters printed on were placed on number '1' and '4' to denote the 'Yes' and 'No' response; the keyboard was rotated by 90 degrees from the normal functional orientation to make it easier for participants to press these keys.

At the end of each block the experimenter was presented with the total correct (yes) responses and the tactile intensity was adjusted according to the staircase method described above. Participants had to responded ‘Yes’ on 40% to 60% of touch present trials (correctly identified 4 – 6 of the 10 tactile present trials as correct) during a thresholding block, if they failed to report the desired number of touch present trials the intensity of the tactile stimulus was adjusted by turning the Tactor dial at the front of the TactAmp in small increments to change the amplitude of the output signal in the Tactor; clockwise to increase and anticlockwise to decrease amplitude after which a new threshold block would commence. As mentioned previously, participants were required to respond ‘Yes’ on 40% to 60% of touch present trials during three consecutive thresholding blocks to be considered as having found their 50% threshold level. Participants only progressed to the experimental blocks after they had met these thresholding requirements. Over course of the experimental session the threshold level for a participant can change due to fatigue and tactile drift (McKenzie et al., 2010). Therefore, a further thresholding procedure was used at the mid-point of the experiment to ensure participants were within the 50% threshold level.

SSDT experiment

The SSDT consisted of four blocks of 80 trials. Each block had four trial types: touch only, light only, light and touch and catch (no stimuli). Each trial type was randomly presented 20 times during each block. The touch only and touch absent trials were identical to those used during the thresholding procedure (touch present and touch absent trials). For the light only trials the tactile pulse was replaced by a 20ms LED flash in the middle of a 1020ms interval. In the light and touch trials the tactile pulse and LED flash were presented simultaneously in the middle of the 1020ms interval (see figure 3.2 for a diagram of the SSDT experimental design). All tactile stimuli were presented at the individuals' threshold level that was determined during the thresholding procedure. Participants were not aware of the significance of the light stimuli (LED flash). A visual cue (green arrow pointing down) to the participants' left index finger was displayed on the screen to indicate the start of each trial, prompting the participant to look at their left index finger and then back at the screen for the response prompt. Participants were to indicate whether they felt a touch sensation on that trial using the appropriate number key on the row above the letter keys on the keyboard. Participants were given four response choices (key 1 "definitely yes," key 2 "maybe yes," key 3 "maybe no," and key 4 "definitely no") to indicate what they felt.

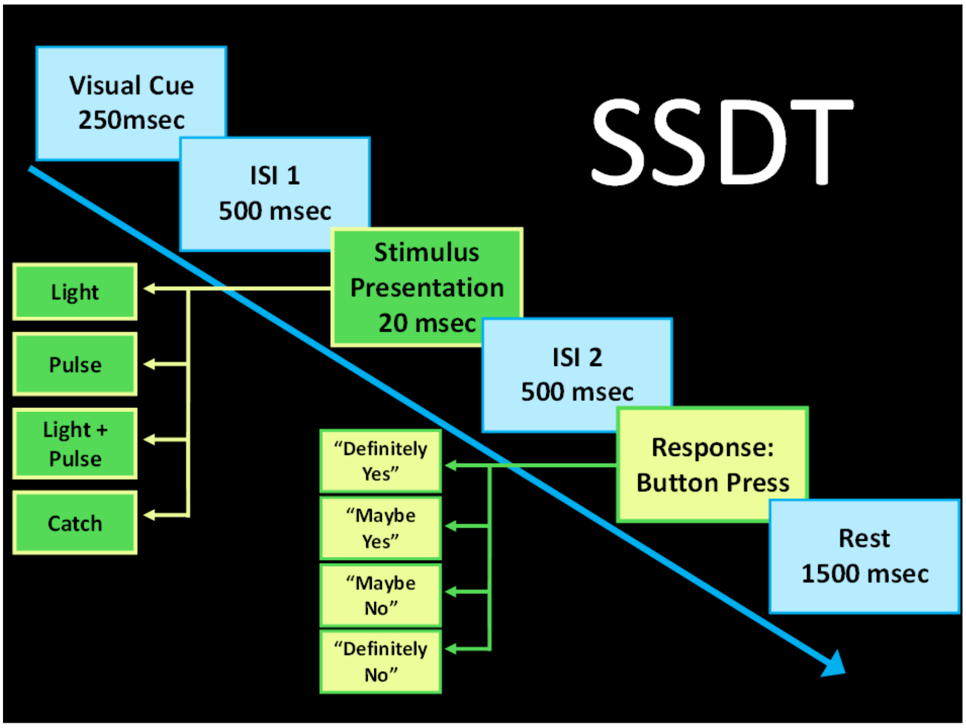


Figure.3.2. Experimental paradigm for the SSDT. Stimuli presentation was a Light along or a Pulse alone, a combination of both Light and Pulse or Catch (no stimuli presentation). The stimuli were presented (or an empty space for Catch trials) for 20ms before participants responded with one key response out of the four possible choices (Definitely Yes, Maybe Yes, Maybe No, Definitely No).

Somatic Signal Discrimination Task (SSDiT)

Thresholding/Practice

Prior to starting the SSDiT, participants were required to undergo a thresholding procedure, the SSDiT thresholding procedure was different to that of the SSDT. To be threshold for the SSDiT was defined as the point at which participants reported detected a tactile pulse on 50% of the trials, through familiarisation trials and practice trials. All participants started this phase at the same level of intensity. Participants were presented with ten tactile pulses, consisting of five 'Strong' and five 'Weak' pulses, which were presented in an alternating sequence. The sound file that generated the 'Weak' pulse was 75% lower in amplitude to that of the 'Strong' pulse. The participants were instructed to be still and that they would receive either a 'Weak' pulse or a 'Strong' pulse on their left index finger on every trial. Participants were asked if they felt a pulse on every trial during the block of ten by pressing 'Y' for yes and 'N' for no. If participants did not feel a pulse for any of these ten trials, the intensity was changed to the appropriate level and was initiated again.

After the familiarisation trials, participants were presented with a practice trial of the main experiment. Participants were presented with one of four stimulus conditions: tactile strength (strong, weak) x light (present, absent) and were asked to report the intensity of the tactile pulse by pressing the corresponding key: 1, 'weakest; 2, 'weak'; 3, 'strong'; 4, 'strongest'. They were instructed that the red LED may flash near their index finger at the same time as the pulse, but they should only rate the strength of the pulse. The practice block consisted of 16 trials. Participants' correct responses were tallied, and participants had to be thresholding to 40% - 60% correct trials.

SSDiT experiment

The equipment was set up as shown in Figure 3.1. The SSDiT consisted of a total of 360 trials, split over four experimental blocks, each block consisted of 80 trials, 20 of each of the four conditions: tactile stimulus Strength (strong/weak) x Light (present/absent). These were presented in a pseudo-randomised order, not repeating the same combination of Strength and Light in series. Participants were asked to report the intensity of the tactile pulse they felt by pressing one of the corresponding keys on the keyboard: 'Strongest; 'Strong; 'Weak; 'Weakest. See figure 3.3 for diagram of experimental design.

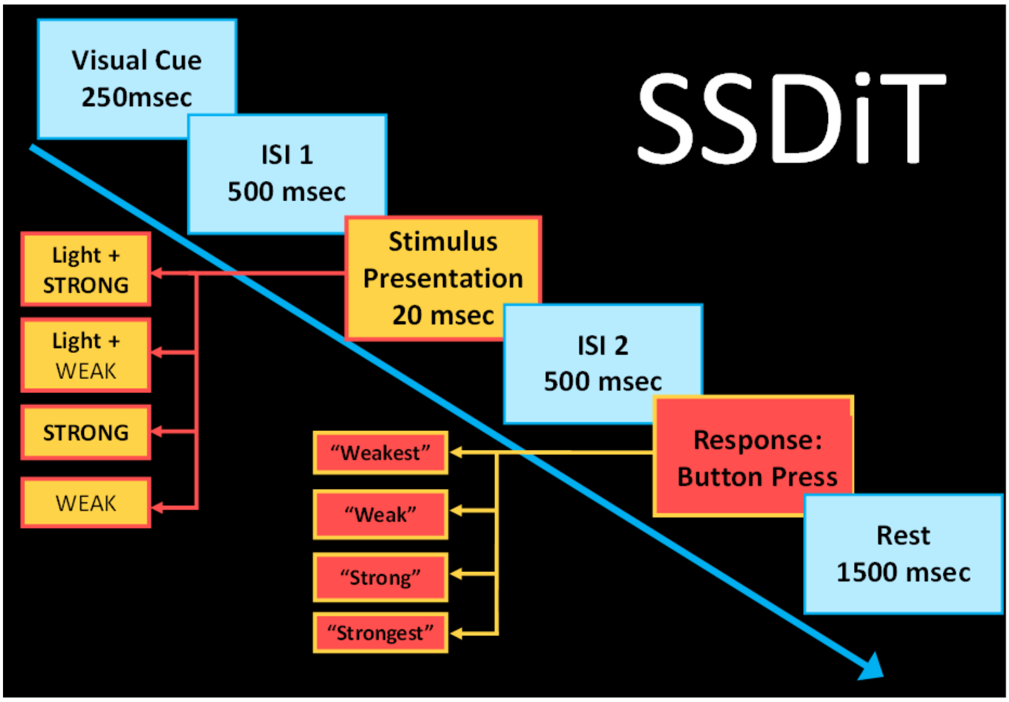


Figure.3.3. Experimental design for the SSDiT. Stimuli consisted of one of condition from 2 Tactile Strength (Strong, Weak) and Light (present or absent) being presented for 20ms before participants responded with one key response out of the four possible choices (Strongest, Strong, Weak, Weakest).

Results

SSDT Data Analysis – Detection Task

In order to calculate signal detection statistics, responses were collapsed across confidence ratings as shown in figure: 'definitely yes' and 'maybe yes' were counted as 'yes' and 'definitely no' and 'maybe no' as 'no' (see table 3.2). The number of hits (tactile-present trials in which participants correctly said 'yes'), false alarms (tactile-absent trials in which they incorrectly said 'yes'), misses (tactile-present trials with an incorrect 'no' response), and correct rejections (tactile-absent trials with a correct 'no' response) were counted. Hit and False Alarm Rates were then calculated, as well as the signal detection theory test statistics *d'* and *c* respectively. The signal detection statistics provided estimates of the participants' perceptual sensitivity (*d'*) and tendency to report stimuli as present (i.e., response bias or *c*) in the light-present and light-absent conditions (MacMillan & Creelman, 1991). To compensate for zero errors in weak tactile pulse condition, when calculating the probability of saying yes, 0.5 was added to the top and 1 to the bottom of the equation for all cases (Snodgrass and Corwin 1988). Table 3.2 shows how the raw data was encoded with signal detection terminology.

Sensitivity indices (*d'*) scores are a way to determine how much the tactile signals differed, if they were distinctly different the distribution of means would be further apart and *d'* would be a large number. If they were not so different the distribution of means would be closer, therefore the task of differentiating between tactile stimuli would be more difficult, which would be reflected by a smaller *d′*. How sensitive an individual is to this task would in turn affect the way they would gauge their confidence in being able to make the judgements; this would affect how many hits and misses participants made during the task. Response bias (*c*) is an indicator of the strategy that participants adopt in order to gauge how to make their judgement. A neutral or unbiased criterion would be indicated by a response bias (*c*) of zero, which would be the midpoint of where the signal distributions cross over for the sensitivity indices (*d′*). A liberal strategy of always saying 'Yes' would be indicated by a negative response bias/criterion (c; expect to observe greater Hit and False Alarm Rates); a conservative strategy of always saying 'No' would be indicated by a positive response bias/criterion (c; expect greater misses and correct rejections).

Table.3.2. Shows how the SSDT responses were collapsed and how signal detection terminology was applied.

<table>
<tr><th colspan="2" rowspan="2">Participant Response</th><th colspan="4">Stimuli</th></tr>
<tr><th>Pulse + Light</th><th>Light</th><th>Pulse</th><th>Catch</th></tr>
<tr><td>Definitely Yes
Maybe Yes</td><td>Yes</td><td>Hit</td><td>False Alarm</td><td>Hit</td><td>False Alarm</td></tr>
<tr><td>Maybe No
Definitely No</td><td>No</td><td>Miss</td><td>Correct Rejection</td><td>Miss</td><td>Correct Rejection</td></tr>
</table>

Table 3.3 shows the percentage mean and standard deviations for hit and false-alarm rates, sensitivity indices (*d′*), and response-criterion statistics (*c*) for Light present and absent conditions. There were greater Hit Rates during Light

Present trials then Light Absent. Similarly, there were greater False Alarm Rates during Light Present then Absent trials.

Table.3.3. Percentage hit and false alarm rates, sensitivity indices (*d'*), and response criterion statistics (*c*) for the light present and light-absent conditions on the SSDT (±1 SD).

	Hit Rate (%)	False Alarm Rate (%)	*d'*	*c*
Light	61.49	9.50	1.83	0.61
present	(0.12)	(0.09)	(0.72)	(0.32)
Light	56.60	6.41	1.82	0.74
absent	(0.11)	(0.05)	(0.54)	(0.25)

Questionnaire data was used as covariates in the univariate analysis that was conducted with Hit and False Alarm Rates, *d'* and *c* with Light Present and Absent conditions. No significant effects of the covariates were found for any of the conditions, all p > .05 and were not used in the subsequent analysis.

In order to investigate the effect of the Light, paired samples t-tests were conducted on Hit Rates, False Alarm Rates, c and *d'*. Hit Rates were significantly greater during Light present trials (M = 0.62, SD = 0.12) than Light absent trials (M = 0.57, SD = 0.12), $t_{(25)} = 3.36$, p = .003. False Alarm Rates were also found to be significantly greater during Light Present trials (M = 0.10, SD = 0.09) than Light Absent trials (M = 0.06, SD = 0.05), $t_{(25)} = 2.26$, p = .03. Participants' response bias (*c*) was significantly less liberal (more conservative) during Light Absent (M = 0.74, SD = 0.25) conditions than Light Present (M = 0.61, SD = 0.32) conditions, $t_{(25)} = 2.77$, p = 0.01. No difference was observed in tactile sensitivity between Light

Present (M = 1.83, SD = 0.72) and Absent (M = 1.82, SD = 0.54) conditions, (*d'*: $t_{(25)}$ = .10, p = .92).

SSDiT Data Analysis – Discrimination Task

SSDiT - Signal Detection Analysis

In order to conduct signal detection analysis all participants' responses were collapsed and detection theory coding was applied to the data, as show in table 3.4.

Table.3.4. Table showing how SSDiT responses were collapsed. If the presented stimuli were Strong and the response was 'strong' it was a Hit; if response was 'weak' then it was a False Alarm. If stimulus was Weak with response of 'strong' it was a Miss, if response was 'weak' then it was a Correct Rejection.

Participant Response		Stimuli	
		Strong + Light	Weak + Light
		Strong	Weak
Strongest Strong	Strong	Hit	Miss
Weak Weakest	Weak	False Alarm	Correct Rejection

Signal detection analysis was also used to explore the discrimination of strong from weak vibrations. The hit rate was the number of strong tactile pulses correctly identified as strong, divided by the total number of strong vibrations detected (i.e., participants said 'strong'). The false alarm rate was the total number of weak vibrations incorrectly identified as strong over the total number of weak vibrations detected (i.e., participants said 'weak'). As with the detection analysis, a correction factor was applied to all data to compensate for cells with ‘0’ responses (Snodgrass and Corwin 1988). The cumulative probabilities were used to calculate sensitivity (d’) for the strong and weak stimuli strong d’ = z (cumulative probability of responding correctly to strong) – z (probability incorrectly to strong); (weak d’ = z (cumulative probability of responding correctly to weak) – z (probability incorrectly to weak), (Macmillan and Creelman 2005). The signal detection data shows Hit and False Alarm rates to illustrate the overall performance on the task. Table 3.5 below provides the percentage Hit and False Alarm Rates, Sensitivity indices (*d’*) and Response criterion (*c*) for Light Present and Absent conditions.

Table.3.5. Percentage Hit and False Alarm rates, sensitivity indices (*d’*), and response criterion statistics (*c*) (±1 SD) for Light Present and Light Absent conditions on the SSDiT.

	Hit Rate %	False Alarm Rate %	*d'*	*C*
Light present	90.12 (10.45)	2.94 (3.13)	3.66 (0.81)	0.23 (0.44)
Light absent	77.54 (21.50)	1.34 (2.45)	3.42 (0.92)	0.66 (0.51)

Univariate ANOVA was conducted with the SSDiT signal detection data (Hit and False alarm rates, *d’* and c for Light Present and Absent conditions with the questionnaire data as covariates. No significant effects of the covariates were found for any of the conditions, all $p > .05$ and were not used in the subsequent analyses.

In order to investigate the effect of the Light, paired samples t-tests were conducted on Hit Rates, False Alarm Rates, *c* and *d'*. There were significantly greater Hit Rates with Light Present conditions (M = 0.90, SD = 0.11) than in Light Absent conditions (M = 0.78, SD = 0.22), $t_{(25)} = 4.36$, $p < .001$. False Alarm Rates were also significantly greater with Light Present (M = 0.03, SD = 0.03) than Light Absent trials (M = 0.01, SD = 0.03), $t_{(25)} = 3.60$, $p = .001$. Response criterion statistics (*c*) were significantly greater in Light Absent trials (M = 0.66, SD = 0.51) than in Light Present trials (M = 0.24, SD = 0.44), $t_{(25)} = 6.31$, $p <.001$. Sensitivity indices (*d'*) were not significantly different between Light Present (M = 3.66, SD = 0.81) and Light Absent (M = 3.42, SD = 0.91) conditions, $t_{(25)} = 1.84$, $p = .07$.

Comparisons between SSDT and SSDiT

Pearson correlations was conducted to see if there was any relationship between the signal detection data of the SSDT and SSDiT during Light present trials. Correlation analysis was carried out only for Light Present conditions as we were interested in how the presence of Light affected responses during the two tasks.

No significant relationship was found between the Hit rates, sensitivity indices (*d'*) and response bias (*c*) of SSDT and SSDiT; all $r < .30$, $p > .13$. A trend towards a significant positive relationship was found between the False Alarm rates of the SSDT with those of the SSDiT, $r = 0.38$, $p = .057$ (see figure 3.4 for plot). This would suggest that participants who had a greater False Alarm rate during the SSDT also had a similar pattern of making False Alarm during the SSDiT although this was marginally significant.

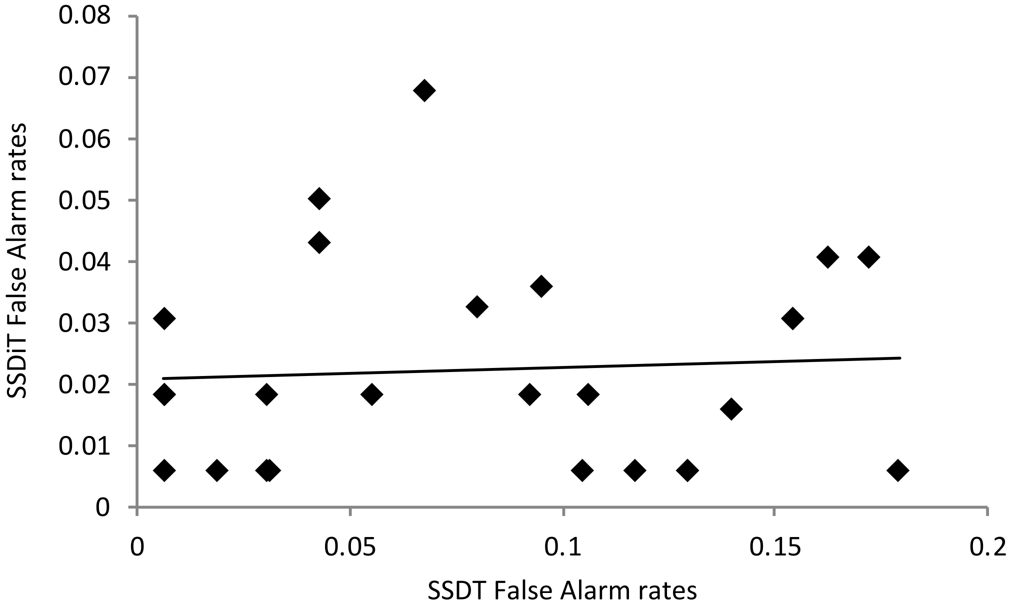


Figure.3.4. Showing the trend to significant positive relationship between Light present SSDT False Alarm rates with SSDiT False Alarm rates (with trend line of best fit).

These findings indicate that while the light appears to affect decision-making on both tasks, as evidenced by changes in Hit Rates, False Alarm Rates and Response criterions, but no difference in tactile sensitivity.

Discussion

This study aimed to investigate whether False Alarm rates on the SSDiT are related to the False Alarm rates on the SSDT. More specifically, this study aimed to determine whether participants' sensitivity to discriminate between different tactile strengths (SSDiT) is related to their ability to detect a tactile stimuli (SSDT). By using the questionnaires, it was hoped that a deeper understanding of why these illusory tactile sensations occur more in some people compared to others. Brown (2004) theorised that over internalisation of external stressors and over focus on these factors could result in the manifestation of these illusory symptoms that subjectively were overwhelming in their existence. However, this pattern did not hold, there appeared to be no strong relationship between participants' responses on the questionnaires and their performances on the tasks, which was unexpected. Participants scoring for the SDQ-20 followed that of Nijenhuis (2003) taking into consideration that our sample was not from a clinical population, the low scores were taken as being 22 or lower and the high scorers were taken as being 28 or higher (Brown et al., 2010; Maaranen et al., 2005). Our results may have not been robust enough due to the range of low and high scorers pooling closer to the maximum (low group 22) or minimum (high group 28). The scope of the difference may have been too weak to show any significant differences. It is not clear what the range of Brown et al. (2010) participant scorers were, though they did have a very large sample size of 80 (40 low and 40 high scorers), future experiments should take this into consideration.

The SSDT did have greater Hit Rates and False Alarm rates as expected during Light Present trials, which is consistent with previous findings (Lloyd et al., 2008; Mirams et al., 2010; McKenzie et al., 2010). Participants increased Hit rates during the Light Present trials were not reflected by their perceptual sensitivity indices (*d′*), which was not different between Light conditions. However, lower response bias (*c*) for Light Present conditions indicates that participants' response criterion had shifted slightly to report tactile stimuli as present (regardless of one being present or not) during Light Present trials. This would indicate that Light Present trials influenced participants' strategy for responding, resulting in greater False Alarm rates during Light Present trials.

The SSDiT results show that simultaneous presentation of light with tactile stimuli does increase accuracy when discriminating tactile stimuli, as evident by the significantly greater Hit Rates during the Light Present trials. Presence of light also results in subjective enhancement of tactile strength, resulting in greater False Alarm rates during Light present trials (Lloyd et al., 2008; Poliakoff et al., submitted). Similarly, to the SSDT findings, participants' response criterion (*c*) were lower during Light Present trials, indicating they were more likely to judge tactile stimuli as 'strong' even if it was 'weak' during Light Present conditions; this finding was found to be significantly different to that of the Light Absent conditions.

There was no significant relationship between the False Alarm rates during Light Present trials on the two tasks. Interestingly, the data trend suggests a marginally significant positive relationship. It was expected that there would be a strong relationship between participants' incorrect detection of tactile stimuli during Light Present conditions (as measured by the SSDT) and participants' ability to discriminate between tactile stimuli (as measured by the SSDiT). The current results suggest that the effect of the light on signal intensity and response bias may be mediated by separate mechanisms, which occur at different stages of processing.

Participants' perceptual judgements of the near threshold tactile SSDT stimuli can be associated with top down processing mechanisms, such as attention and expectation (Poliakoff et al., submitted). Schubert et al. (2006) and Poliakoff et al. (submitted) suggest that this type of top down processing could account for external stimuli being missed, as participants had no expectation of a stimulus or due to the lack of attention they missed the stimuli. However, misperceptions of reporting feeling a tactile pulse when one was not actually present could occur due to external sensory noise (e.g. the simultaneous light flash) affecting top down expectations (Lloyd et al., 2008; Karol and EL-Deredym 2011; Poliakoff et al., submitted). As with the SSDT misperceptions, the enhancement effects found with the SSDiT could occur due to near threshold bottom up sensory information being affected by top down expectations, which in turn could be influenced by external sensory noise. Furthermore, it is possible that the no significant relationship between False Alarm rates of the tasks is due to the difference between the SSDT and SSDiT, which is the question asked (top-down information) of participants; the stimulus type are the same during both tasks (bottom-up information). This would indicate that the weight of the question at hand affects the way the sensory information is processed.

Could the misperceptions of the SSDiT be caused by a conflict in competing mechanisms of memory being affected by bottom-up sensory information, both the true tactile sensation and that of sensory noise? Studies investigating visual-tactile interactions within human participants have indicated that viewing the site of tactile stimulation improves tactile perception even when tactile stimulation is not visible (Kennett, Taylor-Clarke, Haggard, 2001; Taylor-Clarke, Kennett, & Haggard, 2002; Lloyd et al., 2008, Poliakoff et al., submitted). Two forced-choice discrimination tasks have shown that participants do show enhancement of discriminating between two separate tactile events when they view the site of stimulation (Kennett et al., 2001; Taylor-Clarke et al., 2002). These enhancements could have occurred due to the processing of two separate tactile stimuli in the same trial. It is possible that the first stimulus presentation could influence the perceptual intensity of a second tactile stimulus by creating a bias within participants' decision-making criteria. The following chapter will investigate this using an adapted version of the SSDiT to a two forced-choice discrimination task (2FC-SSDiT); participants would have to discriminate between two tactile pulses in order to conduct their judgment of one of the tactile pulse.

Effects of order of judgement on two forced-choice SSDiT

Participants' perceptual judgements of the near threshold tactile SSDT stimuli can be associated with top down processing mechanisms, such as attention and expectation (Poliakoff et al., submitted). Schubert et al. (2006) and Poliakoff et al. (submitted) suggest that this type of top down processing could account for why external stimuli is being missed, due to a lack of attention resulting in them missing the stimulus or due to participants having no prior expectations of the stimulus. Incoming sensory data (bottom up, early sensory processing) could be compared with internal models (top-down, later decision processing) held by the body (Talsma, 2015). However, misperceptions of reporting feeling a tactile pulse when one was not actually present could occur due to external sensory noise (e.g. the simultaneous light flash) affecting top down expectations (Lloyd et al., 2008; Karol and EL-Deredym 2011; Poliakoff et al., submitted).

Research using the SSDiT has found that a concurrent light leads to a significant improvement in people's ability to discriminate 'weak' tactile stimuli from 'strong' ones, and that it leads towards a bias of reporting any tactile stimuli as 'strong' (Poliakoff, Puntis, McKenzie, Lawrence, Brown & Lloyd, submitted). As with SSDT misperceptions, the enhancement effects found with the SSDiT could occur due to near threshold bottom up sensory information being affected by top down expectations that in turn is being influenced by external sensory noise.

Studies investigating visual-tactile interactions within human participants have indicated that viewing the site of tactile stimulation improves tactile perception even when tactile stimulation is not visible (Kennett, Taylor-Clarke, Haggard, 2001; Taylor-Clarke, Kennett, & Haggard, 2002; Lloyd et al., 2008, Poliakoff et al., submitted). Two forced-choice (2FC) tasks have also show an increase in participants' ability to discriminate between tactile stimuli when they view the site of stimulation (Kennett et al., 2001; Taylor-Clarke et al., 2002). These findings would suggest that the illusory effects may be attributed to the attention held by sensory processing mechanisms rather than a result of a learnt behaviour. Participants cannot see the tactile stimulation, therefore, they cannot adapt or learn a strategy based predominantly on what they are seeing. However, participants' tactile sensory mechanisms may now be the more reliable source of sensory information, thus increasing the attention held by that system.

When participants hold a specific goal or belief, for example relating to a discrimination task, the sensory processing mechanisms must be maintaining a representation of that stimulus in order to process it beyond initial sensory detection. A review by Theeuwes (2010) puts forward an explanation of how sensory information is processed, which could help understand these enhancement effects. For example, visual stimuli with no prior expectation or question weighted with it, it is unclear whether it would be processed at an early stage as ambiguous visual information (bottom-up processing). A feedback process, which would occur later in time (after initially sensory processing), would be when any goals, expectancies (e.g. judgement questions) would affect the way in which the initial sensory signal is processed. This top-down processing occurs after the initial sensory detection of the stimulus, and is processed according to the question at hand; the question would cause a slight bias on the initial sensory information. It has also been suggested that early and late sensory integration can be seen as being independent processes that take place at the same time depending on the demand/attention given to one stimuli over another (Calvert & Thesen, 2004; see review by Koelewijn et al. 2010). Furthermore, Jolicoeur and Dell'Acqua (1998) investigated the mechanisms of encoding information into short-term memory (STM) and how there might be three different types of encoding, sensory and perceptual encoding and short-term consolidation (STC); working memory (WM) is considered to be part of the sensory encoding processing. Sensory processing/encodes occurs early and this sensory information is then projected to other areas related to perceptual processing. Perceptual processing is believed to be where patterns are recognised from new sensory information and recalled from the existing representation in longer-term memory (Jolicoeur and Dell'Acqua, 1998). Perceptual processing must be able to receive input from a variety of sensory modalities for this form of recall to occur (Pinker, 1984). The perceptual encoding process would remain active as long as they receive bottom-up sensory input, if this were to stop these representations would decay unless the information undergoes further processing (Jolicoeur and Dell'Acqua, 1998; Brown, 2004; Brown et al., 2010).

The illusory effects of SSDiT (and SSDT) could be the result of the simultaneous processing of both the tactile and task-irrelevant light stimuli; with the later interfering with the discrimination judgement the participants are undertaking. There could be an effect of the task-irrelevant visual stimulus on both tactile sensitivity and on response bias, which is in keeping with previous findings (Calvert & Thesen, 2004; Koelewijn et al. 2010; Theeuwes, 2010; Katzer et al., 2012; Lloyd et al., 2008; Poliakoff et al., submitted). It is possible that the residual sensory trace of the task irrelevant Light during the SSDiT affects the later discrimination process. The present study adapted the SSDiT to a 2FC task (2FC-SSDiT). A 2FC-SSDiT would enable the comparison between First pulse and Second pulse judgements, as participants would be attending to different stimuli presentation intervals. Participants would have to discriminate the tactile strength of either the First or Second pulse. It is expected that participants would show greater False Alarm rates during Light present trials (as with the previous SSDiT findings, Chapter 3) in both First and Second pulse judgements. With First pulse False Alarm rates being greater out of the two judgement groups, due to the length of time the sensory information must be held in memory. Responses during the task will be limited to a 'Yes' or 'No' selection; therefore, participants would be required to make a firm choice. A 2FC-SSDiT experiment would further help identify how sensitive low and high SDQ-20 participants are to the SSDiT stimuli as they would have to make decisions based on the comparison between the two stimuli presentations.

Method

Design

There were two different tactile Comparator stimuli types Weak and Strong. For each of these Comparator conditions there were 2 [Judgement Order Groups (JOG, First pulse, Second pulse)] x 2 [Comparator Light (absent, present)] x2 [Target Light (present, absent)] within-subjects design. Participants' responses to the questions (Yes, No) were recorded. Participants were randomly allocated to one of two JOGs: the first group was asked to make a decision based on the first pulse, i.e. 'Was the First pulse Stronger' or 'Was the First pulse Weaker'; the second group were asked to make a decision based on the second pulse, i.e. 'Was the Second pulse Stronger' or 'Was the Second pulse Weaker' (see table 4.1 and 4.2). Experimental trials were pseudo randomised and key presses were rotated between thresholding and the main experiment.

Participants

A total of 38 participants (4 Males), aged between 18 and 32 years old (M = 21 years, SD = 3.5) were recruited to take part in this study (19 in each Comparator condition, Weak and Strong). All participants were right-handed, as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). All participants had normal or corrected-to normal vision and none reported any sensory deficits. Full informed consent was obtained from each participant, after written and verbal explanations of the tasks were provided. All procedures were approved by the University of Nottingham Malaysia Campus Research Ethics Committee. Participants were recruited at the University of Nottingham Malaysia Campus, and received a RM5 allowance in return for participation.

In order to provide a subjective account of a participant's susceptibility to experience somatoform sensation (illusory sensations) the following questionnaires were used: the Somatoform Dissociation Questionnaire-20 (SDQ-20; Nijenhuis et.al., 1996); Patient Health Questionnaire 15 (PHQ-15; Kroenke et al., 2002); Somatosensory Amplification Scale (SSAS; Barsky et al., 1988); these were used to see if these measures impacted on performance (Brown et al., 2010; McKenzie et al., 2010; Katzer et al., 2011; McKenzie et al., 2012; Poliakoff et al., submitted), see chapter 2, SSDiT 2.1.2 Questionnaires, for more information about these. The participants' questionnaire scores are shown in tables 4.1 and 4.2 below.

Table.4.1. Table of means and ranges of questionnaire scores for First Judgement group (± 1 SD).

	SDQ-20	SSAS	PHQ-15
Mean	21.32	26.84	20.63
(SD)	(2.16)	(6.45)	(4.31)
Range	20 – 28	17 – 39	14 - 32

Table.4.2. Table of means and ranges of questionnaire scores for Second Judgement group (± 1 SD).

	SDQ-20	SSAS	PHQ-15
Mean	23.11	26.26	20.95
(SD)	(4.78)	(5.09)	(4.77)
Range	20 – 37	18 – 36	16 – 33

Stimulus and Materials

Tactile stimuli were composed of a single 20 millisecond 100Hz square wave; the sound file was manipulated and created with Audacity (Audacity Team Version 1.3.14-beta http://audacity.sourceforge.net). When the tactile pulse was presented, this sound file was initiated and was output from the desktop pc into the TactAmp 4.01, which then drove the Tactor to provide the tactile stimulation (TactAmp 4.01 and Tactor are of Dancer Studio Designs, Merseyside, United Kingdom). All tactile stimuli were presented at the individual participants' specific threshold level determined by the participant's lowest tactile threshold level, which was determined during the thresholding procedure (described below) prior to the main experiment. The tactile stimuli intensity for the SSDiT 'Weak' stimuli was determined by the thresholding procedure and the 'Strong' tactile pulse was 50% above their threshold. The Light conditions were triggered by the experimental script and consisted of Light present [trigger on, duration 20 milliseconds, stop] or Light absent [wait 20 milliseconds, this would not trigger the LED]. When the 'LED on' script was triggered, a signal from computer would be sent to the corresponding LED circuit via the serial printer port/cable from the computer to the TactAmp, which would result in the LED illuminating for 20 milliseconds; the Light absent condition would not have any LED lamination. See Chapter 2.1, for detailed SSDiT equipment information (see figure 4.1 below for the experimental set up with the SSDiT stimulus array).

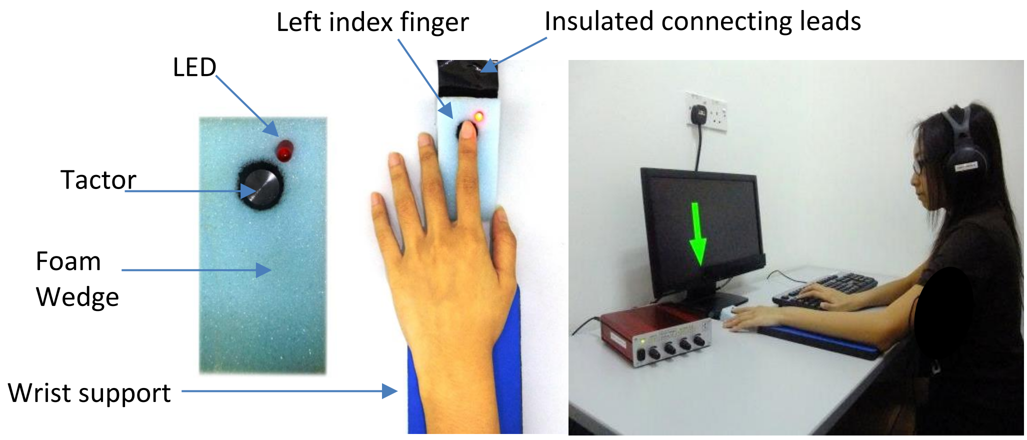


Figure.4.1. SSDiT experimental set up.

Procedure

Participants sat in a light attenuated room approximately 60cm in front of a computer monitor, stimulus array and keyboard, for the duration of the thresholding and main experimental tasks. All indicators lights on the monitor and keyboard were covered as to not cause any visual noise during the task. Throughout all thresholding and experimental trials, the participants' left index finger was attached to the Tactor using a double-sided adhesive circle. This was to minimise movement during the experiment. White noise was played to participants through a digital audio player (iPod Nano) with Philips SHP 1900 stereo over ear headphones; this was to mask the sound of the Tactor and any background or experimentally informative noises. Participants were asked if they could hear any external noise while the white noise played, if they did the volume was increased slightly until they could not hear any ambient sounds. The white noise was turned off during breaks.

Participants were given a modified version of the SSDiT, which was adapted into a two forced-choice decision task. Rather than make a judgement on a single pulse, participants had to distinguish between two tactile pulses. Participants were pseudo-randomly assigned to one of the judgement order groups (JOG; First pulse judgements and Second pulse judgements). There was one experimental session lasting one hour. The experimental procedure was the same for all participants. Only the response keys were rotated between thresholding and the experimental task (see figure 4.1. for the experimental setup).

Two Forced-choice Somatic Signal Discrimination Task (2FC-SSDiT)

Thresholding procedure

Prior to starting the main experiment, participants were threshold and the procedure consisted of a block of 13 trials, consisting of 10 tactile (touch) present and 3 touch absent randomly presented trials, with each trial lasting 1020ms. The participants' left index finger was attached to the Tactor. An on screen green arrow cue (136 x 320 pixels in width and height; the point of the arrow is located pixel at 493 x 623 coordinates) indicated the start of each trial, prompting the participant to look at their left index finger. There was a 500ms wait before the onset of stimuli from the cue: during touch present trials a 20ms tactile stimulus was delivered to the participants' left index finger, followed by a 500ms wait; touch absent trials were the same as touch present trials except there was no tactile stimuli presented and the trial was of the same duration. After each of these trials, participants were prompted on the monitor to indicate whether they had felt a tactile pulse by pressing one of two keys on the number pad of the keyboard, “Y” for yes and “N” for no. Stickers with these letters printed on were placed on number ‘1’ and ‘4’ to denote the ‘Yes’ and ‘No’ response; the keyboard was rotated by 90 degrees from the normal functional orientation to make it easier for participants to press these keys.

At the end of each block the experimenter was presented with the total correct (yes) responses and the tactile intensity was adjusted according to the staircase method described above. Participants had to responded ‘Yes’ on 40% to 60% of touch present trials (correctly identified 4 – 6 of the 10 tactile present trials as correct) during a thresholding block, if they failed to report the desired number of touch present trials the intensity of the tactile stimulus was adjusted by turning the Tactor dial at the front of the TactAmp in small increments to change the amplitude of the output signal in the Tactor; clockwise to increase and anticlockwise to decrease amplitude after which a new threshold block would commence. As mentioned previously, participants were required to respond ‘Yes’ on 40% to 60% of touch present trials during three consecutive thresholding blocks to be considered as having found their 50% threshold level. Participants only progressed to the experimental blocks after they had met these thresholding requirements. Over course of the experimental session the threshold level for a participant can change due to fatigue and tactile drift (McKenzie et al., 2010). Therefore, a further thresholding procedure was used at the mid-point of the experiment to ensure participants were within the 50% threshold level.

After thresholding, participants in both judgement order groups were presented with 16 pairs of practice trials, this was to familiarise participants with how the experiment would be conducted. During the practice trials participants were presented with two stimuli presentations (first pulse, 'FP' and second pulse, 'SP'). Each of the two pulses were composed of one of the following stimuli pairings: Strong tactile pulse with light present, strong tactile pulse without light; weak tactile pulse with light present, weak tactile pulse without light. Eight of the 16 practice trials asked participants in the first pulse judgement order group if the FP was stronger, the reaming eight trials asked if they were weaker. Participants in the second pulse judgement order group were asked if eight of the 16 practice trials if the SP was stronger, the remaining eight trials asked if the SP was weaker. Thresholding and practice trials were the same for both JOGs; only the wording of the task was different between the two groups. Participants were instructed to not move their left index finger during the breaks. After the practice trials, participants moved onto the main experiment.

A trial consisted of two pulses being presented (FP and SP), each of these pulses were comprised of the same stimuli combinations. The main experiment consisted of 384 pairs of trials spread over four experimental blocks, with rests in between each block. Each of the four blocks consisted of 96 trials; each pair of a trial was comprised of one of the stimuli conditions (strong pulse, weak pulse, strong pulse with light, weak pulse with light). Each of the four conditions was presented 24 times in each block in a pseudorandom order to each FP and SP (see figure 4.2 for diagram of the experimental design); no two identical stimuli were the same during first and second pulse presentations. Participants in the First Pulse

JOG were instructed to decide if the First pulse was 'Stronger' or 'Weaker'; Participants in the Second Pulse JOG were asked to decide if the Second pulse was 'Stronger' or 'Weaker'. The weak tactile stimulus was presented at the intensity level established during the thresholding procedure and the strong tactile stimulus was 3 times this level. Participants were instructed that the red LED may flash near their index finger at the same time as the pulse, but they should not report seeing this and base their response on the tactile pulse. They were also informed to make sure they read the question carefully and answer as quickly and accurately as possible.

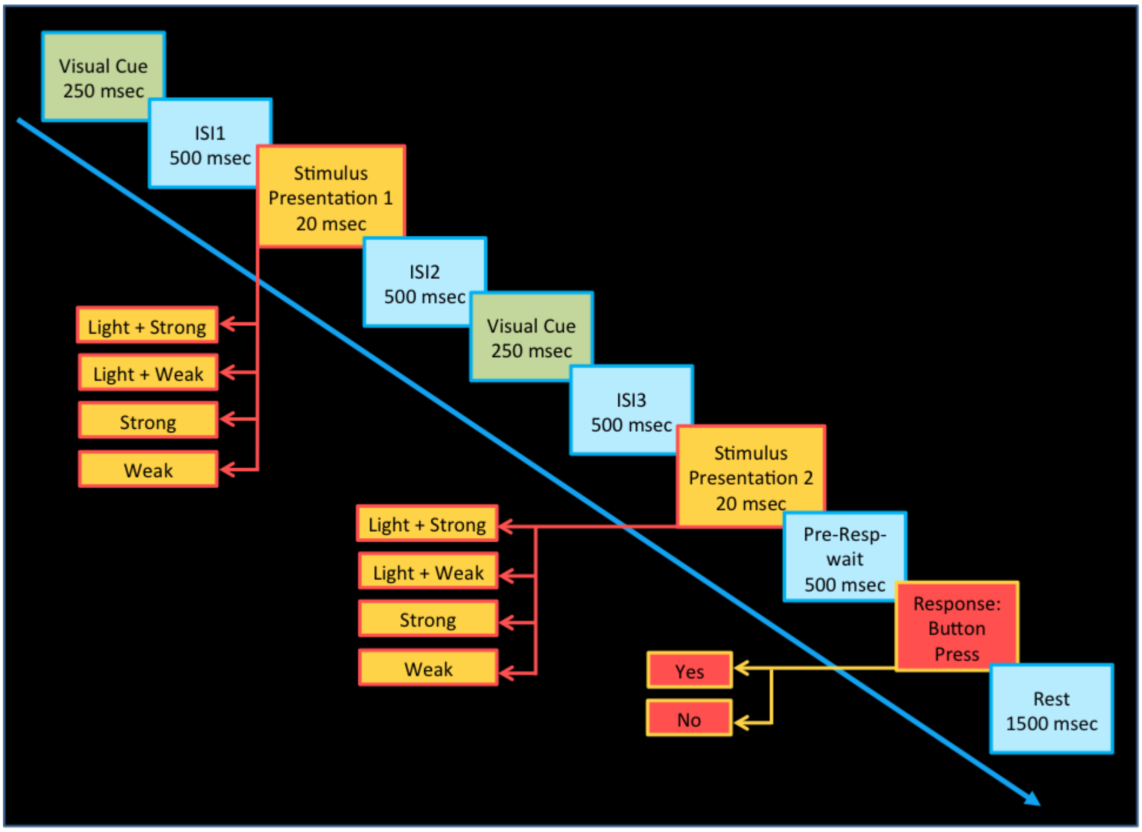


Figure.4.2. Experimental Paradigms for the two-forced choice SSDiT.

Results

Within each Comparator condition there were two judgement order groups (JOG), First and second pulse. Participants' responses to their respective judgement questions (JOG) were analysed separately. The responses were separated and analysed in this way because of the judgement question asked, and the tactile stimuli presented to participants was not counterbalanced by Comparator type: when the comparator pulse strength was Weak (stimulus pulse which participants judged against) the judgement question asked, 'Was the pulse stronger'; trials with Strong comparator pulse strengths (stimulus pulse which participants judged against) the judgement question asked, 'Was the pulse weaker'. The questions asked during the Weak and Strong comparator trials were not the same for first and second pulse judgement groups. Which meant the total of Weak and Strong comparator trials were not balanced; therefore, the results will be presented by Weak comparator and Strong comparator trials by first and second pulse judgements. Early analysis revealed significant differences between the two judgement orders (first and second). To clarify these trends, additional analyses were carried out by partitioning judgement order and are therefore presented separately.

Signal detection analysis was used to understand participants' ability to discriminate between weak and strong vibrations. The hit rate was defined as the number of strong vibrations correctly identified as strong, divided by the total number of strong vibrations presented. The false alarm rate was the total number of weak vibrations incorrectly identified as strong, over the total number of weak vibrations presented. To compensate for zero responses (i.e. participants who never said 'yes'), when calculating the hit and false alarm rates, 0.5 was added to the top and 1 to the bottom of the equation for all cases (Snodgrass and Corwin, 1988). See table 4.3 to show how signal detection terms were applied to the data. All subsequent analysis will use this encoding to determine signal detection statistics.

Weak Comparator and Strong Comparator data was checked to see if the questionnaire data mediated performance on the tasks, the results of the questionnaires (see tables 4.1 and 4.2 for scores) were entered as covariates in ANCOVA. Correlation analysis was conducted to investigate the relationship between Comparator levels and the questionnaire data if they were significant. If the questionnaires were not significant then a repeated measures ANOVA are reported. Significant interactions are followed by post-hoc analysis with paired samples t-test results. This analysis was conducted for both First and Second pulse judgements (judgement order groups, JOG). The results will be presented by signal detection analysis of Hit and False Alarm Rates, sensitivity indices (*d*'), and response-criterion statistics (*c*) for both First and Second pulse judgements (for definition of terms see table 4.3 for Weak Comparator and table 4.6 for Strong Comparator).

Sensitivity indices (*d'*) scores are a way to determine how much the tactile signals differed. If they were distinctly different the distribution of means would be further apart and *d'* would be a large number. If they were not different the means would be closer, which would be reflected by a smaller *d'* (difficult to differentiate). How sensitive an individual is to this task would in turn affect the way they would gauge their confidence in being able to make the judgements. Response bias (*c*) is an indicator of the strategy that participants adopt in order to gauge how to make their judgement. A neutral or unbiased criterion would be indicated by a response bias (*c*) of zero. A liberal strategy of always saying 'Yes' would be indicated by a negative response bias/criterion (c; expect to observe greater Hit and False Alarm Rates); a conservative strategy of always saying 'No' would be indicated by a positive response bias/criterion (c; expect greater misses and correct rejections).

Weak Comparator analysis

Weak Comparator responses were encoded as shown in table 4.3 below. All subsequent results will use this terminology.

Table.4.3. Shows how the two-forced choice SSDiT Weak Comparator was encoded with signal detection terminology (key responses are shown as 'Yes' and 'No').

		Weak Comparator pulse strength (Stimulus pulse which participants judged against) (Question: Was the pulse stronger)	
Target pulse strength and light (judgement was carried out on this pulse)		Light Absent Light Present	
Weak	Light Absent Light Present	False Alarm (Yes)	Correct Rejection (No)
Strong	Light Absent Light Present	Hit (Yes)	Miss (No)

All results in this subsection pertain to Weak Comparator conditions. The results are further separated by Judgement order group (JOG). The percentage Hit and False Alarm rates were calculated for each of the Weak Comparator condition and are shown in table 4.4 (first JOG) and table 4.5 (second JOG). All analysis was conducted after removal of outliers.

Table.4.4. First pulse judgement order group (JOG) with Weak Comparator and Comparator Light and Target Light conditions signal detection results as percentage Hit and False Alarm rates, sensitivity indices (*d'*), and response-criterion statistics (*c*) (±1 SD).

Comparator	Weak Light absent		Weak Light present	
Target Light	Light Present	Light Absent	Light Present	Light Absent
Hit Rate (%)	90.84 (0.11)	90.84 (0.08)	93.58 (0.07)	90.84 (0.08)
False Alarm Rate (%)	48.32 (0.23)	39.89 (0.28)	43.26 (0.26)	37.37 (0.23)
d'	1.62 (0.87)	1.79 (0.88)	1.87 (0.79)	1.82 (0.84)
c	- 0.73 (0.50)	- 0.57 (0.64)	- 0.74 (0.62)	- 0.56 (0.52)

Table.4.5. Percentage Hit and False Alarm rates, sensitivity indices (*d'*), and response-criterion statistics (*c*) for Weak Comparator conditions with Comparator Light and Target Light conditions (±1 SD) for the second JOG.

Comparator	Weak Light absent		Weak Light present	
Target Light	Light Present	Light Absent	Light Present	Light Absent
Hit Rate (%)	93.16 (0.08)	92.95 (0.07)	94.38 (0.06)	92.11 (0.07)
False Alarm Rate (%)	30.42 (0.20)	17.37 (0.14)	21.37 (0.18)	18.01 (0.13)
d'	2.29 (0.85)	2.72 (0.70)	2.77 (0.96)	2.61 (0.78)
C	- 0.53 (0.42)	- 0.28 (0.39)	- 0.38 (0.40)	- 0.27 (0.33)

A 2 [Comparator Light (absent, present)] x2 [Target Light (present, absent)] repeated measures ANCOVA was conducted with SDQ-20, SSAS and PHQ-15 scores as covariates (see table 4.1 for all questionnaire scores), for Hit and False Alarm rates, sensitivity indices (*d'*), and response-criterion statistics (*c*). If the ANCOVA was not significant a 2 [Comparator Light (absent, present)] x2 [Target Light (present, absent)] repeated measures ANOVA was conducted for the signal detection data (ANCOVA not significant for Hit rate second pulse judgements, False Alarm rates, sensitivity indices (*d'*) and response bias(*c*) first pulse judgements).

Weak Comparator Hit Rates

First pulse judgements

ANCOVA results found a significant relationship between Comparator and Target Light absent trials with SDQ-20 scores, $F_{(1,17)} = 8.58$, $p = .009$. Comparator and Target Light present trials with SDQ-20, $F_{(1,17)} = 5.51$, $p = .03$. Pearson's correlation analysis of these relationships found no significant negative relationship between the terms, all $p > .05$. There was no main effect of Comparator Light or Target Light, all $p > .05$. There was no significant interaction effect between the terms, $p > .05$.

Weak Comparator Hit Rates

Second pulse judgement

Repeated measures ANOVA results found there was a significant main effect of Target Light with Hit Rates. With Hit rates being significantly greater during Target Light present (M = 0.94, SD = 0.07) trials than Target Light absent trials (M = 0.93, SD = 0.07), $F_{(1,18)} = 5.35$, $p = .03$. There was no significant main effect of Comparator Light or an interaction between the terms, all $p > .05$.

Weak Comparator False Alarm Rates

First pulse judgements

Repeated measures ANOVA results found a significant main effect of Target Light with False Alarm rates. False Alarm rates were significantly greater with Target Light present (M = 0.46, SD = 0.24) trials than with Target Light absent trials (M = 0.39, SD = 0.25), $F_{(1,18)} = 16.31$, $p = .001$. There was no significant main effect of Comparator Light ($p > .05$) and there was no significant interaction effect between the terms, $F_{(1,18)} = 0.33$, $p = .57$.

Weak Comparator False Alarm Rates

Second pulse judgements

Repeated measures ANOVA results found there was a significant main effect of Comparator Light with False Alarm Rates. With False Alarm rates being significantly greater during Comparator Light absent (M = 0.24, SD = 0.19) trials than Comparator Light present trials (M = 0.20, SD = 0.15), $F_{(1,18)} = 6.16$, $p = .02$. There was a significant main effect of Target Light with False Alarm Rates. With False Alarm rates being significantly greater during Target Light present (M = 0.26, SD = 0.19) trials than Target Light absent trials (M = 0.18, SD = 0.13), $F_{(1,18)} = 9.31$, $p = .007$. There was a trend towards a significant interaction between the terms, $F_{(1,18)} = 4.20$, $p = .055$.

Comparison between first and second judgements for Weak Comparator False Alarm Rates

Paired samples t-test was conducted between first and second pulse judgement False Alarm rates during Weak Comparator with Light absent/present and Target Light present/absent trials.

Table 4.6. Paired samples t-test (Bonferroni corrected) between first and second JOG for Weak Comparator False Alarm rates (* indicates significant findings. Highlight shows both Light present conditions).

	M	*SD*	*df*	*t*	*p*
Comparator Light absent & Target Light present					
First JOG False Alarms X	0.48	0.08	18	2.25	.04*
Second JOG False Alarms	0.30	0.20			
Comparator Light absent & Target Light absent					
First JOG False Alarms X	0.40	0.28	18	2.70	.01*
Second JOG False Alarms	0.17	0.14			
Comparator Light present & Target Light present					
First JOG False Alarms X	0.43	0.26	18	2.65	.02*
Second JOG False Alarms	0.21	0.18			
Comparator Light present & Target Light absent					
First JOG False Alarms X	0.37	0.23	18	2.76	.01*
Second JOG False Alarms	0.18	0.13			

False Alarm rates during Weak Comparator condition were greater during first pulse judgements than second pulse judgements over all Light conditions.

Weak Comparator Sensitivity indices (d')

First pulse judgements

Repeated measures ANOVA found no significant main effects of Comparator and Target Light with Sensitivity indices (*d'*), all $p > .05$. There were no significant interaction effects between the terms, $p > .05$.

Weak Comparator Sensitivity indices (d')

Second pulse judgements

Repeated measures ANOVA results found there were no significant main effects of Comparator Light and Target Lights, all $p > .05$. There was a significant interaction between Comparator Light and Target Light, $F_{(1,18)} = 8.59$, $p = .009$. Post-hoc paired samples t-tests were conducted between Target Light present and absent trials within Comparator Light absent and present trials separately. During Comparator Light absent trials Sensitivity indices (*d'*) were significantly greater during Target Light absent trials (M = 2.72, SD = 0.70) than during Target Light present trials (M = 2.29, SD = 0.85), $t_{(18)} = 2.46$, $p = .02$. During Comparator Light present trials Sensitivity indices (*d'*) were not significantly different between Target Light present (M = 2.77, SD = 0.96) and Target Light absent (M = 2.61, SD = 0.78) trials, $t_{(18)} = 1.14$, $p = .27$.

Comparison between first and second pulse judgements for Weak Comparator Sensitivity indices (d')

Paired samples t-test was conducted between the Sensitivity indices (*d')* of first and second pulse judgements during Weak Comparator with Light absent/present and Target Light present/absent trials.

Table 4.7. Paired samples t-test (Bonferroni corrected) between first and second JOGs for Weak Comparator Sensitivity indices (*d'*; * indicates significant findings. Highlight shows both Light present conditions).

	M	*SD*	*df*	*t*	*p*
Comparator Light absent & Target Light present					
First JOG Sensitivity indices (*d'*) X	1.62	0.87	18	2.19	.04*
Second JOG Sensitivity indices (*d'*)	2.29	0.85			
Comparator Light absent & Target Light absent					
First JOG Sensitivity indices (*d'*) X	1.79	0.88	18	3.14	.006*
Second JOG Sensitivity indices (*d'*)	2.72	0.70			
Comparator Light present & Target Light present					
First JOG Sensitivity indices (*d'*) X	1.87	0.78	18	2.92	.009*
Second JOG Sensitivity indices (*d'*)	2.77	0.96			
Comparator Light present & Target Light absent					
First JOG Sensitivity indices (*d'*) X	1.81	0.84	18	3.02	.007*
Second JOG Sensitivity indices (*d'*)	2.61	0.78			

Sensitivity indices (*d’*) during Weak Comparator conditions were greater during second pulse judgements than first pulse judgements during all Light conditions.

Weak Comparator Response bias (c)

First pulse judgements

Repeated measures ANOVA found no significant main effect of Comparator Light with Response bias (*c*), $p > .05$. There was a significant main effect of Target Light. The Response bias (*c*) were significantly more negative during Target Light present trials (M = - 0.73, SD = 0.56) than with Target Light absent trials (M = - 0.56, SD = 0.57), $F_{(1,18)} = 15.08$, $p = .001$. There was no significant interaction effect between the terms, $p > .05$.

Weak Comparator Response bias (c)

Second pulse judgements

ANCOVA analysis of Comparator Response bias (*c*) with questionnaire SSAS had a significant relationship, only during trials consisting of Comparator Light absent and Target Light present trials, $F_{(1,17)} = 4.66$, $p = .045$. Pearson’s correlation analysis found a significant positive relationship between the Response bias (*c*) during Comparator Light absent and Target Light present trials and questionnaire SSAS, $r = 0.46$, $p = .045$ (see figure 4.3 which illustrates this relationship).

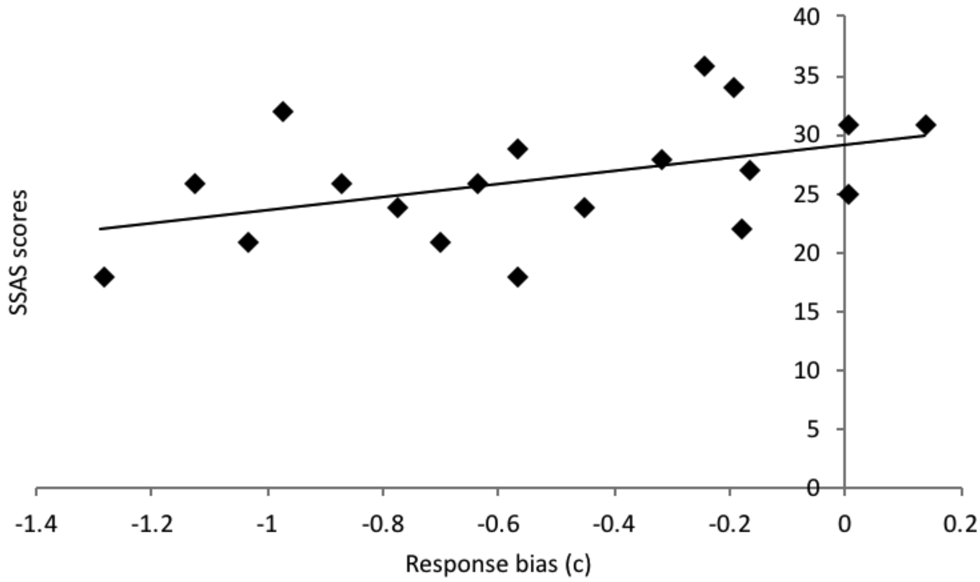


Figure.4.3. Shows the significant positive relationship between the Weak Comparator Response bias (*c*) of Comparator Light absent with Target Light present trials and SSAS scores (with trend line of best fit); response bias (*c*) would be greater (more positive) with those who scored higher on the SSAS.

There was a significant interaction effect between Target Light and questionnaire SSAS, $F_{(1,15)} = 5.64$, $p = .03$. Pearson's Correlation analysis of Target Light and questionnaire SSAS found a trend towards a significant positive relationship between response bias (*c*) scores for Target Light present (M = -0.91, SD = 0.76) and SSAS scores, r = 0.44, p = .06. Correlation analysis did not find a significant relationship between response bias (*c*) scores for Target Light absent trials (M = -0.55, SD = 0.63) and SSAS scores, r = 0.21, p = .39.

A significant main effect of Comparator Light was found with response bias (*c*). Response bias (*c*) were more negative during Comparator Light absent trials (M = -0.40, SD = 0.42) than during Comparator Light present trials (M = -0.32, SD = 0.37), $F_{(1,18)} = 4.64$, $p = .045$. Significant main effect of Target Light was also present. Response bias (*c*) were more negative during Target Light present trials (M = -0.45, SD = 0.41) than during Target Light absent trials (M = -0.27, SD = 0.36), $F_{(1,18)}$ = 12.26, p = .003. There was no significant interaction between Comparator Light and Target Light conditions, p > .05.

Strong Comparator analysis

Table.4.8. Shows how the two-forced choice SSDiT Strong Comparator was encoded with signal detection terminology (key responses are shown as 'Yes' and 'No').

Target pulse strength and light (judgement was carried out on this pulse)		Strong Comparator pulse strength (Stimulus pulse which participants judged against) (Question: Was the pulse weaker)	
		Light Absent	
		Light Present	
Weak	Light Absent	Hit (Yes)	Miss (No)
	Light Present		
Strong	Light Absent	False Alarm (Yes)	Correct Rejection (No)
	Light Present		

All results in this subsection pertain to Strong Comparator conditions. The results are further separated by Judgement order group (JOG). The percentage Hit and False Alarm rates were calculated for each of the Weak Comparator condition and are shown in table 4.9 (first JOG) and table 4.10 (second JOG).

Table.4.9. Percentage Hit and False Alarm rates, sensitivity indices (*d'*), and response-criterion statistics (*c*) for Strong Comparator conditions with Comparator Light and Target Light conditions (±1 SD) for the first JOG.

Comparator	Strong Light absent		Strong Light present	
Target Light	Light Present	Light Absent	Light Present	Light Absent
Hit Rate (%)	71.42 (0.26)	85.79 (0.12)	87.89 (0.12)	85.79 (0.12)
False Alarm Rate (%)	22.42 (0.13)	25.79 (0.15)	24.53 (0.15)	36.53 (0.19)
d'	1.67 (1.11)	1.95 (0.72)	2.15 (0.90)	1.63 (0.83)
c	0.01 (0.56)	- 0.24 (0.40)	- 0.29 (0.35)	- 0.41 (0.39)

Table.4.10. Percentage Hit and False Alarm rates, sensitivity indices (*d'*), and response-criterion statistics (*c*) for Strong Comparator conditions with Comparator Light and Target Light conditions (±1 SD) for the second JOG.

Comparator	Strong Light absent		Strong Light present	
Target Light	Light Present	Light Absent	Light Present	Light Absent
Hit Rate (%)	90.00 (0.07)	90.84 (0.10)	90.21 (0.08)	91.89 (0.06)
False Alarm Rate (%)	37.16 (0.25)	42.63 (0.28)	46.21 (0.25)	55.26 (0.24)
d'	1.77 (0.79)	1.80 (0.85)	1.61 (0.85)	1.35 (0.75)
c	- 0.52 (0.56)	- 0.62 (0.65)	- 0.64 (0.55)	- 0.84 (0.51)

A 2 [Comparator Light (absent, present)] x2 [Target Light (present, absent)] repeated measures ANCOVA was conducted with SDQ-20, SSAS and PHQ-15 scores as covariates (see table 4.1 for all questionnaire scores), for Hit and False Alarm rates, sensitivity indices (*d'*), and response-criterion statistics (*c*). If the covariates were not significant then a repeated measures ANOVA are reported (Strong comparator ANCOVA not significant for second pulse Hit rates, both judgement groups for False Alarm rates, sensitivity indices (*d'*) and response bias, *c*). Significant interactions are followed by post-hoc analysis with Bonferroni corrected paired samples t-test results. This analysis was conducted for both First and Second pulse judgements (judgement order groups, JOG). The results will be presented by signal detection analysis of Hit and False Alarm Rates, sensitivity indices (*d'*), and response-criterion statistics (*c*) for both First and Second pulse judgements.

Strong Comparator Hit Rates

First pulse judgements

ANCOVA analysis found a significant relationship between Hit Rates during Comparator Light and Target Light absent trials and SDQ-20, $F_{(1,15)} = 11.97$, $p = .003$. No other significant relationships were found with questionnaire data. Repeated measures ANOVA found no significant main effects or interactions between Comparator and Target Light, all $p > .05$. Pearson's Correlation analysis of Comparator Light absent and Target Light absent with questionnaire SDQ-20 found a significant negative relationship with Hit Rates (M = 0.91, SD = 0.10), r = -0.64, p = .003 (See figure 4.4 for scatter plot depicting this relationship).

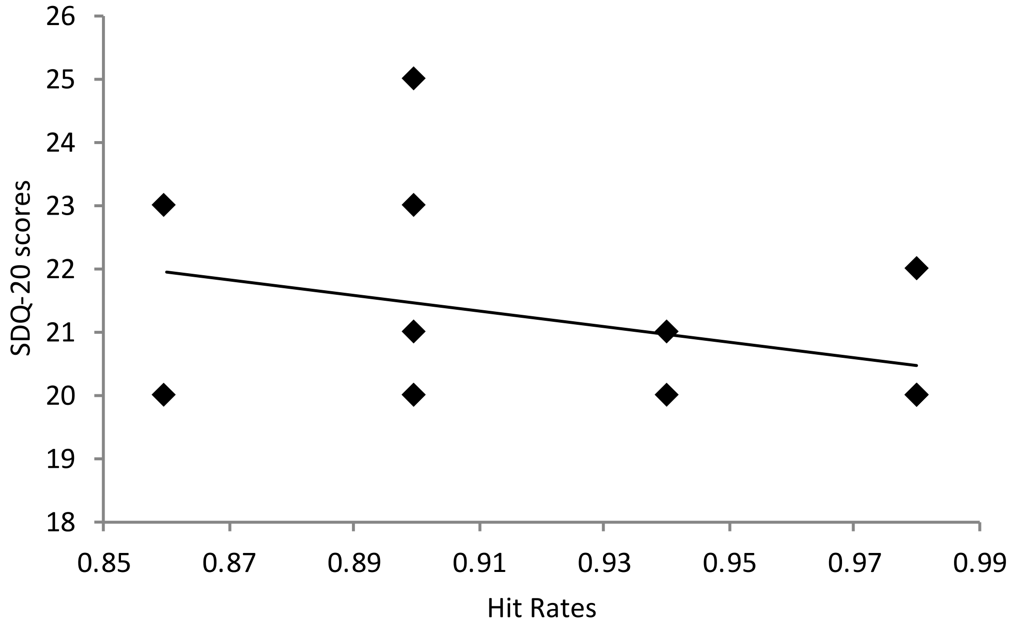


Figure.4.4. Scatter plot showing the significant negative relationship between Hit Rates during Strong Comparator and Target Light absent trials with SDQ-20 scores (with line of best fit) during the first JOG.

Strong Comparator Hit Rates

Second pulse judgements

Repeated measures ANOVA found a significant main effect of Comparator Light, with greater Hit Rates during Comparator Light present (M = 0.87, SD = 0.12) trials than absent (M = 0.79, SD = 0.21) trials, $F_{(1,18)}$ = 5.42, p = .03. There was no significant main effect of Target Light, p > .05. There was a significant interaction between Comparator Light and Target Light, $F_{(1,18)}$ = 4.70, p = .04. Post-hoc paired samples t-tests were conducted between Target Light present and absent trials within Comparator Light absent and present trials separately. No significant difference was observed during Comparator Light present conditions with Target Light present (M = 0.88, SD = 0.12) and Target Light absent (M = 0.86, SD = 0.12) trials, $t_{(18)}$ = 1.39, p = .18. A trend towards Hit Rates being significantly greater during Comparator Light absent conditions and Target Light absent (M = 0.86, SD = 0.12) and Target Light present (M = 0.71, SD = 0.26) trials, $t_{(18)}$ = 2.02, p = .059.

Comparison between first and second pulse judgements for Strong Comparator Hit Rates

Paired samples t-test was conducted between the Hit Rates of first and second pulse judgements during Strong Comparator with Light absent/present and Target Light present/absent trials.

Table 4.11. Paired samples t-test (Bonferroni corrected) between first and second JOGs for Strong Comparator Hit Rates (* indicates significant findings).

	M	*SD*	*df*	*t*	*p*
Comparator Light absent & Target Light present					
First JOG Hit Rates X	0.90	0.07	18	3.25	.004*
Second JOG Hit Rates	0.71	0.26			
Comparator Light present & Target Light absent					
First JOG Hit Rates X	0.92	0.06	18	2.78	.01*
Second JOG Hit Rates	0.86	0.12			

Hit Rates during Strong Comparator conditions were significantly greater during first pulse judgements than second pulse judgements.

Strong Comparator False Alarm Rates

First pulse judgements

Repeated measures ANOVA found a significant main effect of Comparator Light, with Comparator Light present (M = 0.51, SD = 0.24) trials having greater False Alarms than when the Light was absent (M = 0.40, SD = 0.26), $F_{(1,18)} = 20.91$, $p < .001$. There was a significant main effect of Target Light with False Alarm rates. False Alarm rates were significantly greater with Target Light absent (M = 0.49, SD = 0.27) trials than with Target Light present trials (M = 0.42, SD = 0.25), $F_{(1,18)} = 10.34$, $p = .005$. There was no significant interaction effect between the terms, $F_{(1,18)} = 0.95$, $p = .34$.

Strong Comparator False Alarm Rates

Second pulse judgements

The repeated measures ANOVA found a significant main effect of Comparator Light with False Alarm Rates. With False Alarm rates being significantly greater during Comparator Light present (M = 0.31, SD = 0.18) trials than Comparator Light absent trials (M = 0.24, SD = 0.14), $F_{(1,18)} = 10.78$, $p = .004$. There was a significant main effect of Target Light with False Alarm Rates. With False Alarm rates being significantly greater during Target Light absent (M = 0.31, SD = 0.18) trials than Target Light present trials (M = 0.23, SD = 0.14), $F_{(1,18)} = 9.81$, $p = .006$. There was a trend towards a significant interaction between the terms, $F_{(1,18)} = 3.73$, $p = .069$.

Comparison between first and second pulse judgements for Strong Comparator False Alarm rates

Paired samples t-test was conducted between the False Alarm rates of first and second pulse judgements recorded during Strong Comparator trials with Light absent/present and Target Light present/absent trials.

Table 4.12. Paired samples t-test (Bonferroni corrected) between first and second JOGs for Strong Comparator False Alarm rates (* indicates significant findings. Highlight shows both Light present conditions).

	M	*SD*	*df*	*t*	*p*
Comparator Light absent & Target Light present First JOG False Alarm rates X Second JOG False Alarm rates	0.37 0.22	0.25 0.13	18	2.07	.053*
Comparator Light absent & Target Light absent First JOG False Alarm rates X Second JOG False Alarm rates	0.43 0.26	0.28 0.15	18	2.22	.04*
Comparator Light present & Target Light present First JOG False Alarm rates X Second JOG False Alarm rates	0.46 0.25	0.25 0.15	18	2.87	.01*
Comparator Light present & Target Light absent First JOG False Alarm rateas X Second JOG False Alarm rates	0.55 0.37	0.24 0.19	18	2.70	.01*

False Alarm rates during Strong Comparator conditions were significantly greater during first pulse judgements than second pulse judgements for all Light conditions.

Strong Comparator Sensitivity indices (d')

First pulse judgements

Repeated measures ANOVA found a significant main effect of Comparator Light. Sensitivity indices (*d')* were greater during Comparator Light absent (M = 1.78, SD = 0.81) trials than during Comparator Light present (M = 1.48, SD = 0.80) trials, $F_{(1,18)}$ = 11.19, p = .004. There was no significant main effect of Target Light, p > .05. There was no significant interaction effect between the terms, p > .05.

Strong Comparator Sensitivity indices (d')

Second pulse judgements

Repeated measures ANOVA found no significant main effects of Comparator Light and Target Lights, all p > .05. There was a significant interaction between Comparator Light and Target Light, $F_{(1,18)}$ = 6.78, p = .02. Post-hoc paired samples t-tests were conducted between Target Light present and absent trials within Comparator Light absent and present trials separately. During Comparator Light present trials Sensitivity indices (*d'*) were significantly greater during Target Light present trials (M = 2.15, SD = 0.90) than during Target Light absent trials (M = 1.63, SD = 0.83), $t_{(18)}$ = 3.87, p = .001. During Comparator Light absent trials Sensitivity indices (*d'*) were not significantly different between Target Light absent (M = 1.95, SD = 0.72) and Target Light present (M = 1.67, SD = 1.11) trials, $t_{(18)}$ = 0.92, p = .37.

Strong Comparator Response bias (c)

First pulse judgements

Repeated measures ANOVA found significant main effect of Comparator Light. With Comparator Light present (M = -0.74, SD = 0.53) trials having a more negative Response bias (*c*) than Comparator Light absent trials (M = -0.57, SD = 0.60), $F_{(18)} = 6.89$, p = .02. There was also a significant main effect of Target Light, with Response bias (*c*) being more negative during Target Light absent (M = -0.73, SD = 0.59) than Target Light present (M = -0.58, SD = 0.55) trials, $F_{(18)} = 11.88$, p = .003. There was no significant interaction between the terms, p > .05.

Strong Comparator Response bias (c)

Second pulse judgements

Repeated measures ANOVA found significant main effect of Comparator Light. With Comparator Light present (M = -0.35, SD = 0.37) trials having a more negative Response bias (*c*) than Comparator Light absent trials (M = -0.11, SD = 0.49), $F_{(18)} = 7.03$, p = .02. There was also a significant main effect of Target Light, with Response bias (*c*) being more negative during Target Light absent (M = -0.32, SD = 0.40) than Target Light present (M = -0.14, SD = 0.49) trials, $F_{(18)} = 4.80$, p = .04. There was no significant interaction between the terms, p > .05.

Comparison between first and second pulse judgements for Response bias (c)

Paired samples t-test was conducted between the Response bias (*c*) of first and second pulse judgements recorded during Strong Comparator trials with Light absent/present and Target Light present/absent trials.

Table 4.13. Paired samples t-test (Bonferroni corrected) between first and second JOGs for Strong Comparator Response bias (*c*; * indicates significant findings).

	M	*SD*	*df*	*t*	*p*
Comparator Light absent & Target Light present					
First JOG Response bias (*c*) X	- 0.52	0.56	18	2.65	.02*
Second JOG Response bias (*c*)	0.01	0.56			
Comparator Light absent & Target Light absent					
First JOG Response bias (*c*) X	- 0.62	0.65	18	2.34	.03*
Second JOG Response bias (*c*)	- 0.24	0.40			
Comparator Light present & Target Light present					
First JOG Response bias (*c*) X	- 0.63	0.55	18	2.07	.053*
Second JOG Response bias (*c*)	- 0.29	0.35			
Comparator Light present & Target Light absent					
First JOG Response bias (*c*) X	- 0.84	0.51	18	2.92	.009*
Second JOG Response bias (*c*)	- 0.41	0.39			

Response bias (*c*) were significantly more positive during second pulse judgements than during first pulse judgements across all Light conditions.

Discussion

It was expected that participants would show greater False Alarm rates during Light present trials (as with the previous SSDiT findings, Chapter 3) in both First and Second pulse judgements for both Comparator Strength conditions (Weak and Strong). With First pulse False Alarm rates being greater out of the two judgement groups, due to the length of time the sensory information must be held in memory.

The aim was to investigate whether using a two forced-choice discrimination task would affect participants' sensitivity indices (*d'*) and response bias (*c*) and in turn the number of Hit and False Alarm Rates. By using the questionnaires as covariates it was hoped that participants individual differences in their sensitivity the task would help further our understanding of why these illusory enhancement sensations occur more in some people than others. Each of the two pulses during the task are composed of two original SSDiT designs (Chapter 3) being presented in succession, therefore it can be said that participants were discriminating between two separate SSDiT pulses in one trial. Each judgement order group (JOG) would consider one of the pulses as the Target and the other as a Comparator. Participants were presented with the first pulse (FP) and then the second pulse (SP) and were asked one of two questions: 'Was the First Pulse Stronger?' or 'Was the First Pulse Weaker?' The Target for the FP judgement order group (JOG) was the FP and the Comparator was the SP. The Target for the SP JOG was the SP and the comparator was the FP. Both first and second tactile stimuli were presented with the presence or absence of a simultaneous LED flash. The results will be discussed by Comparator type (Weak, Strong).

Weak Comparator conditions

First and second pulse Hit Rates had no significant relationship with the questionnaires. There were no significant relationships with these measures with second pulse judgements. There was however, a significant main effect of Target Light present trials having a greater number of Hit Rates during second pulse judgements.

False Alarm Rates did not have any significant relationship with the questionnaire data during first pulse judgements. It was expected that there would be a relationship between False Alarm Rates and SDQ-20 scores; one would expect to see positive relationship between SDQ-20 scores and False Alarm rates. Somatoform Dissociation Questionnaire 20 (SDQ-20) measures an individual’s tendency to experience pseudo-neurological symptoms. False Alarm rates were significantly greater during Target Light present trials during first and second pulse judgements. The Second pulse judgement False Alarm rates also had a significant main effect of Comparator Light, with False Alarm rates being greater during Comparator Light absent trials. False Alarm rates were significantly greater during first pulse judgements during both Comparator and Target Light present and absent conditions.

Sensitivity indices (*d')* of the first and second pulse judgements had no significant relationship with the questionnaire data. There was an interaction between the second pulse Sensitivity indices (*d')* with Comparator and Target Light conditions. The Sensitivity indices (*d')* were greater (more positive) during second pulse judgements with all Comparator and Target Light stimuli pairings; Comparator Light absent or present (the first pulse stimulus) with Target Light present or absent (the second pulse stimulus) trials than those during first pulse judgements. Greater sensitivity indices (*d'*) would indicate that participants were able to differentiate between the two stimuli presentations during the second judgement order group more than the first; this is reflected in the lower second pulse judgement groups False Alarm Rates, they were greater during first pulse judgements than those from the second JOG. For there to be lower False Alarms and a greater *d'* in the second JOG one would expect there to be more correct reports of tactile stimuli (greater Hit Rates). However, there was no significant difference between Hit Rates of the first and second pulse judgements, though False Alarm rates were significantly greater during first pulse judgements than second pulse judgements.

First pulse judgement groups response bias *(c)* had no significant relationship with questionnaire data. Response biases *(c)* were significantly more negative during Target Light present trials than absent during first pulse judgements. Response biases *(c)* during second pulse judgements were found to have a significant positive relationship with questionnaire SSAS during Comparator Light absent and Target Light present trials. There was also a trend towards a positive relationship between Target Light present Response bias *(c)* and SSAS scores; the Somatosensory Amplification Scale (SSAS) measures the tendency to notice and experience vague sensory events as unpleasant. This would suggest that there may be a relationship between those who have a higher tendency to notice and experience vague sensory experiences as unpleasant (score higher on the SSAS) as having greater Response biases (*c*) within the second pulse judgement group; they may have adopted a more liberal response criterion (more likely to respond strong). Response bias (*c*) for the second pulse judgement group was significantly more negative, participants adopted a more liberal criterion, during Comparator Light absent trials than Comparator Light present trials; they were more negative during Target Light present trials than Target Light absent trials. This is reflected by the greater number of False Alarm rates during Target Light present trials. This is also reflected during second pulse judgement group, there was a main effect of Target Light with Hit Rates, with Hit rates being significantly greater during Target Light present trials. During second pulse judgements participants were also found to have a significantly more liberal (more negative response bias (*c*); responding strong) during Comparator Light absent trials.

Strong Comparator judgements

During Strong Comparator conditions, there was a significant negative relationship between first pulse judgement groups Hit Rates and SDQ-20 during Comparator and Target Light absent trials; those who scored high on the SDQ-20 had lower Hit Rates. Those with a greater tendency to experience pseudo-neurological symptoms had lower Hit Rates during Comparator Light present trials. Second pulse judgement groups had greater Hit Rates during Comparator Light present trials than Comparator Light absent trials. Comparator and Target Light absent trials also had a trend towards being significantly greater than when the Target Light was present. Hit Rates were found to be greater during first pulse judgements than second pulse judgements. Comparator Light present with Target Light absent trials had greater Hit Rates during first pulse judgements than the second pulse judgement groups.

False Alarm rates during strong first and second pulse judgements were found not to have any significant relationship with the questionnaires. First pulse and second pulse judgements had greater False Alarm rates during Comparator Light present trials than when the Light was absent. Target Light absent trials had greater False Alarm rates than when the Target Light was present during both first and second pulse judgements. False Alarm rates were found to be greater during first pulse judgements than second for all trial conditions, when Comparator and Target Light were present and absent. Overall the False Alarm rates were significantly greater during first pulse judgements than with second pulse judgements with Strong Comparator trials.

There was no significant relationship between first and second pulse judgement groups Sensitivity indices (*d′*) and the questionnaire data. Sensitivity indices (*d′*) were greater during Comparator Light absent conditions during first pulse judgements. This would indicate that participants were able to differentiate between the two stimulus signals when there was no accompanying light within the Comparator pulse; for first pulse JOG this would have been the second pulse participants were presented with. Sensitivity indices (*d′*) of second pulse judgements were greater during Target Light absent trials. This would indicate that participants during second pulse judgement group were better able to distinguish between the Target (second pulse) and Comparator (first pulse) when the Target Light was absent.

Response bias (*c*) had no significant relationship with the questionnaire data over first and second pulse judgements. Comparator Light present trials were found to be significantly less negative, they were less liberal, than during Comparator Light absent trials. This was also found with the Response bias (*c*) being less negative during Target Light absent conditions during both first and second pulse judgements, they were less liberal during both judgement order groups. Response bias (*c*) was more positive (less negative) during second pulse judgements with both Comparator and Target Light absent and present conditions. This is reflected by there being fewer False Alarm rates with Target Light present trials during second pulse judgements. Overall the response biases (*c*) were less negative/closer to zero during second pulse judgement group. The less liberal criterion during second pulse judgements is also reflected by there being greater False Alarm rates during first pulse judgement group than in the second.

Implications

Both Comparator Strength groups were identical in all forms apart from the questions participants were asked when making judgements and the Comparator Strengths. The signal detection data indicates that participants experienced illusory sensations (as evident by the Weak Comparator False Alarm rates). The Target (the stimulus they were judging) for the first pulse judgement order group was the first pulse and their Comparator (stimulus that the target would be compared with) was the second pulse. For those in the second pulse judgement order group, the Target was the second pulse and their Comparator was the first pulse.

There were a large number of Hit Rates during both Weak and Strong Comparator conditions; however, Hit Rates were lower during second pulse judgements in the Strong Comparator condition. It could be said that this could be due to a thresholding issue, as participants' individual sensitivity to the tactile stimuli would be assessed and set during the thresholding task prior to starting the experimental trials. However, the thresholding procedure used (adapted staircase method from Lloyd et al., 2008; Poliakoff et al, submitted; originally from Cornsweet, 1962) is a validated and well-established method to assess sensory thresholds.

Subjective sensitivity and tendency to experience illusory tactile sensations was accounted for through the use of questionnaires, however, they were only significant for a small number of experimental conditions. The Somatosensory Amplification Scale (SSAS) had a significant positive relationship with Response bias (*c*) during second pulse judgement group Weak Comparator strength trials; those who have a higher tendency to notice and experience vague sensory experiences as unpleasant (score higher on the SSAS) would adopted a more liberal response criterion (more likely to respond strong) during this trial type. The final significant negative relationship found was between Somatoform Dissociation Questionnaire 20 (SDQ-20) and Hit Rates that occurred during first pulse judgement group with Strong Comparator strength; those with a greater tendency to experience pseudo-neurological symptoms had lower Hit Rates during Comparator Light present trials.

The possible explanation as to why there was a large difference between the two experiments could be down to the only actual difference between the tasks and what effect this would have on the 2FC-SSDiT. This is the actual temporal difference between which stimulus pulse participants judged. Jolicoeur and Dell'Acqua (1998) investigated the mechanisms of encoding information into short-term memory (STM). Jolicoeur and Dell'Acqua (1998) conducted a series of two-alternative discrimination task experiments, where participants were presented with visual stimuli that participants had to recall at the end of the trial. In their experiment participants were asked to only respond to the tone, and ignore visual stimuli, the auditory task was defined as the primary task in all experiments. Jolicoeur et al. (1998) conclude from their experiments that two alternative discrimination tasks did show a slower response speed on the tasks where visual information could be remembered when there were no response speed pressures. Jolicoeure and Dell'Acqua (1998) conclude that the dual task interference effect on reaction time greatly reduced the more time participants had to wait before they were prompted for a response (onset times > 800ms had decreased reaction time), suggesting that their observed effects of longer reaction times at shorter response cues were the result of encoding processes occurring. Jolicoeure and Dell'Acqua (1998) findings can be said to have shown an STC processing mechanism is utilised during the encoding mechanisms of WM to later perceptual processing mechanisms, one of their experiments was designed not to engage STC and their findings suggest no explicit memory trace was formed during this task, and they conclude that that to process through STC takes time and it may be a necessary operation for the formation of memory representations. The consolidation process is also thought to have limited capacity (Jolicoeure and Dell'Acqua, 1998; Vogel et al., 2006).

The findings of Jolicoeure and Dell'Acqua (1998) could perhaps help explain the present findings. First pulse judgement order group (JOG) participants had to make judgements on the 'First Pulse' making this the Target and the 'Second Pulse' the Comparator stimuli; for second pulse JOG, judgements were made on the 'Second Pulse' making this the Target and the 'First Pulse' the Comparator stimuli (see table 4.14 to help illustrate this along with the timings of stimuli presentation).

Table.4.14. Showing Judgement rationale and duration of first stimulus onset to end of second stimulus presentation milliseconds (ms).

Experiment	Cue and ISI1	First Stimulus onset	ISI2	Second Stimulus Onset	Pre-response wait	Total time before Response prompt
First Pulse JOG	750	20 (Target)	1250	20 (Comparator)	500	2540
Second Pulse JOG	750	20 (Comparator)	1250	20 (Target)	500	2540

All participants were exposed to the same timings of the experiment. Table 4.14 shows the Target and Comparator stimulus intervals. Participants in the first judgement group were presented with their Target (first stimuli onset) stimulus first, and were then presented with their Comparator stimulus (second stimulus onset) a total of 2020ms after trial start. Participants in the second pulse judgement group were presented with their Comparator stimulus during the first stimulus onset; and were presented with their Target stimulus during the second stimulus onset, total of 2020ms after trial start. The focus in both judgement order groups was on the Target stimuli, which participants had to conduct their discrimination judgement on. Looking at table 4.14 it is clear that first JOG participants had longer to encode their Target than the second JOG, and a shorter time to encode their Comparator stimulus. The opposite is true for the second JOG, who had a greater time to encode their Comparator and a shorter time to encode their Target.

The signal detection data for participants within the first JOG does not look dissimilar to that of previous findings (Chapter 3, SSDiT). Participants within the first JOG may have been influenced by the illusory sensations elicited during the Comparator trials, as the time to process this information was relatively shorter than that of Target stimuli. This would indicate that there was a later decision-making mechanism that was not able to fully process the detected sensory information, resulting in a greater number of False Alarm rates; this aspect of the data would be similar to previous SSDiT findings). Target sensory information for first JOG, had a minimal significant effect during the signal detection analysis. This could this be due to there being greater time for encoding to occur. There were fewer errors during first pulse judgements, which would account towards the greater Hit Rates. The earlier Target trials may have had a reduced illusory capacity due to decay of the sensory signal or due to a later decision-making mechanism that enabled participants to make a more confident decision when judging the Target with the Comparator strength. However, the results presented indicate that False Alarm rates differed by the presence of a simultaneous Light presentation either during the Comparator Light or Target Light. Weak first pulse judgements with Target Light present trials along with Strong first pulse judgements with Comparator Light present and with Target Light absent trials resulted in significantly greater False Alarm rates. This fluctuation in False Alarm rates and Light presence is also evident with sensitivity indices (*d'*) and response bias (*c*), as indicated earlier in this discussion. It could be plausible in suggesting that not only was there interference order of Target and Comparator stimulus presentation, but that there was also an illusory effect present from the complete processing of the Target (FP) giving results that were not as robust as expected but also exhibited signs of an illusory mechanism occurring.

In comparison, the second JOGs Target (SP) stimuli would be processed a similar way to the original SSDiT paradigm and like that of the first pulse JOG SP Comparator stimuli. Resulting in the second JOGs participants moving further on from the earlier sensory processing to a later decision-making process and for the illusory sensory information to decay which would result in fewer False Alarm Rates. Jolicoeure and Dell'Acqua (1998) stated that STC process takes time; they found greater errors and enhancement effects with early prompts. With second pulse JOGs Comparator being the FP, sensory information had a longer time to be processed (over 1000ms) which would have enabled the information to have undergone perceptual encoding. Thus, reducing the illusory effects of the Comparator trials (SP) in the second pulse JOG, the same can be said about first pulse JOG, however it would be the Target stimuli where this occurs. The resulting competing illusory information during each pulse presentation along with the focus on stimuli Target of the discrimination judgement may have resulted in second pulse JOG showing different results. The signal detection encoding would have reflected the Target Light causing an effect during trials, and would have reduced False Alarm Rates due to the decay and full processing of this sensory information. The effect between Target and Comparator might be the result of the Target stimuli being a form signal noise as participants try and retrieve perceptual references of the Comparator stimuli (FP). There were a number of findings that were not expected during the second pulse JOG and were significantly different to those of the first pulse JOG. Target Light is in affect causing disruption/interference with participants during the decision-making process, as if there are two separate mechanisms working to experience these illusory effects, an early sensory process and a later decision making process, the Target during the second pulse JOG may have acted as an inhibitor of this later mechanism.

It is my understanding that the observed findings from the second pulse JOG could be the result of conflicting SSDiT illusory mechanisms occurring at the same time. Stripping back this two-forced-choice decision making task and looking at it from a single pulse presentation (not a two forced-choice task) this task is comprised of two original SSDiT paradigm designs. Therefore, the illusory enhancement effects (False Alarm Rates) of the Light on tactile stimuli during the SSDiT might be due to the bimodal sensory information overwhelming the short-term consolidation (STC) processing for this early sensory processing, participants would have 500ms until they were prompted to and their attention was drawn to the discrimination process. As Jolicoeure and Dell'Acqua (1998) suggest, responses would be less accurate due to the later perceptual encoding system not being able to fully process the early sensory information as the 'attention' of the encoding process might be disrupted by a feedback mechanism that helps maintain the sensory information so that it is not degraded during encoding (Jolicoeure and Dell'Acqua, 1998; Kennett et al., 2001; Taylor-Clarke et al., 2001).

The time it takes to consolidate sensory information may also differ by type of sensory stimulus. The rate of consolidation is considered to be very quick but can be affected by the accumulated decision mechanisms that would also be working (Vogel et al., 2006). Which supports the theory put forward by Theeuwes (2010), the weighted sensory stimuli of the 2FC-SSDiT would require a feedback mechanism (top-down modulation) for the judgement to be conducted on the bottom-up sensory information. According to Theeuwes (2010), this top-down processing occurs after participants initially detect the stimulus of the stimulus presentation (pulse), and as this processing is accompanied by a question there would be a feedback mechanism that discriminates between the two pulses that were delivered. The feedback process would fit with the encoding aspect as Vogel et al. (2006) and Jolicoeure and Dell'Acqua (1998) have suggested. This feedback mechanism (top-down modulation) could recall all sensory information that pertain to the judgement question and recalls both tactile and visual stimuli as they both occurred at the same time. Due to the limiting capacity of consolidation, the tactile sensory memory maybe influenced by the visual sensory noise of the task-irrelevant light; resulting in participants having a False Alarm.

With the present study there are two pulses, each of these is a form of the original SSDiT, therefore the robust illusory effects observed during the SSDiT (Chapter 3) would not be as strong. This would be due to there being two sets of illusory mechanisms occurring, one that was able to process for a longer period of time (first pulse stimuli) and those of the second pulse which would have elicited similar illusory effects as the standard SSDiT.

These findings could be an indication of a dissociation effect occurring between the two presented pulses (FP and SP). Each pulse would be processing sensory information independently from one another (like the standalone original SSDiT), but would be utilising the same underlining mechanisms twice due to two pulse presentations. The findings of this study could therefore be due to the temporal overlap of these mechanisms, and could be the result of two separate mechanisms working during a single pulse overlapping with the same mechanisms working during the second pulse.

The behavioural findings are not sensitive enough to draw firm conclusions as the temporal effects of the 2FC-SSDiT. An EEG/ERP investigation would provide a more sensitive means to investigate the underlying mechanisms of these illusory reports. Rather than using the 2FC-SSDiT design, the original SSDiT paradigm would be a more appropriate choice for EEG/ERP investigation (Chapter 2, SSDiT). The next step after this study is to understand what processes are occurring to elicit the illusory effects of the SSDiT; by conducting an EEG/ERP with the original SSDiT. A recent study has already investigated the temporal aspects of the SSDT and the results suggest that there are two separate mechanisms that underline the illusory mechanisms of the SSDT (Poliakoff et al., submitted).

Chapter five

An ERP investigation of cross-modal enhancement using the SSDiT

There are many processes occurring simultaneously during cross-modal tasks. Cross-modal ERP investigations have helped identify what level of processing is present during the given task by identifying the presence of specific ERP components and how they relate to specific sensory mechanisms. Eimer (2001) conducted an investigation into the cross-modal connections in spatial attention between vision, audition and touch. Eimer (2001) wanted to understand at what stage cross-modal connections would affect the sensory stimuli processing. Participants attention was directed to a specific location (left or right side) for one (primary) modality (from visual, auditory and tactile), while all other stimuli (secondary) modality were to be ignored regardless of their position. Eimer (2001) found that there were cross-modal connections with the spatial attention task, with early sensory specific ERP components between 100ms and 200ms PSP. Any cross-modal ERP components greater than 200ms were small or completely absent, this suggests that cross-modal connections with spatial attention affect only modality specific cortical regions and have small impact on later processing stages (Eimer 2001). ERP modulation of somatosensory processing due to the cross-modal spatial attention was invested further by Eimer and Forster (2003). They used a task similar to Eimer (2001), participants responded to the presence of tactile stimuli presented to their left or right index finger. The attended hand was either constant at that site (sustained) or was changed between each trial (transient attention). Eimer and Forster (2003) found the same attentional modulation of N140 component in both attention conditions. There were also different early ERP component modulations between the two conditions. Sustained attention resulted in early components N80 and P100 components at electrode sites opposite to that of the attended hand; whereas transient attention showed bilateral P100 ERP components (Eimer and Forster, 2003). These findings would indicate that sustained and brief attention (bottom-up information) affect different somatosensory areas. The sustained attention could be filtering out sensory noise from attended stimuli in the primary somatosensory cortex (SI). Whereas the transient attention could be showing evidence of shifts in tactile attention due to visuo-spatial cues in other somatosensory processing areas (such as secondary somatosensory cortex, SII; Eimer and Forster, 2003).

Research into somatosensory cross-modal integration utilised ERPs have found early components from 50ms to 140ms after stimulus onset, which are thought to reflect processing in primary (SI) and secondary (SII) somatosensory cortices. This type of processing is believed to originate from posterior parietal areas, with activation then spreading forward to anterior regions of the brain in a feed forward mechanism (Michie et al. 1987; Eimer and Driver, 2000; Eimer and Forster, 2003; Zopf et al. 2004; Schubert et al. 2008). Later positive peaks around 300 – 400ms are also present and believed to be generated by non-modality-specific generators in frontal and temporal-parietal regions (Yamaguchi and Knight, 1991; Zhu et al. 2007). Earlier components are also believed to be sensitive to attention, with attended stimuli generating larger P100 components (Eimer and Forster, 2003).

Poliakoff et al. (in prep) conducted an ERP investigation to understand the temporal occurrences of the somatosensory mechanisms underpinning the tactile misrepresentation of the SSDT. They were interested in what the difference was between tactile stimuli (touch) correctly perceived (Hits) versus when it was missed (Misses). They also investigated the difference between when touch is reported as present when in fact there was none (False Alarm) versus when participants correctly reported not feeling a touch (Correct rejection). Poliakoff et al. (in prep) predicted that more perceptual attention to the incoming stimuli would be reflected by correct responses (Hits, Correct rejections) whereas reduced perceptual attention (e.g. due to sensory interference) from other sensory noise would be reflected by errors made in responding (False Alarms, Misses). They selected electrodes over both left and right hemispheres and found key timeframes of 120-160ms and 360-400ms post stimulus presentation after conducting global field power analysis. Poliakoff et al. (in prep) also calculated source localisation of the ERP signal, to help identify where the potentials were generated. Both Hits and Misses were found to have early (120-160ms) and later (360-400ms) components. Source localisation data provided a general location of bilateral precuneus. This region has been found to relate with attending to tactile stimuli (Poliakoff et al., in prep). The researchers did not find any significance at the early time points but did for the later time points which fit with primary (S1) and secondary (S2) somatosensory cortices activity. Poliakoff et al. (in prep) conducted analysis on tactile absent light present only trials to investigate the

False Alarm rates versus Correct rejections, as Lloyd et al. (2011) had found similar activation of False Alarms with and without light. Poliakoff et al. (in prep) found a trend for a difference with the SSDT False Alarms and Correct rejections, with the insula being involved with False Alarms at both early and late ERP time points. They also found early activation of the angular gyrus and anterior cingulate with False Alarms as compared to correct rejections. The False Alarms during the SSDT were observed directly after the stimulus presentation period and Poliakoff et al. (in prep) concluded that this shows that participants were not randomly guessing nor did they have late response bias. These findings support the notion that sensory misrepresentations are based on subjective experiences and not the result of the experimental design (Brown et al., 2010; McKenzie et al., 2010; Katzer et al., 2011; McKenzie et al., 2012; Poliakoff et al., in prep).

Understanding of the temporal mechanisms underlying the SSDiT have not been investigated before. Previous findings have indicated that the early sensory ERP components could arise from feedback projections from multimodal neurons to the unimodal neurons at an early processing mechanism (Eimer and Driver, 2000). Cross-modal ERP components that are less than 200ms suggest that cross-modal connections with spatial attention affect only early sensory processing modality specific cortical regions and have small impact on later processing stages (Eimer, 2001). Furthermore, cross-modal ERP findings have shown that sustained attention could be filtering out sensory noise from attended stimuli in the primary somatosensory cortex (SI; Eimer and Forster, 2003). The relevance of the task question (desired behaviour) during cross-modal interactions has shown modulation in early somatosensory ERP comments (P50 and P100). Relevant visual and tactile inputs can enhance attentional processing at early stages to complete goal orientated behaviour (Popovich and Staines, 2004). The findings somatosensory ERP findings of Poliakoff et al. (in prep) of the SSDT, indicates that there are both early and late mechanisms underlying the processes involved with somatosensory integration in cross-modal tasks. ERP investigation into illusory mechanisms of the SSDT indicated early ERP components that showed a difference between correct responses and incorrect responses on a detection task (SSDT). Polikaoff et al (in prep) also emphasised that individual sensitivity differences to internal and external factors must partially account for the occurrence of these subjective misperceptions (i.e. incorrectly reporting the presence of a tactile stimulus, a False Alarm).

The present study aimed to utilise ERPs to investigate the temporal mechanisms that contribute to the generation and maintenance of misperceptions of illusory enhancement induced by the SSDiT. This is a very exploratory experiment and has never been conducted before. Behavioural results are expected to replicate that of past research (previous chapters SSDiT findings), with participants having greater false alarm rates during light present trials. It is expected that ERP component analysis would provide evidence of two time frames, of early and late processing as the behavioural studies in the previous chapters have indicated. The ERP time points are expected to with within what previous studies have identified as when somatosensory mechanisms occur, i.e. between 100ms to 400ms. The exact time windows are not known, as this study is the first to investigate enhancement misperceptions of tactile stimuli during the SSDiT with the use of ERP.

Method

Design

This study had three within-participants factors: 2 [Hemisphere (left/right, which relates to the ERP data] x 2 [Light condition (present, absent)] x 2 [Tactile Stimulus strength (strong, weak)]. The dependant variable was the participants' responses: 'Strongest', 'Strong', ' Weak', 'Weakest'.

Participants

30 right-handed participants were initially tested, however due to poor EEG recordings six participants' data was removed providing a total of 24 participants (7 male), mean age 21 years (SD = 2.06). All participants were right-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). Controlling for handedness was essential as previous studies found that the non-dominant hand has increased sensitivity to vibrotactile and somatosensory stimuli compared to the dominant hand (Goldblatt 1956; Ghent 1961; Rhodes and Schwartz 1981). All participants had normal or corrected-to normal vision and none reported any sensory deficits. Full informed consent was obtained from each participant, after written and verbal explanations of the tasks were provided. All procedures were approved by the University of Nottingham Malaysia Campus Research Ethics Committee. Participants were recruited at the University of

Nottingham Malaysia Campus, and received a RM15 allowance in return for participation.

Five questionnaires were used to determine participants' level of sensitivity to experience internal and external factors, these were: the Health Anxiety Inventory short (HAIs, Salkovskis et al., 2002), Patient Health Questionnaire 15 (PHQ-15; Kroenke et al., 2002), Somatoform Dissociation Questionnaire-20 (SDQ-20; Nijenhuis et.al., 1996), Somatosensory Amplification Scale (SSAS; Barsky et al., 1988), State-Trait Anxiety Inventory (STAI, Spielberger et al., 1983). The previous measures used in earlier chapters were not consistent, therefore, the STAI-State and Trait questionnaire was used to see if anxiety levels be accounted for by those who experience the illusory effects of the SSDiT. See Chapter 2, SSDiT 2.1.2 Questionnaire for more details. Participants' scores on these questionnaires can be found in Table 5.1 below.

Table.5.1. Mean and range of scores across all questionnaires (± 1 SD).

	SDQ 20	SSAS	PHQ 15	HAI Short	STAI - State	STAI - Trait
Mean	21.88	26	6.54	31.33	34.42	36.54
(Sd)	(4.10)	(5.94)	(4.67)	(4.67)	(6.78)	(9.88)
Range	20 – 38	15 – 37	1-19	20 – 48	22-54	22 – 56

Stimulus and Materials

Tactile stimuli were composed of a single 20 millisecond 100Hz square wave; the sound file was manipulated and created with Audacity (Audacity Team Version 1.3.14-beta http://audacity.sourceforge.net). When the tactile pulse was presented, this sound file was initiated and was output from the desktop pc into the TactAmp 4.01, which then drove the Tactor to provide the tactile stimulation (TactAmp 4.01 and Tactor are of Dancer Studio Designs, Merseyside, United Kingdom). All tactile stimuli for the SSDiT were presented at the individual participants' specific threshold level determined by their lowest tactile threshold level, which was determined during the thresholding procedure (described below) prior to the main experiment. The tactile stimuli intensity for the SSDiT 'Weak' stimuli was determined by the thresholding procedure and the 'Strong' tactile pulse was 50% above their threshold. The Light conditions were triggered by the experimental script and consisted of Light present [trigger on, duration 20 milliseconds, stop] or Light absent [wait 20 milliseconds, this would not trigger the LED]. When the 'LED on' script was triggered, a signal from computer would be sent to the corresponding LED circuit via the serial printer port/cable from the computer to the TactAmp, which would result in the LED illuminating for 20 milliseconds; the Light absent condition would not have any LED illumination. See Chapter 2, for detailed SSDiT equipment information. See figure 5.1 and 5.2 below for the experimental set up with the SSDiT stimulus array.

Figure.5.1. Participant seated within the Faraday cage, and the stimulus array for the SSDiT EEG.

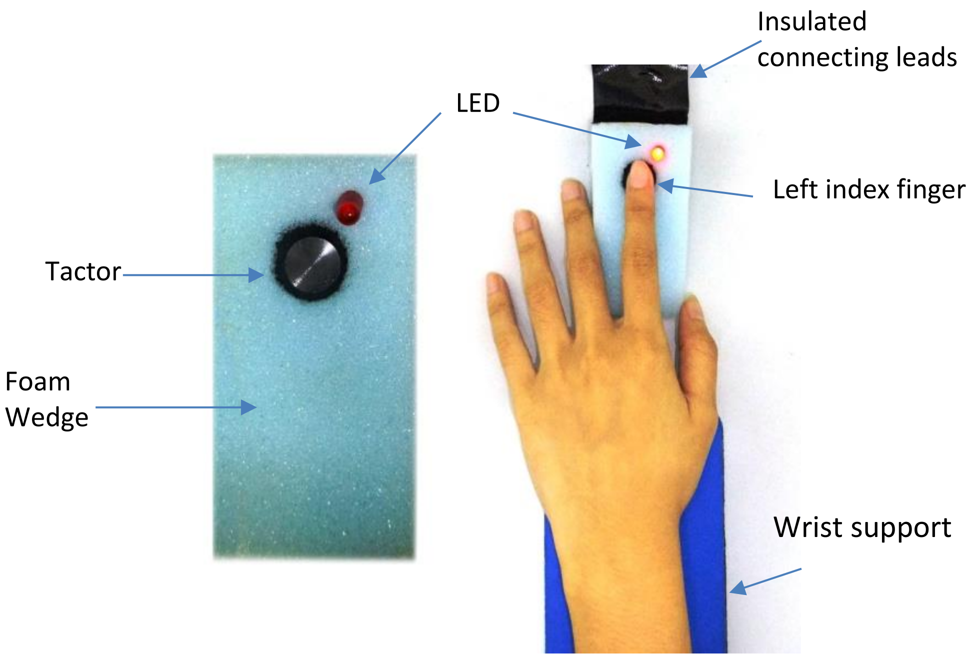


Figure.5.2. SSDiT stimulus array.

Electroencephalography Recording

The electroencephalogram (EEG) was continuously recorded from a 128-channel HydroCel Geodesic Sensor Net (HGSN; see Chapter 2, 2.2.3) with the Net

Amp 300 (Electrical Geodesics Inc., Eugene, Oregon; Tucker, 1993). Impedances were kept below 50 KΩ. The EEG signal was digitized online from all 128 electrodes at 4KHz and band-pass filtered between .1 Hz and 1000 Hz. The ground electrode was positioned at the vertex (along the midline, CZ). See Chapter 2, EEG for more details.

Participants were then fitted with the electrode net and were seated within the Faraday cage and underwent impedance checks. This was to make sure the level of resistance across all 128 channels was less than 50 kΩ. The participants' left index finger (non-dominant hand) was then fixed to the Tactor using a double-sided adhesive circle, this was to minimise movement during the experimental session (see figures *51 and 5.2* for experimental setup). All participants were instructed to keep their head and left hand still throughout the experiment and during breaks. All visible indicator lights on the monitor were covered to reduce any visual noise during the task. Participants also wore foam earplugs to reduce ambient audible noise creating artefact noise on the EEG.

Procedure

Prior to starting the experiment, each participant underwent a thresholding procedure. Thresholding procedure consisted of participants being presented with a block of 13 trials, consisting of 10 tactile (touch) present and 3 touch absent randomly presented trials, with each trial lasting 1020ms. The participants' left index finger was attached to the Tactor using a double-sided adhesive circle, this was to minimise movement during the experiment. An on screen green arrow cue (136 x 320 pixels in width and height; the point of the arrow is located pixel at 493 x 623 coordinates) indicated the start of each trial, prompting the participant to look at their left index finger. There was a 500ms wait before the onset of stimuli from the cue: during touch present trials a 20ms tactile stimulus was delivered to the participants' left index finger, followed by a 500ms wait; touch absent trials were the same as touch present trials except there was no tactile stimuli presentation during the 20ms and an empty trial was presented lasting the same duration of 1020ms. After each of these trials participants were prompted on the monitor to indicate whether they had felt a tactile pulse by pressing one of two keys on the number pad of the keyboard, "Y" for yes and "N" for no. Stickers with these letters printed on were placed on number '1' and '4' to denote the 'Yes' and 'No' response; the keyboard was rotated by 90 degrees from the normal functional orientation to make it easier for participants to press these keys. At the end of each block the experimenter was presented with the total correct (yes) responses and the tactile intensity was adjusted according to the staircase method described above. Participants had to responded 'Yes' on 40% to 60% of touch present trials during a thresholding block, if they failed to report the desired number of touch present trials the intensity of the tactile stimulus was adjusted by turning the Tactor dial at the front of the TactAmp in small increments to change the amplitude of the output signal in the Tactor; clockwise to increase and anticlockwise to decrease amplitude after which a new threshold block would commence. As mentioned previously, participants were required to respond 'Yes' on 40% to 60% of touch present trials during three consecutive thresholding blocks to be considered as having found their 50% threshold level. Participants only progressed to the main experimental blocks after they had met these thresholding requirements.

This thresholding method was repeated after the third experimental block to ensure that participants were within the 50% threshold level. Each experimental session consisted of a total of 600 trials, split over five experimental blocks, each block consisted of 120 trials, 30 of each of the four conditions: tactile stimulus Strength (strong/weak) x Light (present/absent). These were presented in a pseudo-randomised order. Participants were asked to report the intensity of the tactile pulse they felt by pressing one of the corresponding keys on the response box: ‘Strongest; ‘Strong; ‘Weak; ‘Weakest (see figure 5.3 for diagram of experimental design).

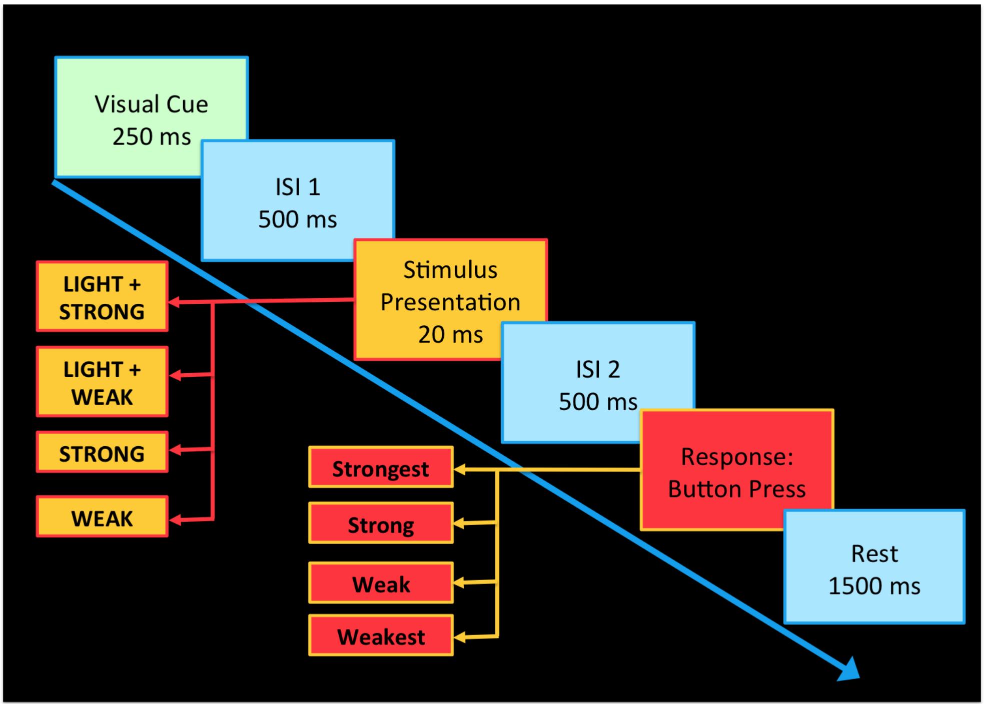


Figure.5.3. Experimental design of the SSDiT. Stimuli consisted of one of condition from 2 Tactile Strengths (Strong, Weak) and Light (present or absent) being presented for 20ms before participants responded with one key response out of the four possible choices (Strongest, Strong, Weak, Weakest).

Results

Behavioural

SSDiT Signal detection

In order to conduct single detection analysis all participants' responses were collapsed and detection theory coding was applied to the data, as shown in table 5.2. All subsequent analysis was conducted after the removal of outliers.

Table.5.2. Explanation of how responses were collapsed to provide signal detection terminology. The terms Hit and False Alarm, Correct Rejection and Incorrect Response used from this point forward will be based on the experimental conditions and responses as outlined in this table.

Participant Response		Stimuli	
		Strong + Light	Weak + Light
		Strong	Weak
Strongest Strong	Strong	Hit	False Alarm
Weak Weakest	Weak	Incorrect Response	Correct Rejection

Signal detection analysis was also used to explore the discrimination of strong from weak vibrations. The hit rate was the number of strong tactile pulses correctly identified as strong, divided by the total number of strong tactile pulses incorrectly detected (i.e., participants said 'weak'). The false alarm rate was the total number of weak vibrations incorrectly identified as strong over the total number of weak vibrations detected (i.e., participants said 'weak'). As with the detection analysis, a correction factor was applied to all data to compensate for cells with '0' responses (Snodgrass and Corwin 1988). The cumulative probabilities were used to calculate sensitivity (*d'*) for the strong and weak stimuli strong d' = z (cumulative probability of responding correctly to strong) – z (probability incorrectly to strong); (weak d' = z (cumulative probability of responding correctly to weak) – z (probability incorrectly to weak), (Macmillan and Creelman 2005). Table 5.3 below provides the percentage Hit and False Alarm Rates, *d'* and *c* for light present and absent conditions.

Table.5.3. Shows the Hit Rates (%), False Alarm Rates (%), d' and c, for light present and absent condition (± 1 SD).

	Hit Rate %	False Alarm Rate %	*d'*	*c*
Light present	92.58 (10.69)	13.74 (17.32)	3.16 (1.10)	-0.17 (0.50)
Light absent	91.17 (9.41)	7.64 (11.38)	3.33 (0.94)	0.10 (0.46)

Univariate ANOVA was conducted with the SSDiT signal detection data (Hit and False alarm rates, *d'* and c). The signal detection data was the dependent variable and Light was the fixed factor (present, absent). The questionnaires were used as covariates and are reported when they were found to be of significance, if they are not reported then these covariates did not play a role in providing accountability to other factors ($p > .05$). Where appropriate Pearson's correlations were conducted to understand the relationship between the questionnaire scores and the data.

Hit Rate

A Main effect of Light was not found, light present (M = 0.93) was not significantly different to light absent (M = 0.91) conditions, $F_{(1,42)} = .30$, $p = .59$. A trend to significance was found between SDQ-20 and Hit rates, $F_{(1,42)} = 3.40$, $p = .07$. A significant effect of SSAS was found with Hit rates, $F_{(1,42)} = 16.013$, $p < .001$. Pearson correlation was conducted with the SSAS and both light conditions for Hit rates. Hit rates within the Light present (M = 0.93, SD = 0.11) condition were found to have a significant positive relationship, $r = .50$, $p = .01$, with SSAS scores. Hit rates within the Light absent (M = 0.91, SD = 0.94) condition were also found to have a significantly positive relationship with SSAS scores, $r = .57$, $p = .004$ (see figure 5.4). This indicates that those who scored higher on the SSAS also had greater Hit rates across both light conditions.

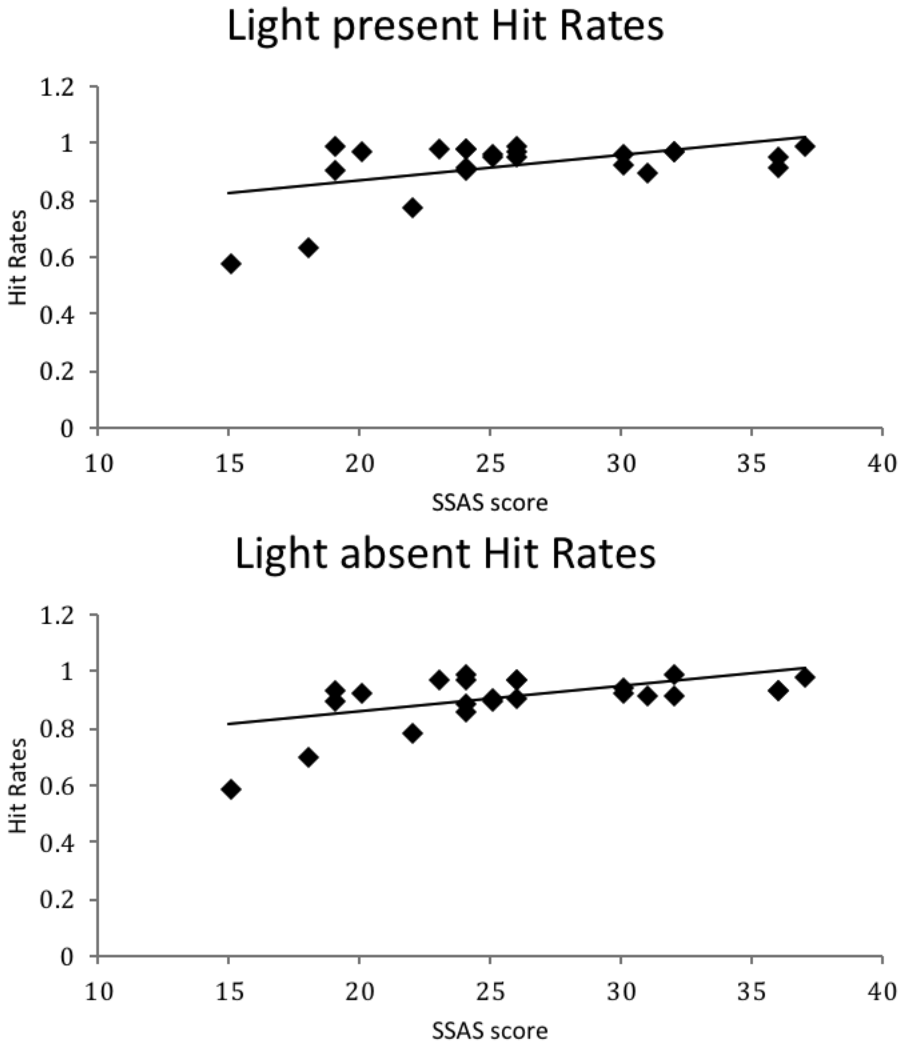


Figure.5.4. Shows the positive relationship between Hit Rates and SSAS during Light present and absent conditions (with trend line of best fit). Participants who scored higher on the SSAS had greater Hit Rates.

False Alarm Rate

A Main effect of Light was not found to be significantly different between Light present (M = 0.14) and absent (M = 0.08) conditions, $F_{(1,42)} = 2.42$, $p = .13$. SDQ 20 was of significance when accounting for False Alarm Rates, $F_{(1,42)} = 18.12$, $p < .001$. SSAS was also of significance, $F_{(1,42)} = 6.53$, $p = .01$. Pearson correlation was conducted with both SDQ-20 and SSAS with False Alarm rates. False Alarm with SDQ-20 scores did not have significant relationship, $p = .06$ and SSAS scores were found not to have a significant relationship, $p > .05$.

Sensitivity indices (d')

There was no significant difference between Light present ($M = 3.17$) and absent ($M = 3.33$), $F_{(1,45)} = .42$, $p = 52$. However, SSAS scores were found to be of significance with *d'*, $F_{(1,45)} = 12.61$, $p = .001$. Pearson correlation was conducted with SSAS scores and both light conditions for *d'*. Light present ($M = 3.17$, $SD = 1.10$) condition *d'* was found to have a positive relationship with SSAS scores, $r = .497$, $p = .01$. Light absent ($M = 3.33$, $SD = 0.94$) *d'* were also found to have appositive relationship with SSAS scores, $r = .437$, $p = .03$ (see figure 5.5). This indicates that the more sensitive someone is to notice and experience vague sensory events, as measured by the SSAS, the greater their sensitivity at reporting feeling near threshold tactile stimuli.

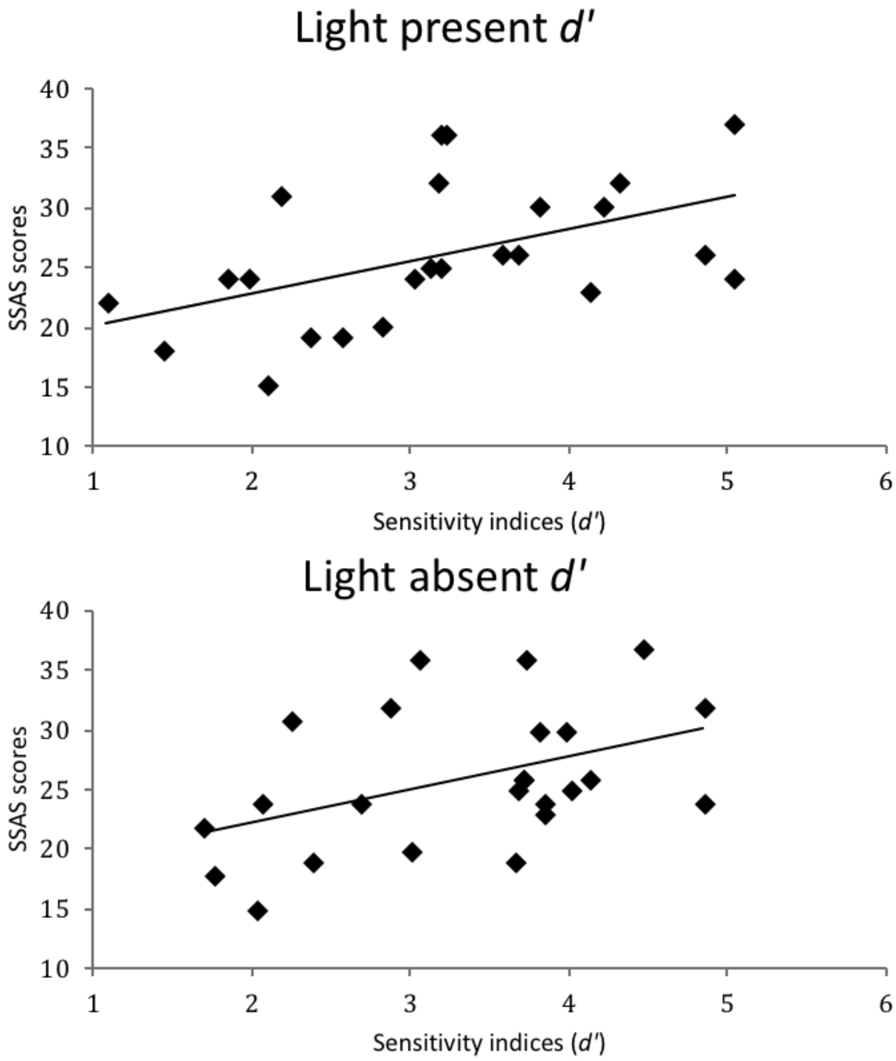


Figure.5.5. Shows the positive relationship between Sensitivity indices (d') and SSAS during Light present and absent conditions (with trend line of best fit). Participants who had greater Sensitivity indices (*d'*) scored higher on the SSAS.

Response bias (c)

A significant main effect of Light was found, $F_{(1,42)} = 4.35$, $p = .04$. SDQ 20 was also found to be significant, $F_{(1,42)} = 17.59$, $p < .001$. Pearson correlation analysis was conducted between SDQ-20 scores and both light conditions with participants' response criterion (*c*). A significant negative relationship was found between the Light present (M = -0.17, SD = 0.50) condition and SDQ-20 scores, r = -.46, p = .02. There was also a significant negative relationship between Light absent (M = 0.10, SD = 0.46) response criterion (*c*) and SDQ-20 scores, r = -.62, p = .001 (see figure 5.6). This would suggest that individuals with a smaller tendency to experience pseudo-neurological symptoms (scored lower on SDQ-20) are less likely to respond to stimuli as ‘strong’ in both light conditions.

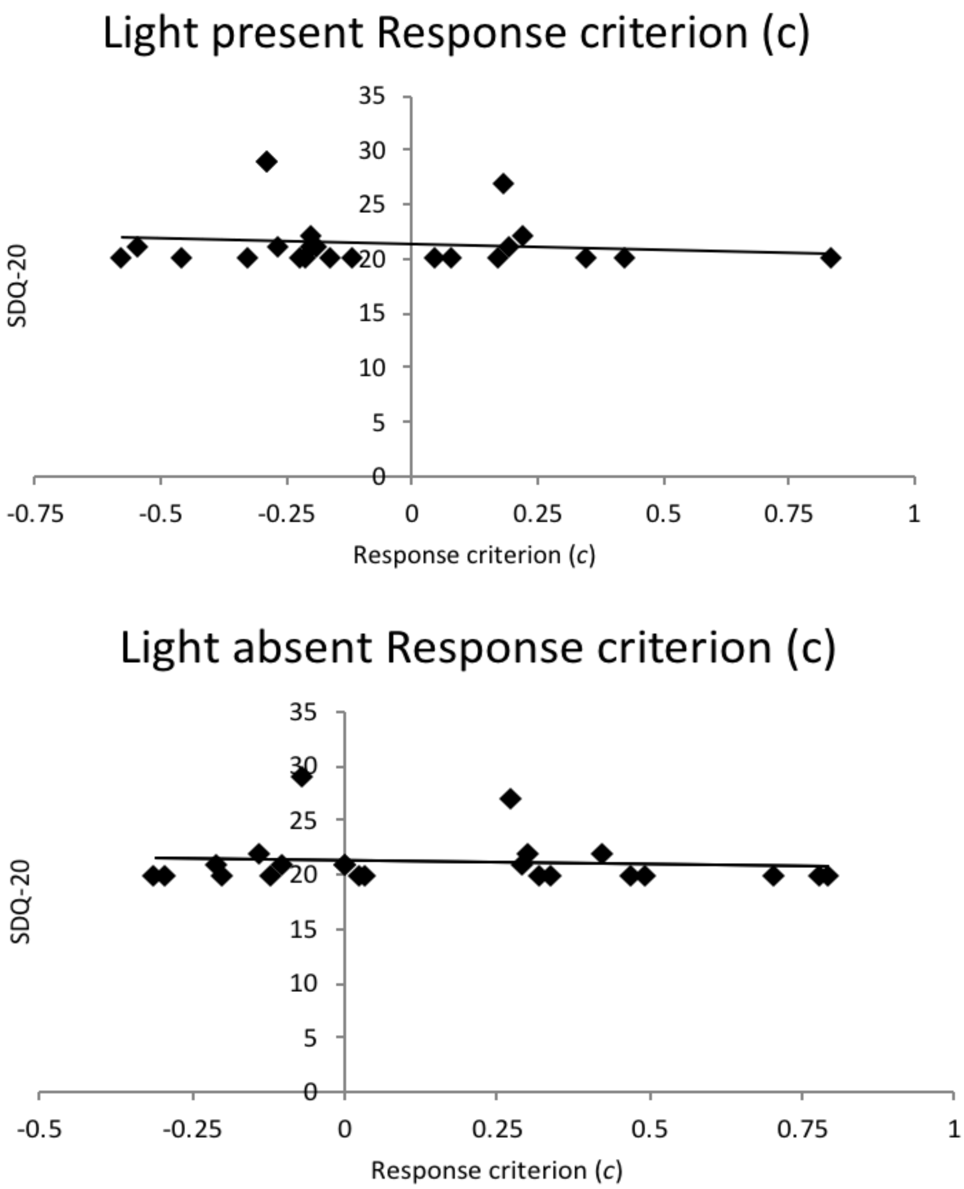


Figure.5.6. Shows the negative relationship between Response criterion (c) and SDQ-20 during Light present and absent conditions (with trend line of best fit). Participants who scored lower on the SDQ-20 were less likely to respond to stimuli as ‘strong’ in both light conditions.

EEG component data analysis

EEG data was segmented off-line by participants' responses, into single-trial epochs of 1200 ms (200ms pre-stimulus) and low-pass filtered at 40 Hz. Eye blink and movement artefacts were removed using NetStation software (Electrical Geodesics Inc., Eugene, Oregon). Next, Ocular Artifact Removal (OAR) was conducted. OAR corrects the EEG data by detecting and removing eye blinks and eye movements based on eye movement correction procedure (EMCP). The OAR algorithm differentiates between eye blinks and eye movements, applying appropriate correction factors. The eye movement channels were 125 and 128, and the eye blink channels were 8 and 26. The blink slope threshold was 14 µV/ms (Electrical Geodesics Inc., Eugene, Oregon; Tucker, 1993). After which epochs containing noisy channels, as well as artefacts were detected and omitted from further analysis. The EEG was re-referenced to the average reference. For details of the EEG setup and parameters see Chapter 2, 2.2.3 EEG. To determine the time periods and topographical regions of significance, group differences from stimulus onset (0ms onwards), was calculated using a point-wise paired-samples t-tests for each electrode and time point ($p < .01$) (this approach was taken in place of visual inspection of the data). This procedure was conducted first to establish group differences in the ERPs pooled over the conditions. This resulted in selection of 48 – 420ms post stimulus onset time windows, which also visually showed the largest activation over the subsequent selection of electrodes over the Parietal and Frontal regions (see figure 5.7 for a diagram of the selected electrodes).

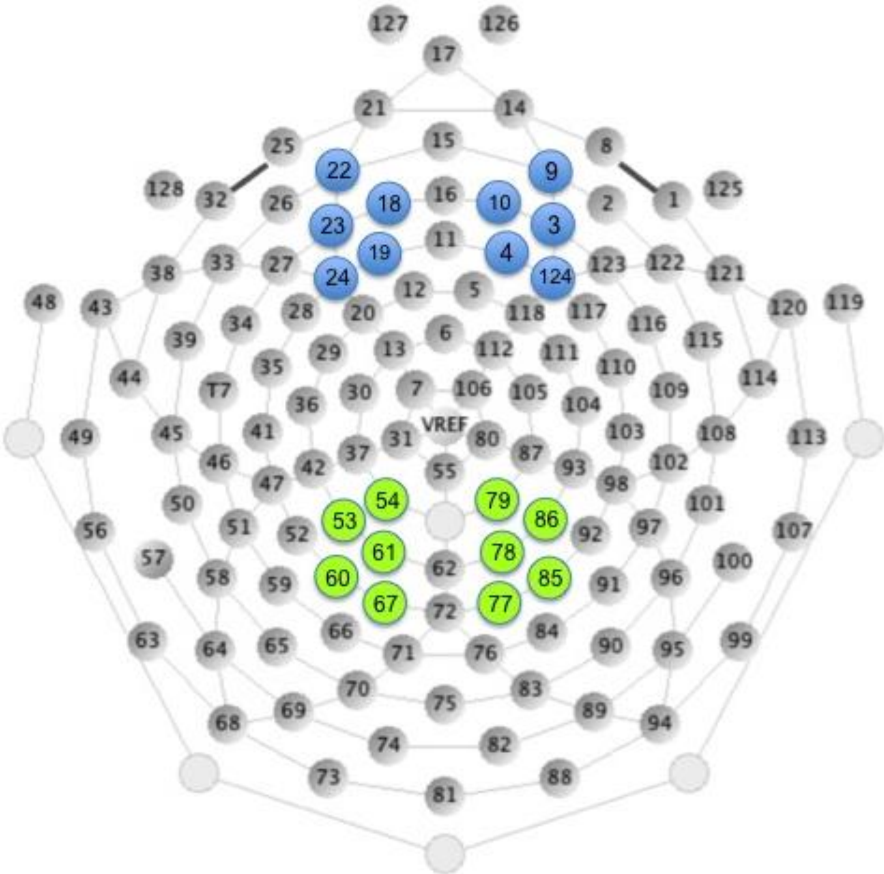


Figure.5.7. Map of electrodes selected for analysis: Frontal left and right hemisphere electrodes in blue; Parietal left and right hemisphere electrodes in green.

Following this, the same procedure was used to test for differences with all effect as reflected in ERPs, resulting in the selection of four time windows of interest: a time window of 53 - 133ms revealing a more positive ERP waveform (indicative of an early P120 component); the second time window of 138 - 183ms post-stimulus showing a positive ERP waveform (indicative of a P160 component effect); the third time window of a positive ERP waveform from 373 – 381ms (indicative of a P360 component); and the fourth time window of 383 – 402ms (indicative of a P400 component). Visual inspection of the EEG data found peaks at these time frames over three different regions, Frontal, Parietal (left and right hemisphere). Statistical extraction of the Adaptive Mean Amplitude (AMA, the raw value of the amplitude of the ERP waveform measured in microvolts, µV) and the Latency (time between actual stimuli onset and the electro-physiological response and the identified components of interest, measured in milliseconds) was conducted for each of these components from the selected electrodes of interest.

The extracted AMA for each of the electrode selection regions (Parietal and Frontal) was then coded with signal detection terminology using the same method used for the behavioural data, as shown in table 5.4 below.

Table.5.4. Explanation of how responses were collapsed to provide signal detection terminology. The terms Hit and False Alarm, Correct Rejection and Incorrect Response used from this point forward will be based on the experimental conditions and responses as outlined in this table.

Participant Response		Stimuli	
		Strong + Light	Weak + Light
		Strong	Weak
Strongest Strong	Strong	Hit	False Alarm
Weak Weakest	Weak	Incorrect Response	Correct Rejection

A 2[Region (left, right)] x2 [Light (present, absent)] repeated measures ANCOVA was conducted with SDQ-20, SSAS, PHQ-15, HAIs, STAI State and STAI Trait scores as covariates (see table 5.1 for all questionnaire scores), for Hits, Incorrect Response, False Alarm, and Correct Rejection. If they were not of significance a repeated measures ANOVA is reported. If sphericity was violated the

Greenhouse-Geisser correction was applied, pairwise comparisons were conducted with and all post-hoc paired samples t-test were conducted using Bonferroni corrections. The interactions between the terms and the covariates were further analysed by conducting Pearson's Correlations, the significant results and those of trends are presented (full analysis can be found in Appendix A and B). The results are presented by electrode selection region (Parietal and Frontal).

Parietal Region

A summary of the findings has been presented below, for full univariate analysis and scatter plots for the Parietal region see Appendix A.

Hits

Univariate analysis of the Parietal region AMA for Hits (see Appendix A, table A.1) found a significant interaction between the Right Parietal region during both Light present and absent conditions with SDQ-20 scores across all four components of interest. There was also a trend towards a significant relationship between the AMA of Hits from Left region and SDQ-20. Pearson's correlation between the Right region and SDQ-20 scores were found to have a positive relationship during both Light conditions. Indicating that participants who scored higher on the SDQ-20 also had a greater AMA for Hits (see Appendix A, figures A.1 and A.2 for scatter plots).

Repeated measures ANOVA found a significant main effect of Region. The AMA for Hits over the Right Parietal region were found to be significantly greater than the Left across all components of interest, all $F_{(1,23)} = 13.41$, $p = .001$; there was no significant effect of Light, $p > .05$. This can be seen in the electrode waveforms in Figures 5.8 to 5.10. The AMAs were found to be significantly more positive over the Right region than the Left region.

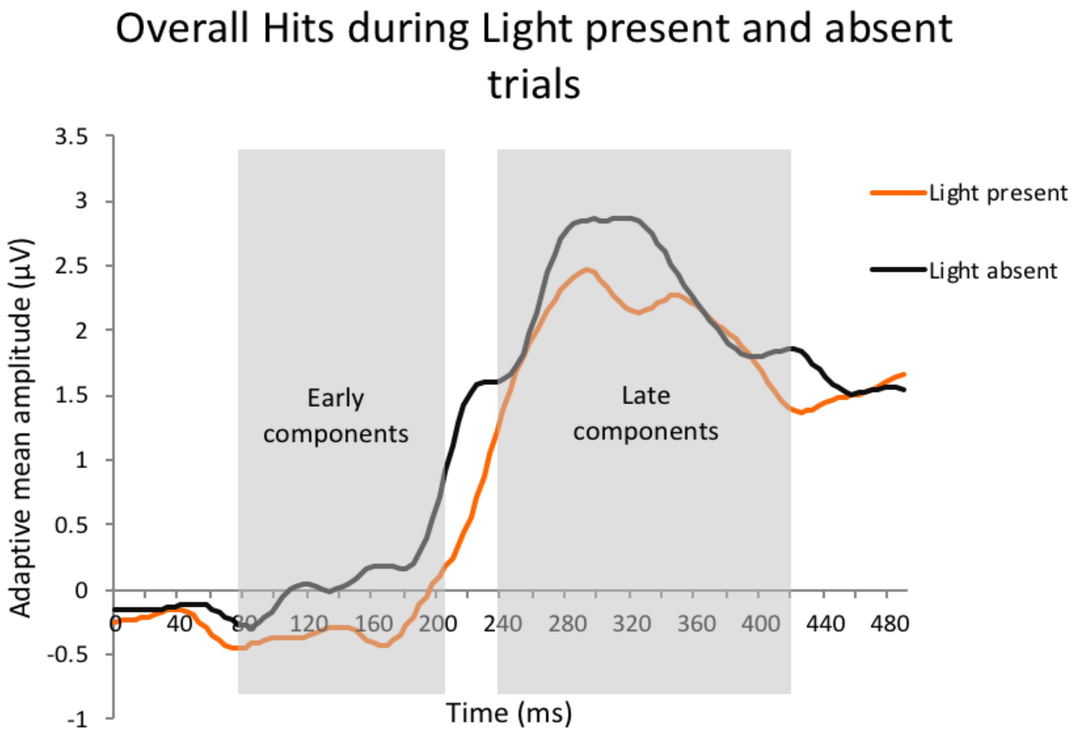


Figure.5.8. The figures show the ERP waveform during Light present and absent Hits, with the AMA for early and late ERP components over the Parietal regions. The AMA is greater during Light absent trials for early and late components.

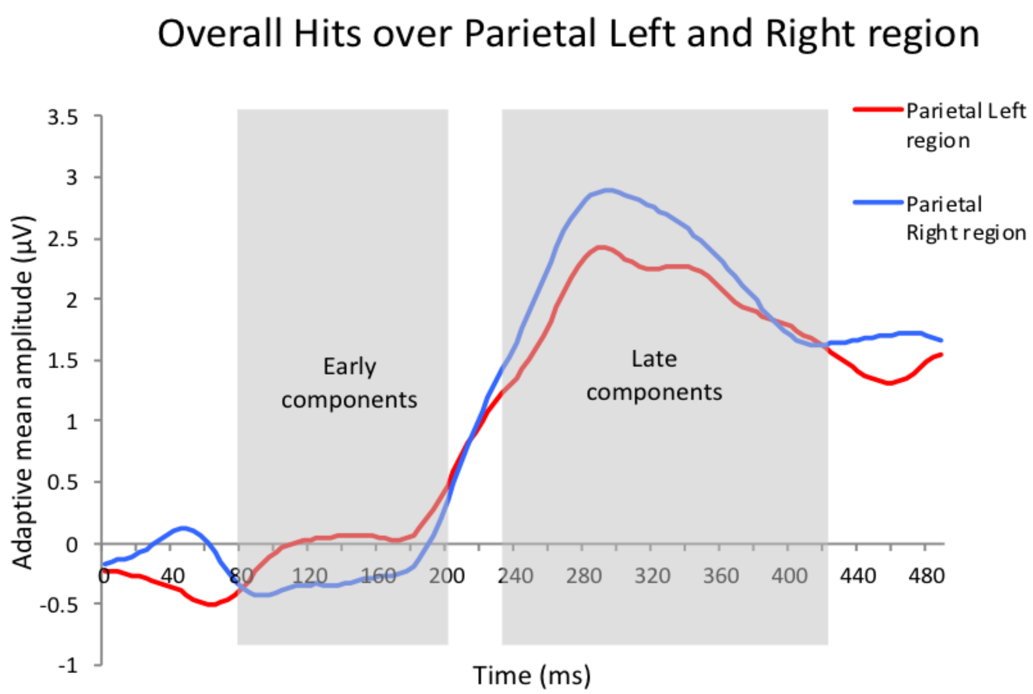


Figure.5.9. The figure shows the ERP waveform for the AMA of Hits over Left and Right Parietal regions. The AMA is greater over the Left region during the early components (80 – 190ms) and is greater over Right region during the late components (240-420ms).

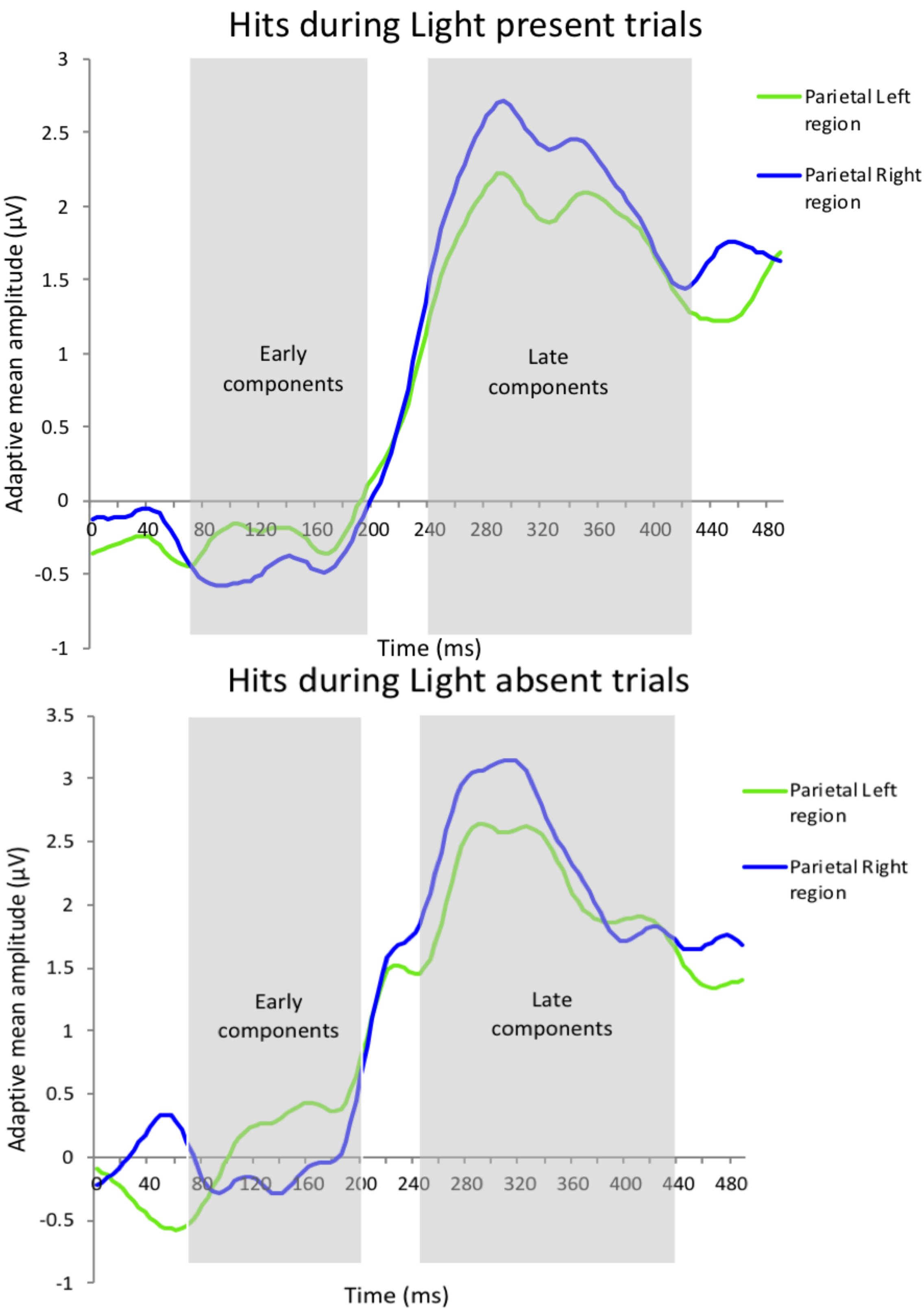


Figure.5.10. The figures show the ERP waveform during Light present and absent Hits, with the AMA for early and late ERP components over the Parietal electrode regions. The AMA is greater over the Left region during early components (80 – 200ms), whereas the AMA is greater over the Right region during later components (250 – 420ms) during both Light conditions.

Incorrect Responses

Repeated measures ANOVA for Parietal electrode AMA of Incorrect Responses found a main effect of Region, with significantly larger AMAs over Right Parietal region than Left Parietal region across all four components of interest: all $F_{(1,23)} = 6.22$, $p = .02$. No main effect of Light was found and no interaction was found, $p > .05$. The AMAs were found to be significantly more positive during Light absent conditions, figures 5.11 and 5.12, and were greater over the Left region during early components, and greater over Right region during late components (figure 5.13).

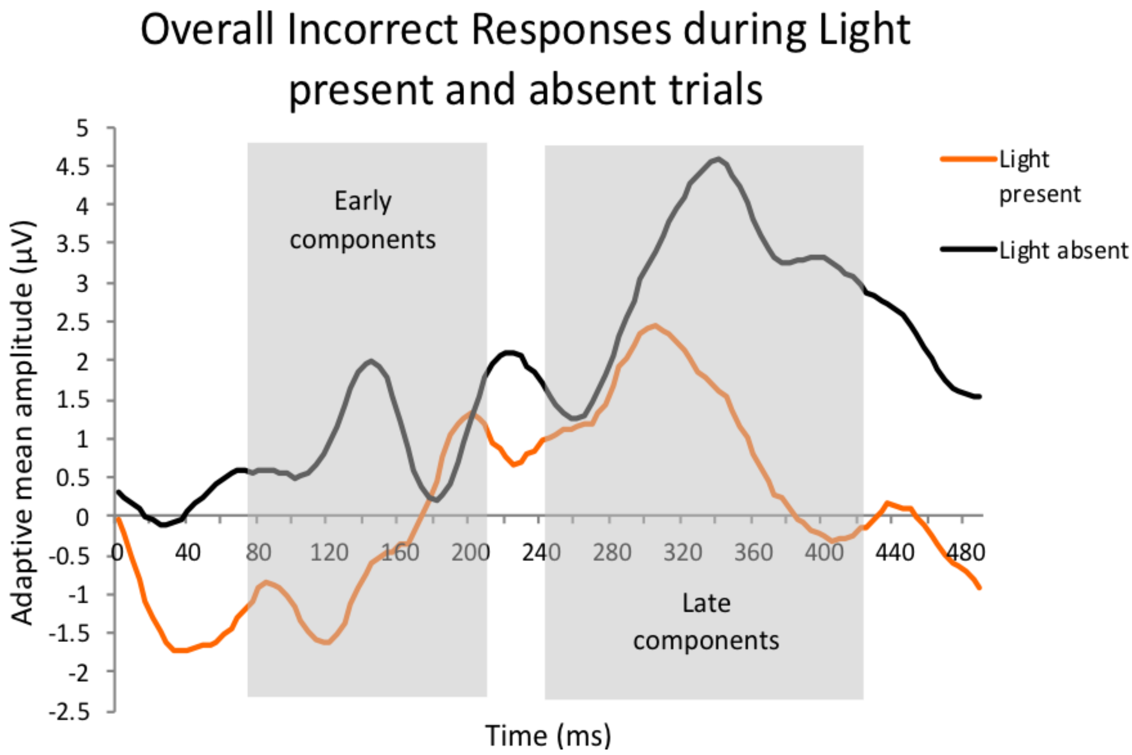


Figure.5.11. The figures show the ERP waveform during Light present and absent Incorrect Responses, with the AMA for early and late ERP components over the Parietal regions. The AMA is greater during Light absent trials for early and late components.

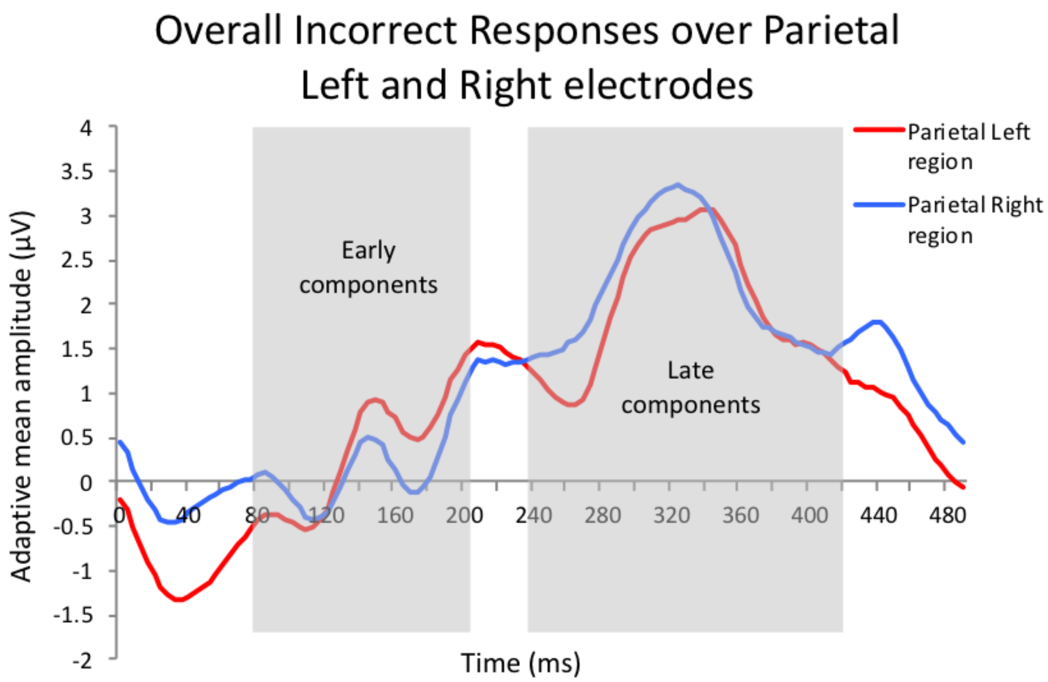
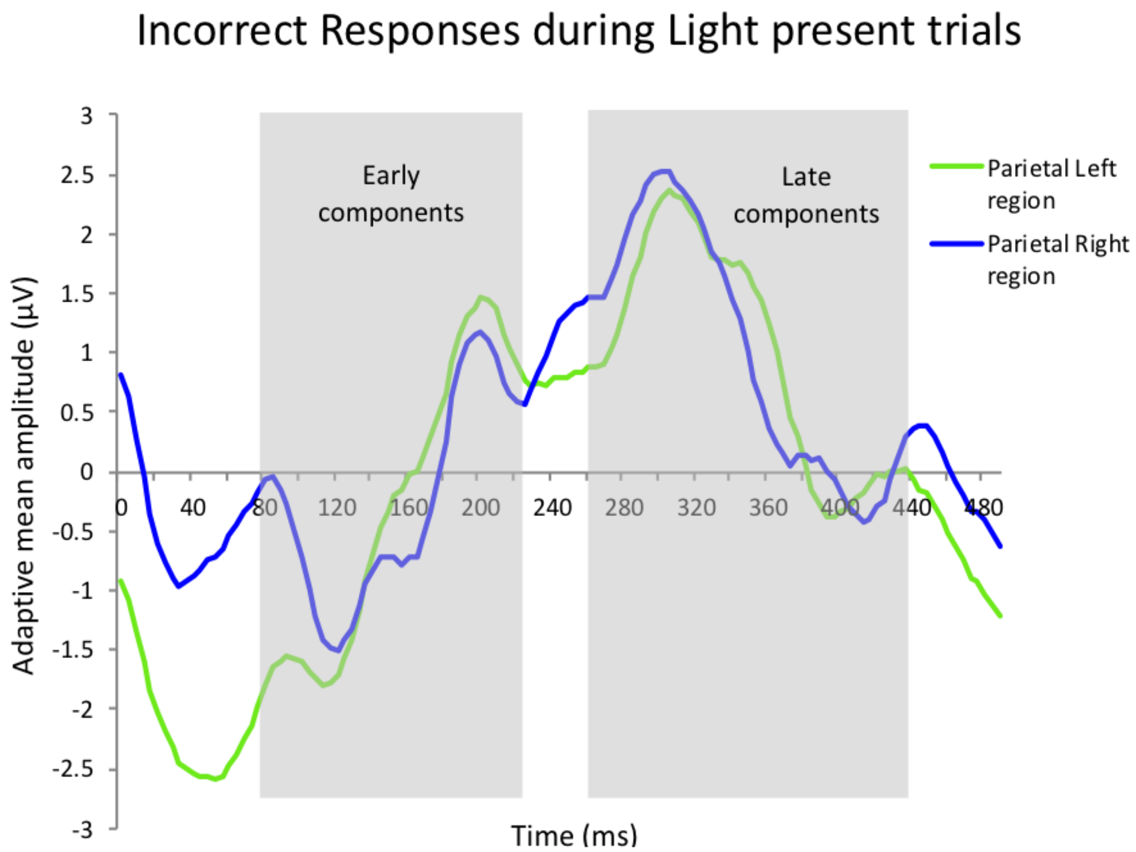


Figure.5.12. The figure shows the ERP waveform for the AMA of Incorrect Responses over Left and Right Parietal regions. The AMA is greater over the Left region during the early component (90 – 220ms) and is greater over Right region during the late components (260-440ms).



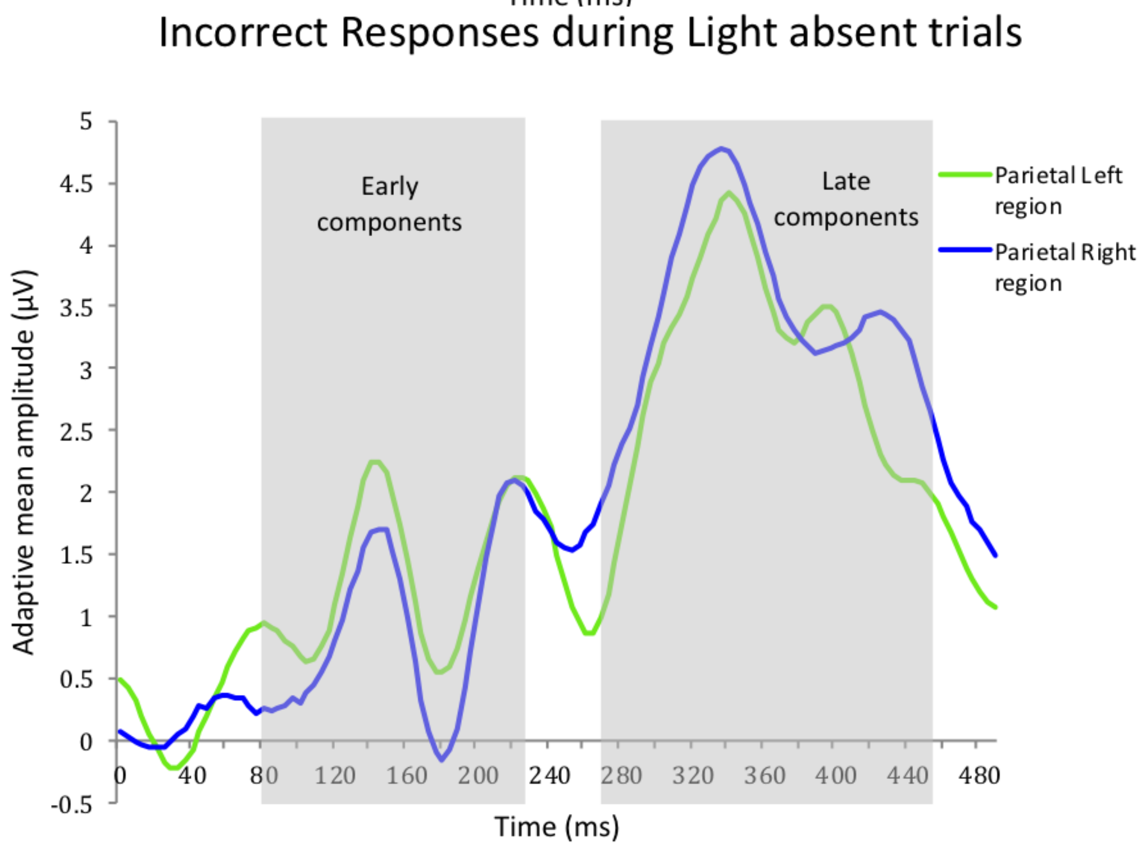


Figure.5.13. The figures show the ERP waveform during Light present and absent Incorrect Responses, with the AMA for early and late ERP components over the Parietal regions. The AMA is greater over the Left region around the early components, whereas the AMA is greater over the Right region during later components during both Light conditions.

False Alarms

Univariate analysis of the Parietal region False Alarm AMAs (see Appendix A, table A.3) found a significant interaction between Left and Right Parietal regions during both Light present and absent conditions with SDQ-20 scores across all four components of interest. Pearson's correlation between the Left and Right regions with SDQ-20 scores were found to have a positive relationship during both Light conditions. Indicating that participants who scored higher on the SDQ-20 also had a greater AMA for False Alarms (see Appendix A, figures A.3 to A.6).

Repeated measures ANOVA found a trend towards a significant main effect of Light (present begin greater) across all components of interest with the AMA of False Alarms, all $F_{(1,23)} = 3.26$, $p = .08$. There was also a trend towards a significant interaction between Region and Light (Right electrodes with Light present) across all components of interest, all $F_{(1,23)} = 3.23$, $p = .08$. There was a significant main effect of Region, with AMA of False Alarms over the Parietal Right region to be significantly greater than the Parietal Left region across all components of interest, all $F_{(1,23)} = 6.26$, $p = .02$. This can be seen in the electrode waveforms in Figures 5.14 to 5.16. The AMAs were found to be significantly more positive over the Right Parietal region than the Left Parietal region.

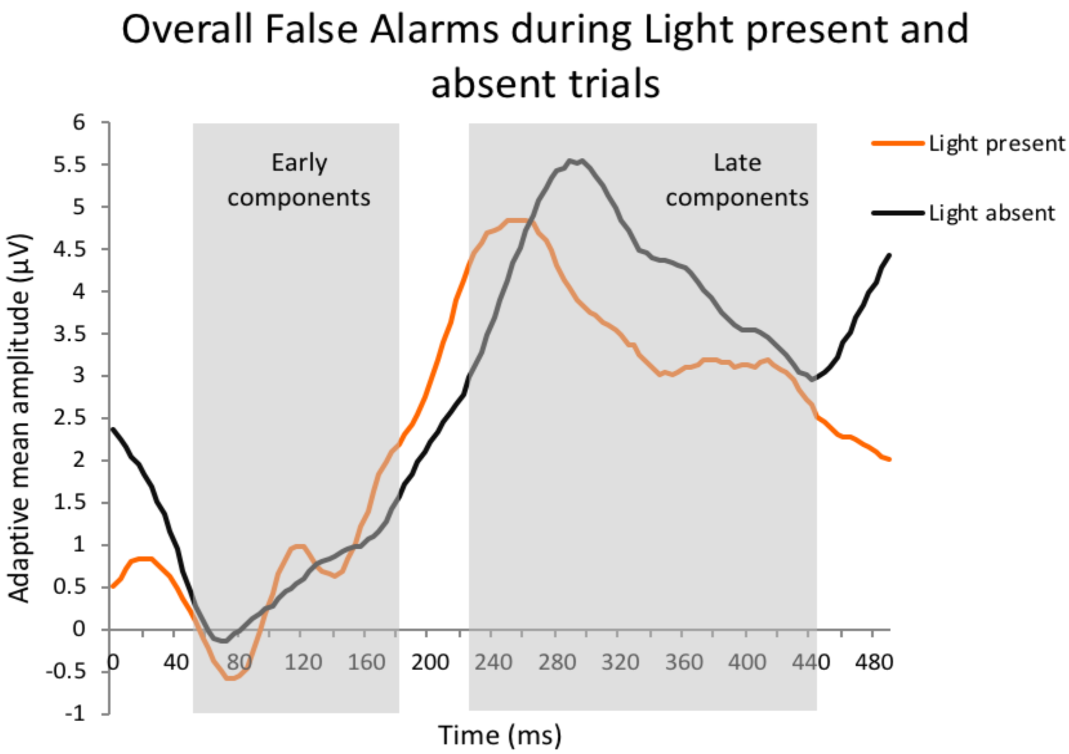


Figure.5.14. The figures show the ERP waveform during Light present and absent False Alarms, with the AMA for early and late ERP components over the Parietal regions. The AMA is greater during Light absent trials for early and late components.

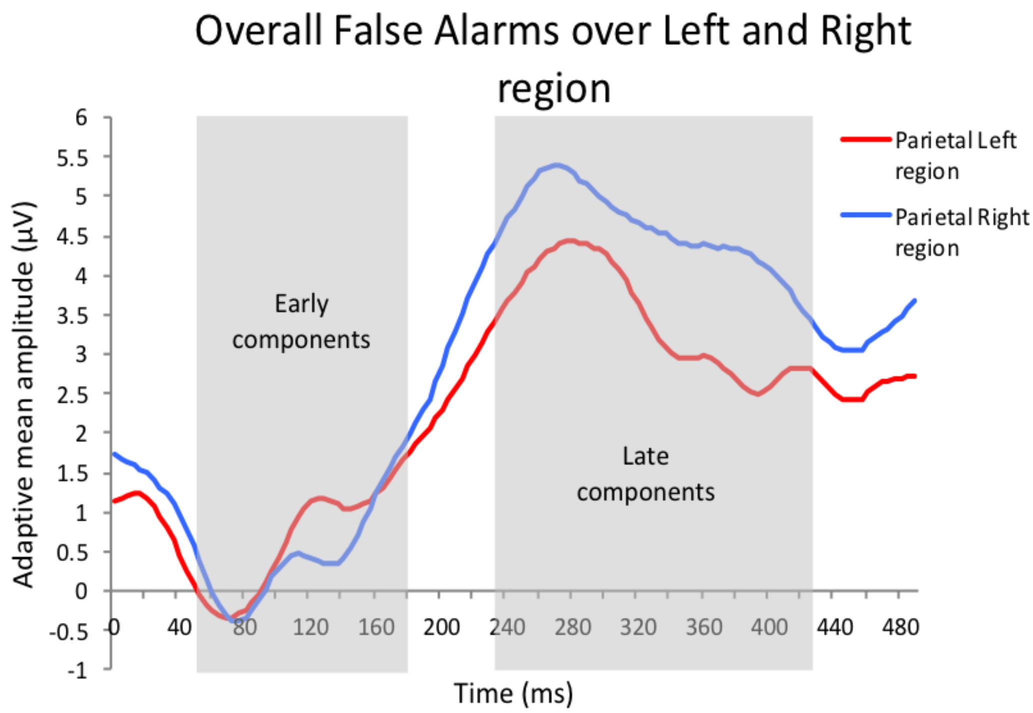
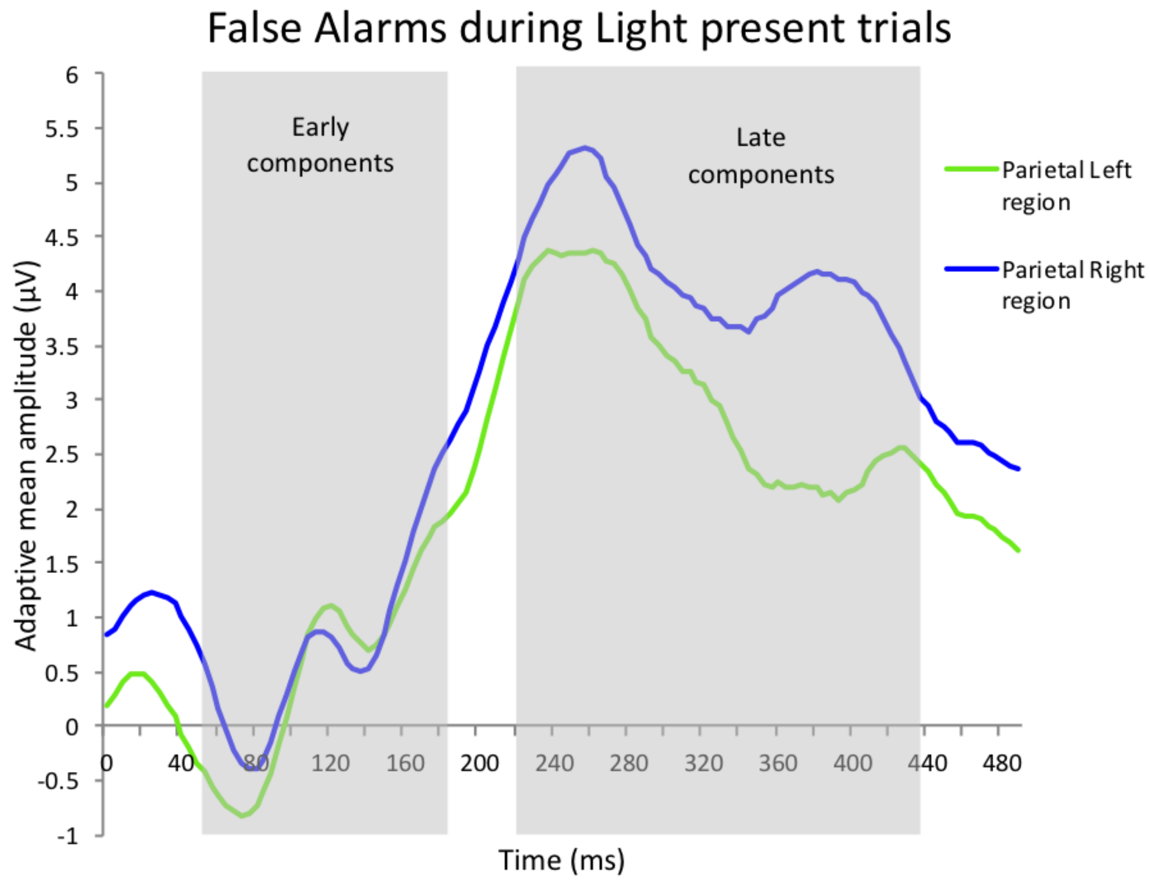


Figure.5.15. The figure shows the ERP waveform for the AMA of False Alarm over Left and Right Parietal regions. The AMA is greater over the Left region for the early components and is greater over Right region during the later components.



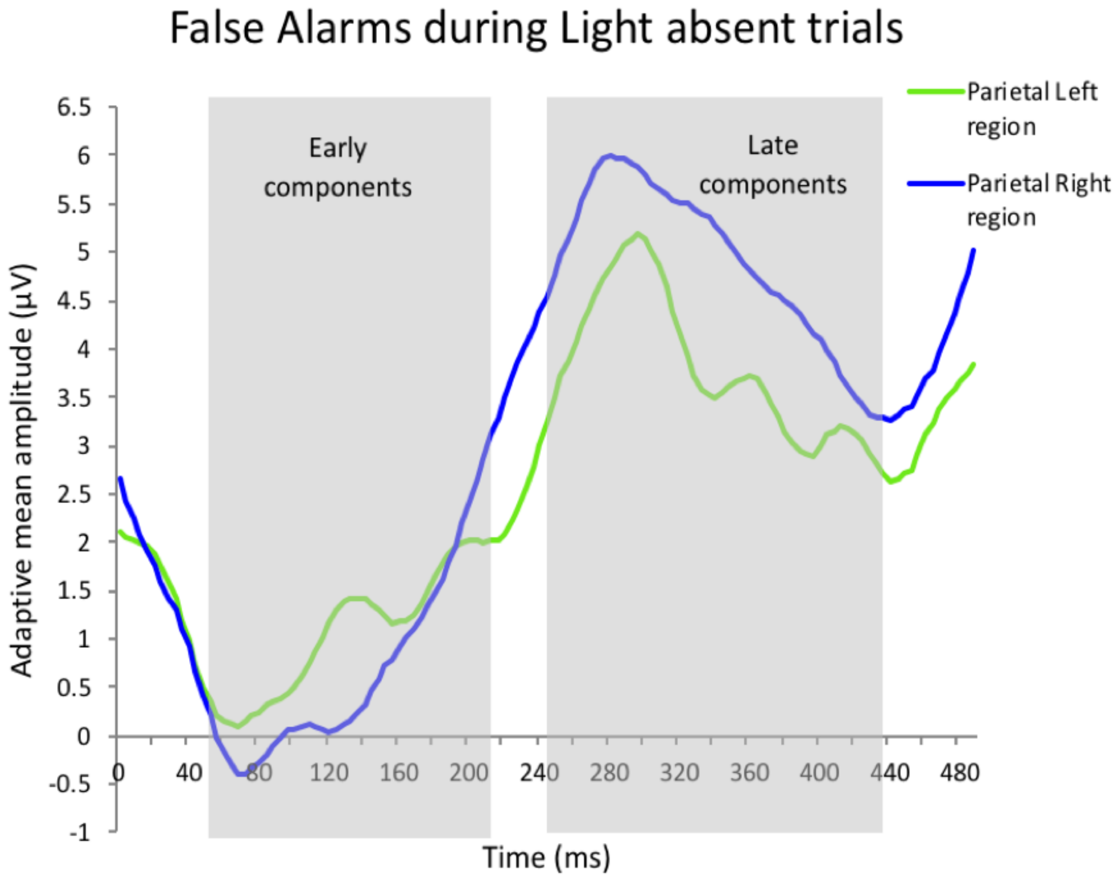


Figure.5.16. The figures show the ERP waveform during Light present and absent False Alarms, with the AMA for early and late ERP components over the Parietal electrode region. The AMA is greater over the Left region around the early components, whereas the AMA is greater over the Right region during later components during both Light conditions.

Correct Rejections

Univariate analysis of Parietal region AMA for Correct Rejections (see Appendix A, table A.4) found a significant interaction between the Right Parietal region during both Light present and absent conditions with SDQ-20 scores across all four components of interest. There was also a trend towards a significant relationship between the AMA of Correct Rejections from Left region and SDQ-20. Pearson's correlation between the Right region and SDQ-20 scores were found to have a positive relationship during both Light conditions. Indicating that participants who scored higher on the SDQ-20 also had a greater AMA during Correct Rejections (see Appendix A, figures A.5 and A.6).

Repeated measures ANOVA found a significant main effect of Region. The AMA for Correct Rejections for Right region was found to be significantly greater than the Left across all components of interest, all $F_{(1,23)} = 14.24$, $p = .001$; there was no significant effect of Light, $p > .05$. Correct Rejections AMAs were found to be significantly more positive over the Right region than the Left region. This can be seen in the electrode waveforms in Figures 5.17 to 5.19.

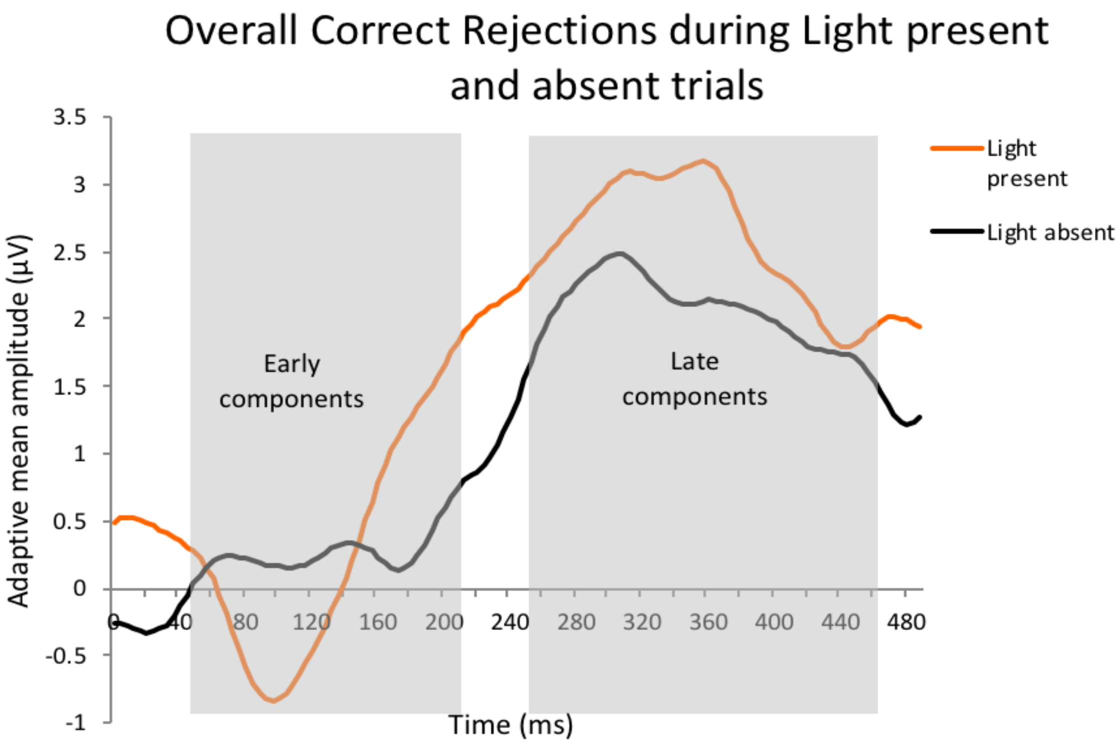


Figure 5.17. The figures show the ERP waveform during Light present and absent Correct Rejections, with the AMA for early and late ERP components over the Parietal regions. The AMA is greater during Light absent trials for early components and Light present trials for later components.

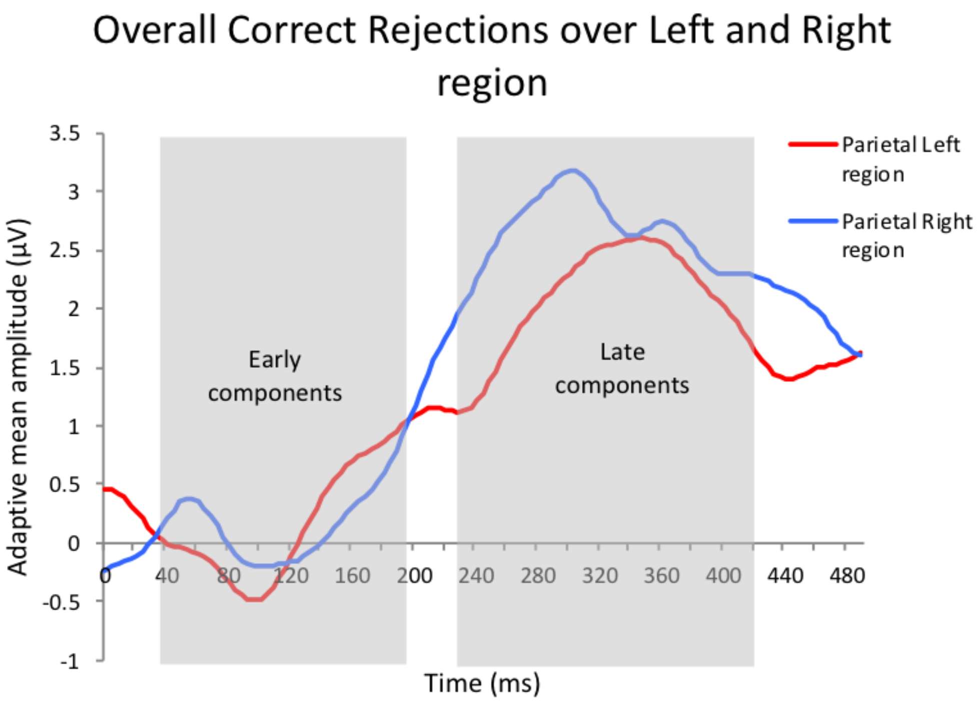
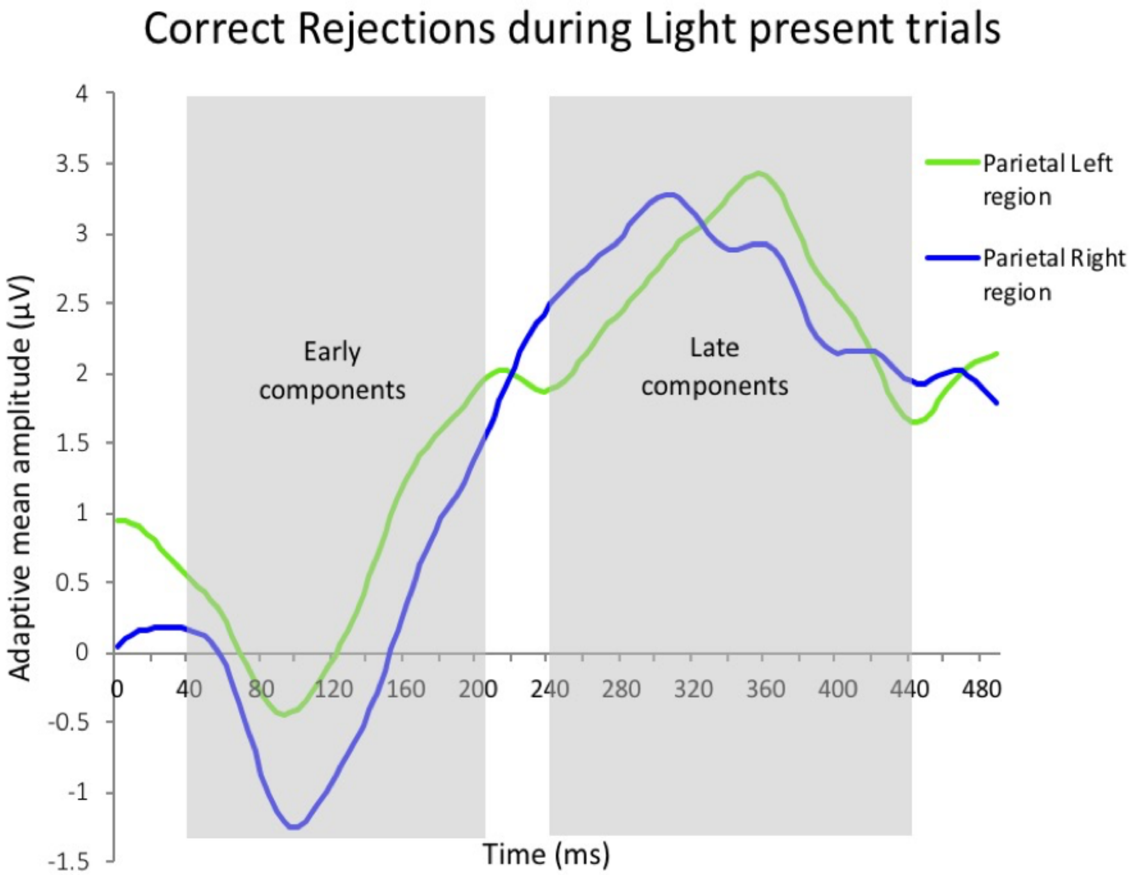


Figure.5.18. The figure shows the ERP waveform for the AMA of Correct Rejection over Left and Right Parietal regions. The AMA is greater over the Right region during the later components and part of the early components.



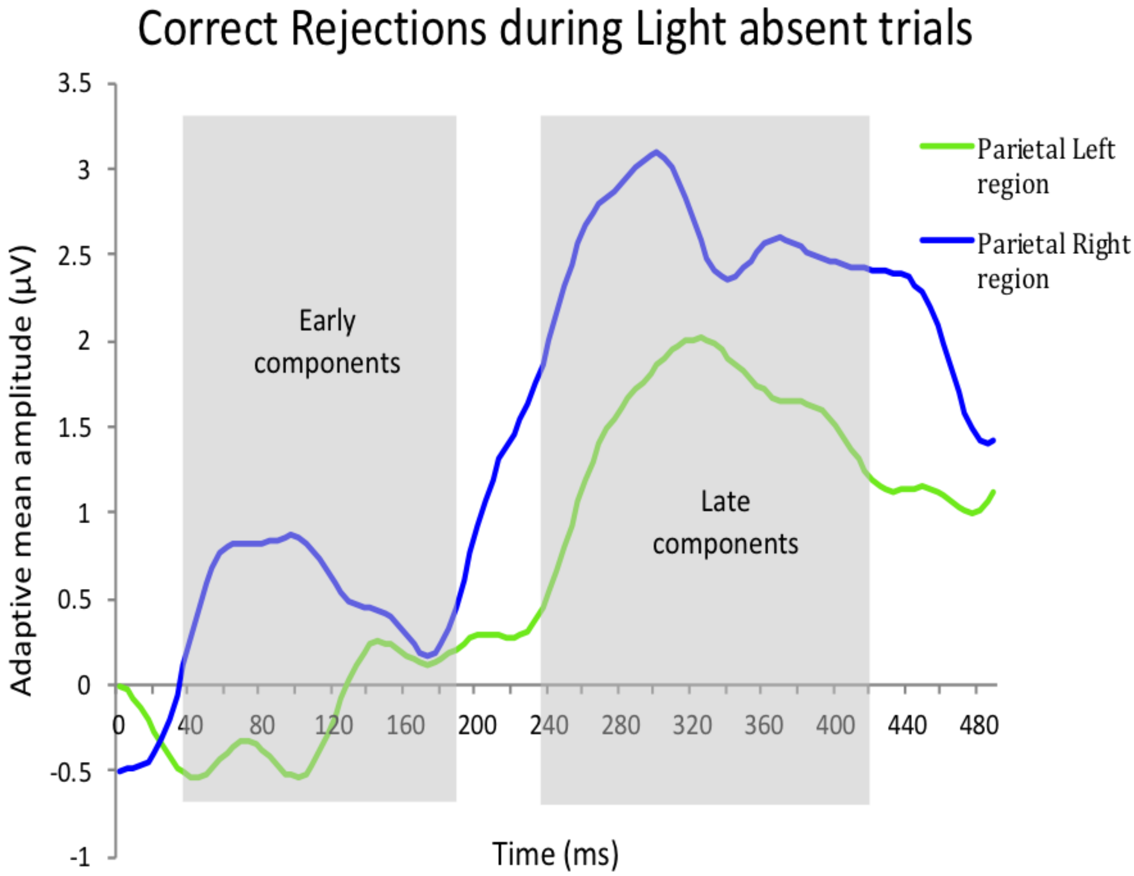


Figure.5.19. The figures show the ERP waveform during Light present and absent Correct Rejection, with the AMA for early and late ERP components over the Parietal regions. The AMA is greater over the Right region for all components during Light absent conditions. The AMA during Light absent conditions is greater over Left region for early components and is greater over the Right region during later components.

The Adaptive Mean Amplitude (AMA) for Hit, Incorrect Response, False Alarm and Correct Rejections were compared with each other within each Light condition across all four components of interest. This was conducted to see how the AMA differed within each Light condition between Hits, Incorrect Responses, False Alarms and Correct Rejections (see figure 5.20, table 5.5 to 5.8 for the paired samples t-test).

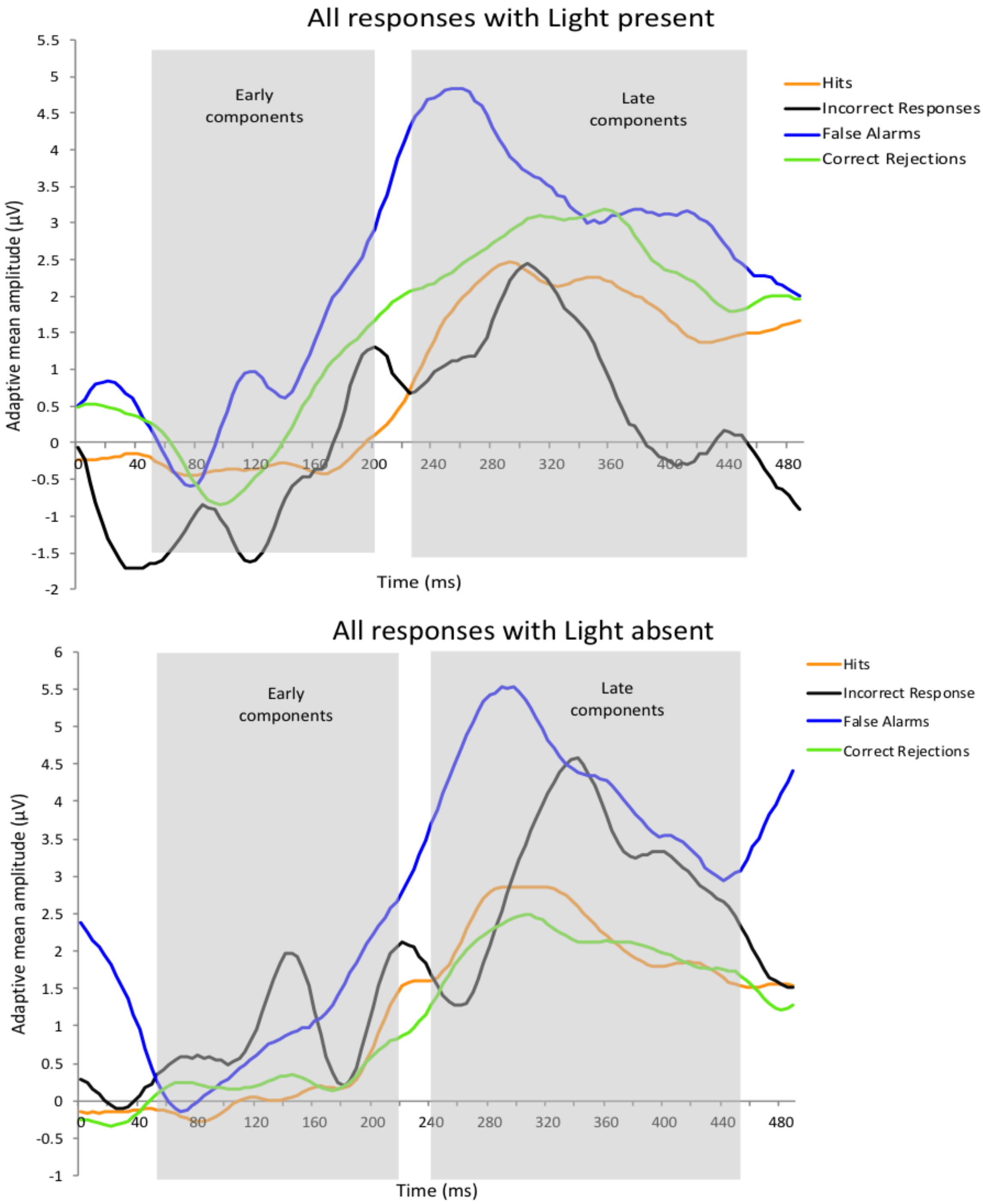


Figure.5.20. The figures show the ERP waveform for Hit, Incorrect Response, False Alarm and Correct Rejections during Light present and absent conditions for the AMA of early and late ERP components over the Parietal regions.

Table.5.5. Paired samples t-test comparing between the AMA of P120 during Light present and absent conditions and Hits, Incorrect Responses, False Alarms and Correct Rejections.

		P120				
Light		*M*	*SD*	*df*	*t*	*p*
Present	Hit X Incorrect Response	5226.90 3321.37	3906.75 3719.43	23	2.43	.02*
	Hit X False Alarm	5226.90 3397.74	3906.75 3149.36	23	2.09	.048*
	Hit X Correct Rejection	5226.90 5141.26	3906.75 3785.87	23	0.82	.42
	False Alarm X Incorrect Response	3397.74 3321.37	3149.36 3719.43	23	0.08	.94
	Correct Rejection X Incorrect Response	5141.26 3321.37	3785.87 3719.43	23	2.47	.02*
	Correct Rejection X False Alarm	5141.26 3397.74	3785.87 3149.36	23	2.09	.048*
Absent	Hit X Incorrect Response	5182.57 2995.60	3807.61 2686.10	23	2.34	.03*
	Hit X False Alarm	5182.57 3101.81	3807.61 3259.66	23	2.47	.02*
	Correct Rejection X Hit	5206.92 5182.57	3904.87 3807.61	23	0.50	.62
	False Alarm X Incorrect Response	3101.81 2995.60	3259.66 2686.10	23	0.21	.83
	Correct Rejection X Incorrect Response	5206.92 2995.60	3904.87 2686.10	23	2.32	.03*
	Correct Rejection X False Alarm	5206.92 3101.81	3904.87 3259.66	23	2.44	.02*

Table 5.5 shows the P120 AMA during Hits with Light present and absent conditions were greater than that of the incorrect responses and False Alarms. The P120 AMA of Correct Rejections was greater than Incorrect Responses and False Alarms during both Light conditions. The AMA of Hits and Correct Rejections were not significantly different during both Light conditions. False Alarm and Incorrect Response AMAs were also not significantly different in the two Light conditions.

Table.5.6. Paired samples t-test comparing between the P160 AMA during Light present and absent conditions and Hits, Incorrect Responses, False Alarms and Correct Rejections.

		P160				
Light		*M*	*SD*	*df*	*t*	*p*
Present	Hit X Incorrect Response	5227.10 3321.51	3906.82 3719.95	23	2.43	.02*
	Hit X False Alarm	5227.10 3397.96	3906.82 3149.41	23	2.09	.048*
	Hit X Correct Rejection	5227.10 5141.54	3906.82 3785.75	23	0.82	.42
	False Alarm X Incorrect Response	3397.96 3321.51	3149.41 3719.95	23	0.08	.94
	Correct Rejection X Incorrect Response	5141.54 3321.51	3785.75 3719.95	23	2.47	.02*
	Correct Rejection X False Alarm	5141.54 3397.96	3785.75 3149.41	23	2.09	.048*
Absent	Hit X Incorrect Response	5182.70 2995.67	3807.55 2686.56	23	2.34	.03*
	Hit X False Alarm	5182.70 3101.79	3807.55 3259.32	23	2.47	.02*
	Correct Rejection X Hit	5206.91 5182.70	3904.76 3807.55	23	0.50	.62
	False Alarm X Incorrect Response	3101.79 2995.67	3259.32 2686.56	23	0.21	.84
	Correct Rejection X Incorrect Response	5206.91 2995.67	3904.76 2686.56	23	2.32	.03*
	Correct Rejection X False Alarm	5206.91 3101.79	3904.76 3259.32	23	2.44	.02*

Table 5.6 shows the P160 AMA during Hits with Light present and absent conditions were greater than that of the Incorrect responses and False Alarms. The P160 AMA of Correct Rejections was greater than the P160 AMA of Incorrect Responses and False Alarms during both Light conditions. The P160 AMA of Hits and Correct Rejections were not significantly different during both Light

conditions. False Alarm and Incorrect Responses P160 AMAs were also not significantly different in the two Light conditions.

Table.5.7. Paired samples t-test comparing between the P360 AMA during Light present and absent conditions and Hits, Incorrect Responses, False Alarms and Correct Rejections.

		P360				
Light		*M*	*SD*	*df*	*t*	*p*
Present	Hit X	5228.51	3906.29	23	2.43	.02*
	Incorrect Response	3321.94	3720.24			
	Hit X	5228.51	3906.29	23	2.09	.048*
	False Alarm	3400.49	3150.55			
	Hit X	5228.51	3906.29	23	0.81	.42
	Correct Rejection	5143.42	3785.94			
	False Alarm X	3400.49	3150.55	23	0.08	.94
	Incorrect Response	3321.94	3720.24			
	Correct Rejection X	5143.42	3785.94	23	2.47	.02*
	Incorrect Response	3321.94	3720.24			
	Correct Rejection X	5143.42	3785.94	23	2.09	.048*
	False Alarm	3400.49	3150.55			
Absent	Hit X	5185.72	3807.75	23	2.35	.03*
	Incorrect Response	2997.25	2686.22			
	Hit X	5185.72	3807.75	23	2.48	.02*
	False Alarm	3103.88	3261.59			
	Correct Rejection X	5210.16	3905.41	23	0.50	.62
	Hit	5185.72	3807.75			
	False Alarm X	3103.88	3261.59	23	0.21	.84
	Incorrect Response	2997.25	2686.22			
	Correct Rejection X	5210.16	3905.41	23	2.32	.03*
	Incorrect Response	2997.25	2686.22			
	Correct Rejection X	5210.16	3905.41	23	2.44	.02*
	False Alarm	3103.88	3261.59			

Table 5.7 shows the P360 AMA during Hits with Light present and absent conditions were greater than that of the Incorrect responses and False Alarms. The P360 AMA of Correct Rejections was greater than the P360 AMA of Incorrect Responses and False Alarms during both Light conditions. The P360 AMA of Hits and Correct Rejections were not significantly different during both Light

conditions. False Alarm and Incorrect Response P360 AMAs were also not significantly different in the two Light conditions.

Table.5.8. Paired samples t-test comparing between the P400 AMA during Light present and absent conditions and Hits, Incorrect Responses, False Alarms and Correct Rejections.

		P400				
Light		*M*	*SD*	*df*	*t*	*p*
Present	Hit X Incorrect Response	5229.36 3322.83	3906.63 3720.49	23	2.43	.02*
	Hit X False Alarm	5229.36 3401.54	3906.63 3150.41	23	2.08	.048*
	Hit X Correct Rejection	5229.36 5144.87	3906.63 3786.45	23	0.81	.43
	False Alarm X Incorrect Response	3401.54 3322.83	3150.41 3720.49	23	0.08	.94
	Correct Rejection X Incorrect Response	5144.87 3322.83	3786.45 3720.49	23	2.47	.02*
	Correct Rejection X False Alarm	5144.87 3401.54	3786.45 3150.41	23	2.09	.048*
Absent	Hit X Incorrect Response	5185.72 2997.25	3807.75 2686.22	23	2.35	.03*
	Hit X False Alarm	5185.72 3103.88	3807.75 3261.59	23	2.48	.02*
	Correct Rejection X Hit	5210.16 5185.72	3905.41 3807.75	23	0.50	.62
	False Alarm X Incorrect Response	3103.88 2997.25	3261.59 2686.22	23	0.21	.84
	Correct Rejection X Incorrect Response	5210.16 2997.25	3905.41 2686.22	23	2.32	.03*
	Correct Rejection X False Alarm	5210.16 3103.88	3905.41 3261.59	23	2.44	.02*

Table 5.8 shows the P400 AMA during Hits with Light present and absent conditions were greater than that of the Incorrect responses and False Alarms. The P400 AMA of Correct Rejections was greater than the P400 AMA of Incorrect Responses and False Alarms during both Light conditions. The P400 AMA of Hits

and Correct Rejections were not significantly different during both Light conditions. False Alarm and Incorrect Response P400 AMAs were also not significantly different in the two Light conditions.

Frontal Region

A summary of the findings has been presented below, for full univariate analysis and scatter plots for the Frontal region see Appendix B.

Hits

Univariate analysis of the Frontal region AMA for Hits (see Appendix B, table B.1) found a significant interaction between the Left and Right Frontal regions during both Light present and absent conditions with STAI-State scores across all four components of interest. Pearson's correlation between the Left and Right regions with STAI-State scores were found to have a negative relationship during both Light conditions. Indicating that participants who had a more positive AMA for Hits scored low on the STAI-State (see Appendix B, figures B.1 to B.4).

Univariate analysis of the Frontal region AMA for Hits (see Appendix B, table B.2) found a significant interaction between the Right region during Light present conditions with STAI-Trait scores across all four components of interest. There was also a trend towards a significant relationship between the AMA of Hits from Right region Light absent trials and STAI-Trait. Pearson's correlation between the Right region Light present trials and STAI-Trait scores were found to have a negative relationship. Indicating that participants who scored lower on the STAI-Trait had a more positive AMA for Hits (see Appendix B, figure B.5).

Repeated measures ANOVA found a significant main effect of Region. The AMA for Hits over the Right region were found to be significantly more positive than the Left across all components of interest, all $F_{(1,23)} = 9.26$, $p = .006$; there was no significant effect of Light and no interaction between the terms, all $p > .05$. This can be seen in the waveforms in Figures 5.21 to 5.23. The AMAs were found to be significantly more positive over the Right region than the Left region.

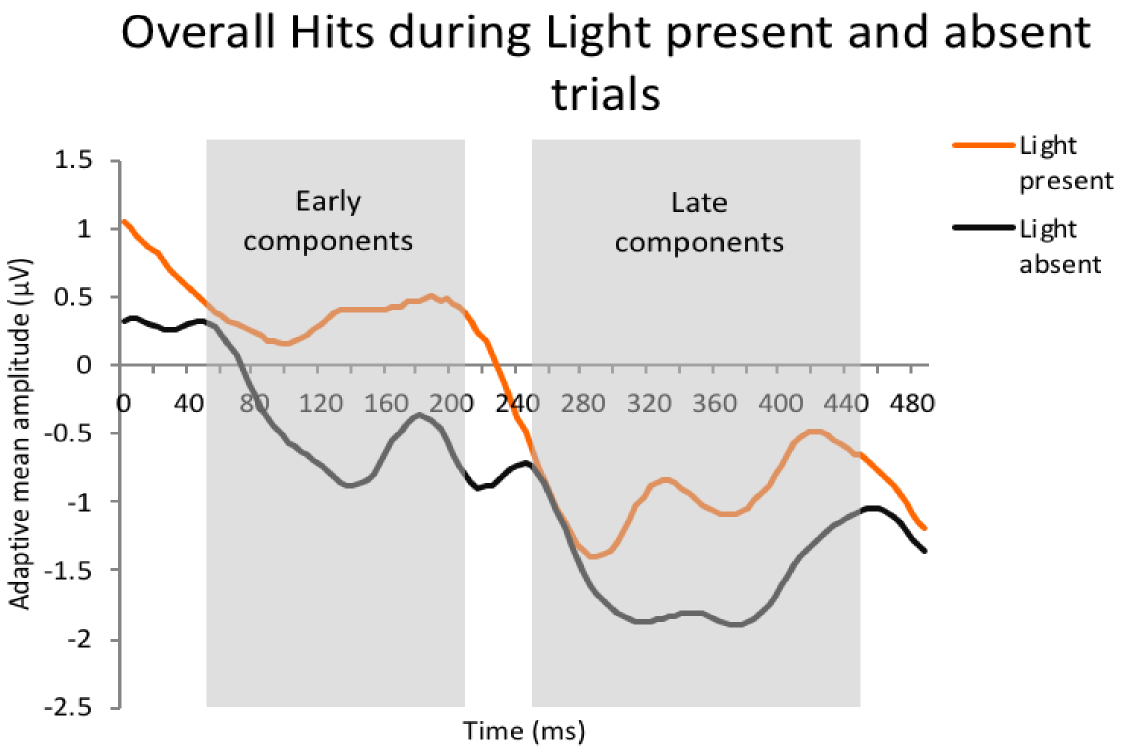


Figure.5.21. The figures show the ERP waveform during Light present and absent Hits, with the AMA for early and late ERP components over the Frontal regions. The AMA is more positive during Light present trials for early and late components.

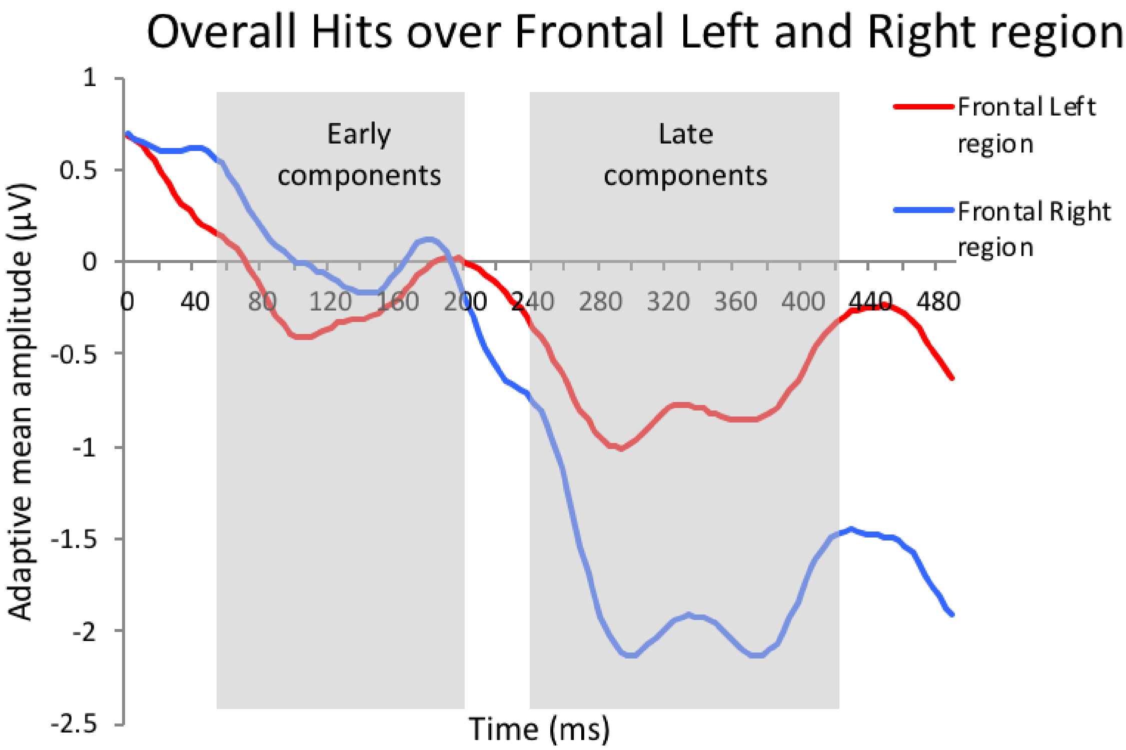
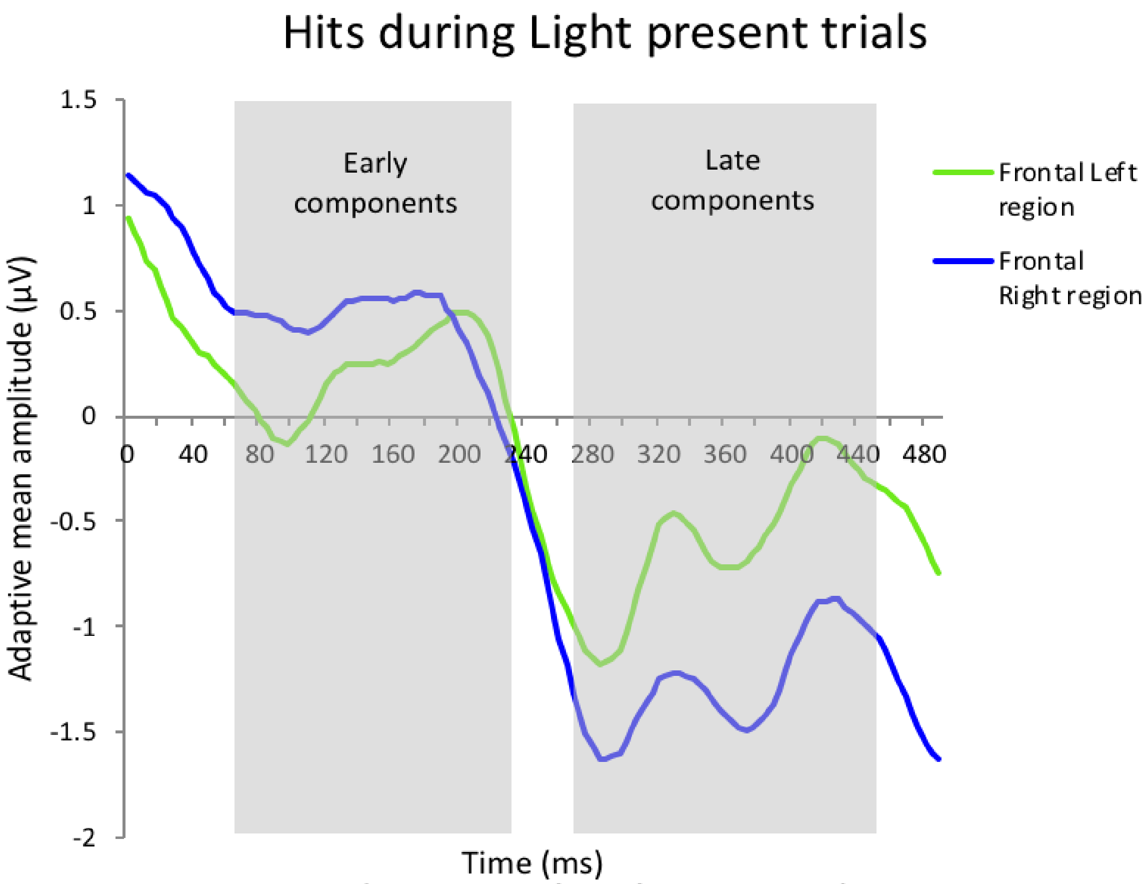


Figure.5.22. The figure shows the ERP waveform for the AMA of Hits over Left and Right Frontal regions. The AMA is more positive over the Right region during the early components (70 – 220ms) and the late components (260 – 460ms).



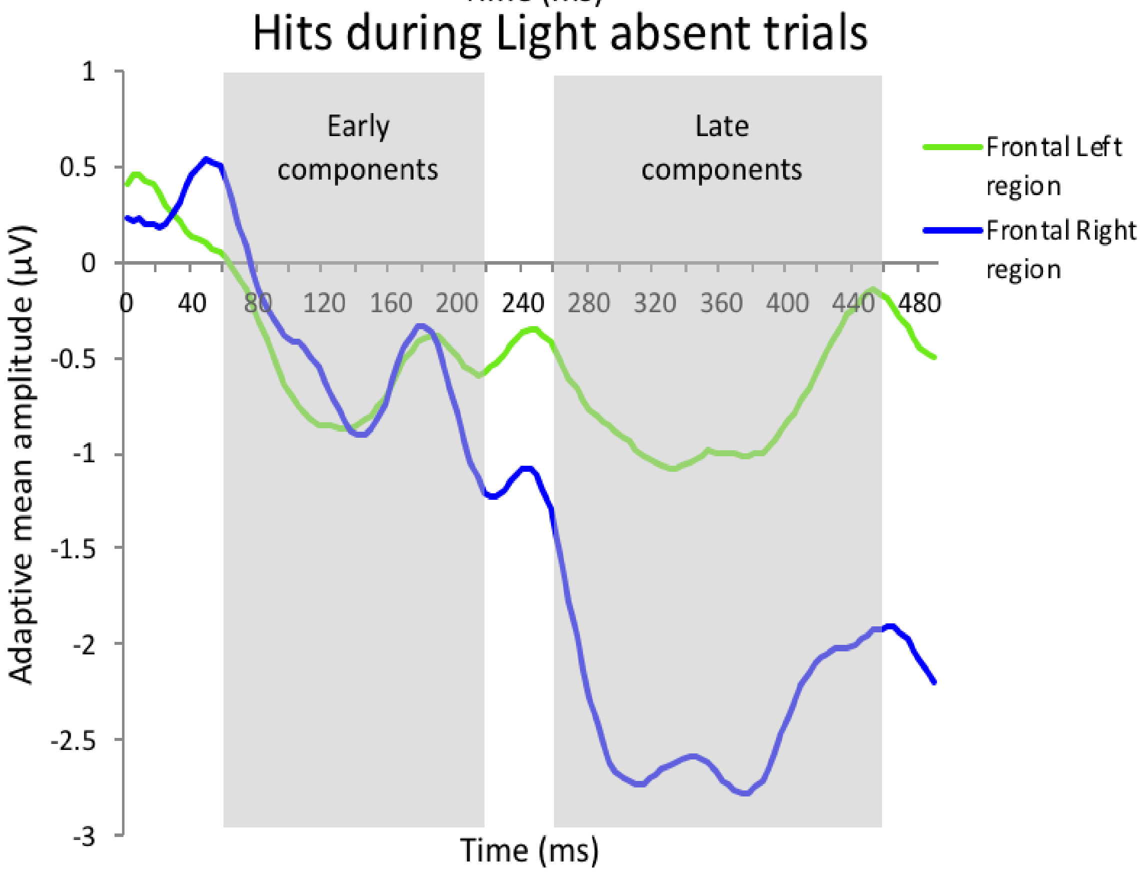


Figure.5.23. The figures show the ERP waveform during Light present and absent Hits, with the AMA for early and late ERP components over the Frontal regions. The AMA is more positive over the Right region during early components (60 – 220ms), whereas the AMA is more positive over the Left region during later components (260 – 460ms) during both Light conditions.

Summary

The AMAs of Hits over the Frontal region was found to have a significant negative relationship with the State-Trait Anxiety Inventory (STAI) during both Light conditions. The STAI-State was used to measure current anxiety of participants at the time of the data collection. The negative relationship indicates that those participants who were not as anxious (low scorers on STAI-State) had more positive AMA for Hits for all components of interest. The Trait scale of the State-Trait Anxiety Inventory (STAI) was also found to have a significantly negative relationship with the AMA of Hits over Right region during Light present trials with all components of interest. The STAI-Trait scale is used to account for the effects of negative affectivity. Therefore, those who scored low on the STAI-Trait, indicate not experiencing any negative feelings/emotions at the time of data collection, had more positive AMA for Hits over the Right region during Light present trials. The AMAs of Hits were found to be greater over the Right region than the Left region for all components of interest.

Incorrect Responses

Univariate analysis of the Frontal region AMA for Incorrect Response (see Appendix B, table B.3) found a significant interaction between the Right region during both Light present and absent conditions with PHQ-15 scores across all four components of interest. Pearson's correlation between the Right region and PHQ-15 scores found to have a negative relationship during both Light conditions.

Indicating that participants who had a more positive Incorrect Response AMA had scored lower on the PHQ-15 (see Appendix B, figures B.6 and B.7).

Repeated measures ANOVA found a significant main effect of Region. The AMA for Incorrect Responses over the Right regions were found to be significantly more positive than the Left region across all components of interest, all $F_{(1,23)} = 8.73$, $p = .007$; there was no significant effect of Light and no interaction between the terms, all $p > .05$. This can be seen in the waveforms in Figures 5.24 to 5.26. The AMAs were found to be significantly more positive over the Right region than the Left region.

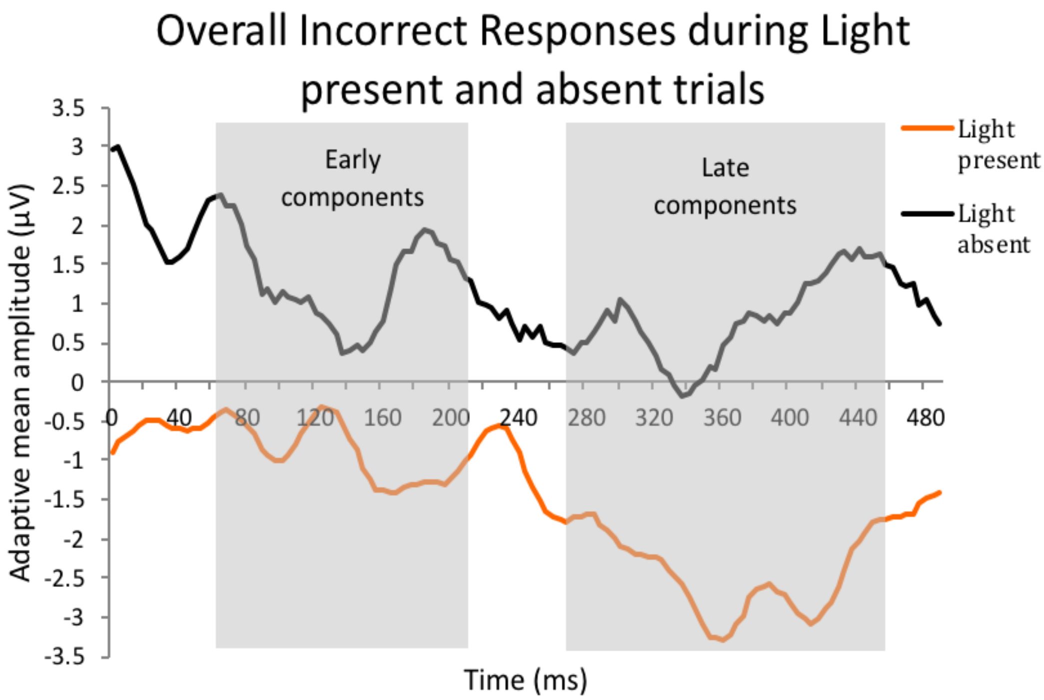


Figure.5.24. The figures show the ERP waveform during Light present and absent Incorrect Responses, with the AMA for early and late ERP components over the Frontal regions. The AMA was more positive during Light absent trials for early and late components.

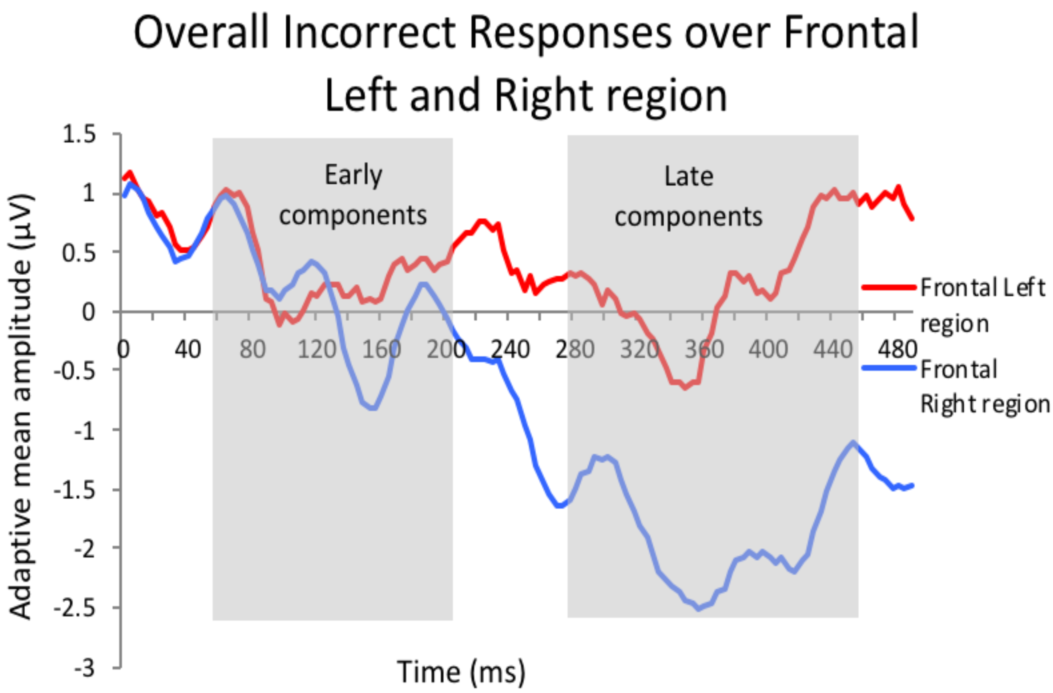


Figure.5.25. The figure shows the ERP waveform for the AMA of Incorrect Responses over Left and Right Frontal regions. The AMA of early components (60 – 220ms) appears to vary between the Left and Right regions and was more positive over Left region during the late components (260 – 460ms).

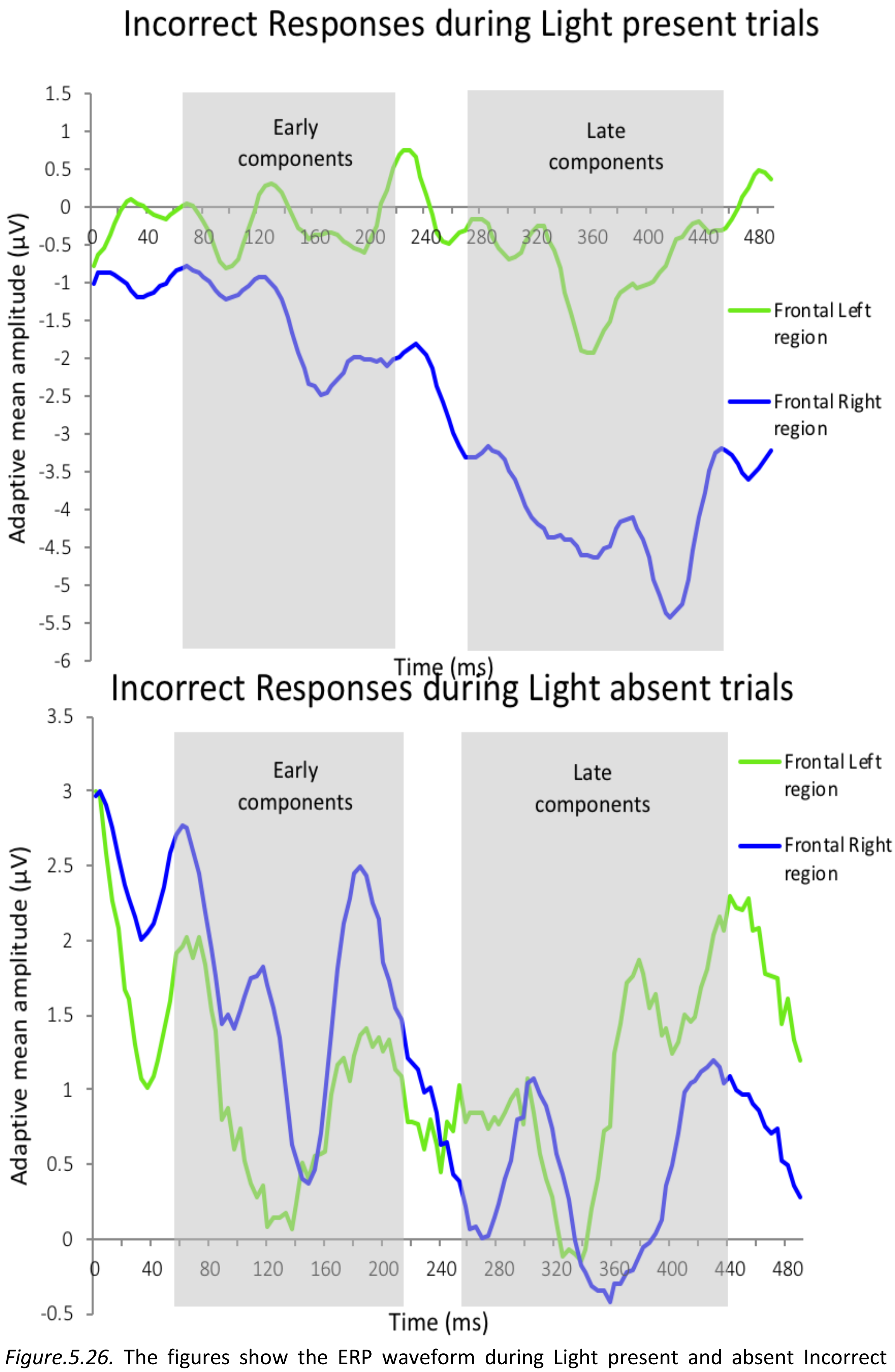


Figure.5.26. The figures show the ERP waveform during Light present and absent Incorrect Responses, with the AMA for early and late ERP components over the Frontal regions. The AMA was more positive over the Left region for early and late components during Light present trials. The AMA during Light absent trials was more positive over the Right region during early components but varied between the two for the later components.

Summary

The AMA of Incorrect Responses over the Right region during both Light present and absent conditions had a negative relationship with PHQ-15 scores across all four components of interest. The Patient Health Questionnaire 15 (PHQ-15) provides a means to determine the level of an individual’s somatosensory symptoms. The negative relationship indicates that participants who reported having low somatosensory symptoms had a more positive Incorrect Response AMA during both Light conditions over the Right region. The AMAs of Incorrect Responses were found to be greater over the Right region than the Left region for all components of interest.

False Alarms

Univariate analysis of the Frontal region AMA for False Alarms (see Appendix B, table B.4) found a significant interaction between the Left and Right regions during Light present and absent conditions with PHQ-15 scores across all four components of interest. Pearson’s correlation between the Left and Right regions with PHQ-15 scores were found to have a negative relationship during both Light conditions. Indicating that participants who had more positive AMA for False Alarms scored lower on the PHQ-15 (see Appendix B, figures B.8 to B.11 for scatterplots).

Repeated measures ANOVA found a significant main effect of Region, with AMA of False Alarms over the Right region being significantly more positive than the Left region across all components of interest, all $F_{(1,23)} = 6.66$, $p = .02$; there was no significant effect of Light and no interaction between the terms, all $p > .05$. This can be seen in the waveforms in Figures 5.27 to 5.29. The AMAs were found to be significantly more positive over the Right region than the Left region.

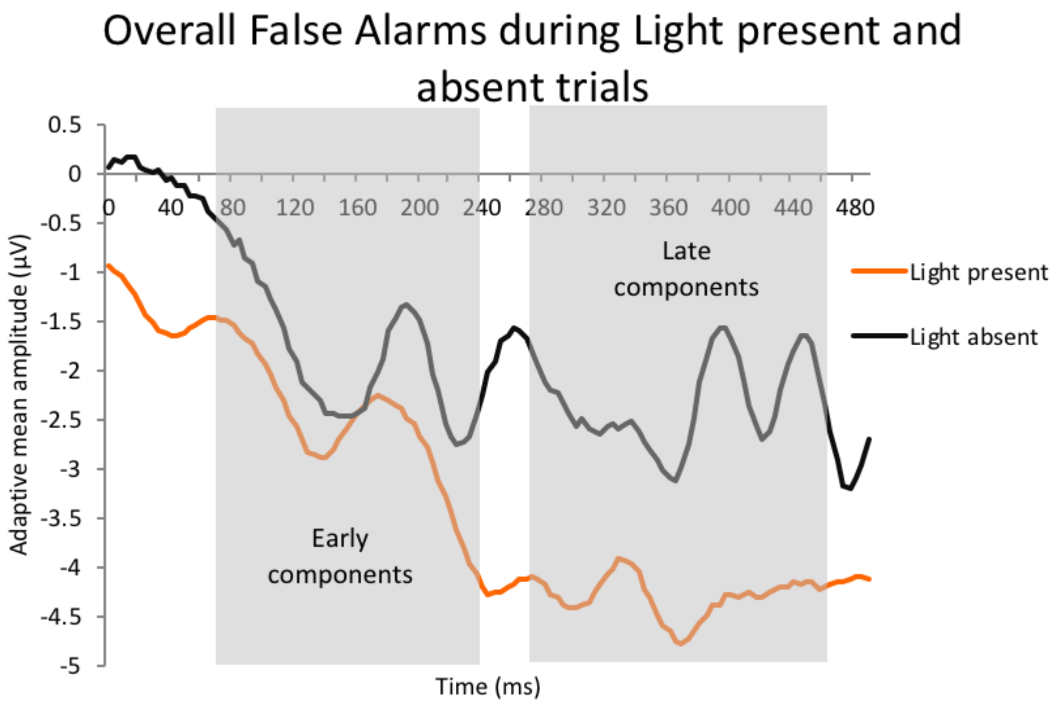


Figure.5.27. The figures show the ERP waveform during Light present and absent False Alarms, with the AMA for early and late ERP components over the Frontal regions. The AMA was more positive during Light absent trials for early and late components.

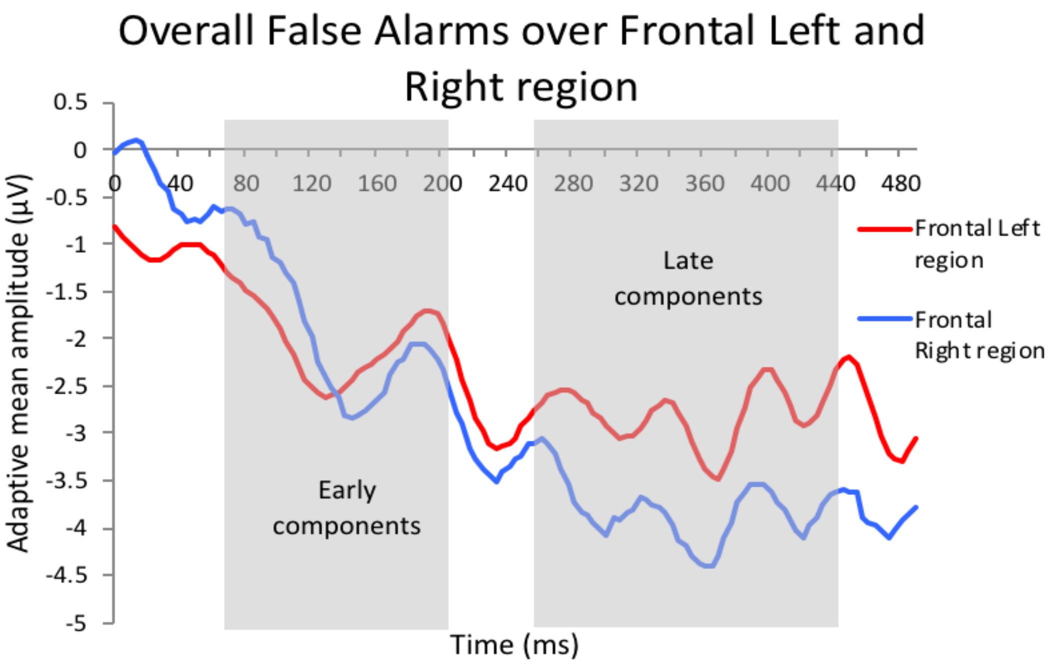


Figure.5.28. The figure shows the ERP waveform for the AMA of False Alarm over Left and Right Frontal region. The more positive AMA of early components varied between Left and Right region and was more positive over Left region during the later components.

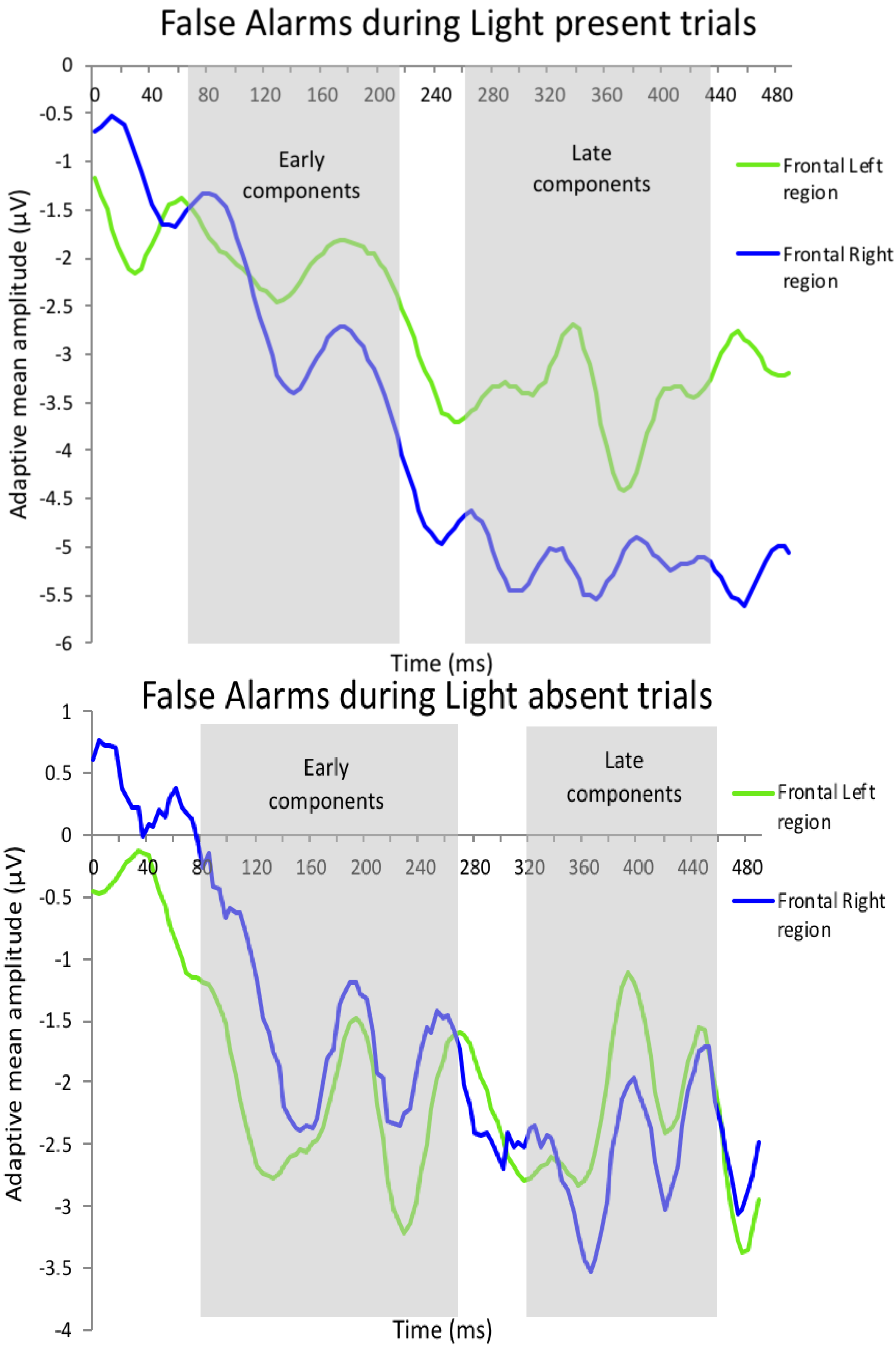


Figure.5.29. The figures show the ERP waveform during Light present and absent False Alarms, with the AMA for early and late ERP components over the Frontal region. During Light present trials the AMA was more positive over predominantly Left region for early and late components. During Light absent trials the more positive AMA varied between Left and Right regions during early and later components.

Summary

The AMA of False Alarms during both Light conditions over Frontal Left and Right regions were found to have a negative relationship with PHQ-15 across all four components of interest. The Patient Health Questionnaire 15 (PHQ-15) provides a means to determine the level of an individual's somatosensory symptoms. Participants who reported having low somatosensory symptoms had a more positive False Alarm AMA during both Light conditions over both Left and Right regions. The AMAs of False Alarms were found to be greater over the Right region than the Left region for all components of interest.

Correct Rejections

Univariate analysis of Frontal region AMA for Correct Rejections (see Appendix B, table B.5) found a significant interaction between the Left and Right regions during both Light present and absent conditions, only during Light present trials for Right region, with PHQ-15 scores across all four components of interest. There was a trend towards a significant relationship between the AMA of Correct Rejections from Right region with Light absent trials and PHQ-15. Pearson's correlation between the terms found a negative relationship during both Left Light present and absent conditions and during Right region with Light present conditions. Indicating that participants who had more positive AMAs for Correct Rejections had scored lower on the PHQ-15 during both Light conditions for Left region and only during Light present conditions for the Right region (see Appendix B, figures B.12 to B.15 for scatterplots).

Univariate analysis of Frontal region AMA for Correct Rejections (see Appendix B, table B.6) found a significant interaction between the Left and Right regions during both Light present and absent conditions with SDQ-20 scores across all four components of interest. Pearson's correlation between the terms found a negative relationship during both Left and Right Light present and absent conditions. Indicating that participants who had more positive AMAs for Correct Rejections had lower scores on the SDQ-20 (see Appendix B, figures B.16 to B.19).

Univariate analysis of Frontal region AMA for Correct Rejections (see Appendix B, table B.7) found a significant interaction between the Right region during both Light present and absent conditions with HAI-Short scores across all four components of interest. Pearson's correlation between the terms found a negative relationship during both Right Light present and absent conditions. Indicating that participants who had more positive AMAs for Correct Rejections had lower scores on the HAI-Short during both Light conditions for Right region (see Appendix B, figures B.20 and B.21).

Univariate analysis of Frontal region AMA for Correct Rejections (see Appendix B, table B.8) found a significant interaction between the Left and Right regions during both Light present and absent conditions with STAI-State scores across all four components of interest. Pearson's correlation between the terms found a negative relationship during both Left Light present and absent conditions. Indicating that participants who had more positive AMAs for Correct Rejections had lower scores on the STAI-State during both Light conditions for Left and Right regions (see Appendix B, figures B.22 to B.25).

Univariate analysis of Frontal region AMA for Correct Rejections (see Appendix B, table B.9) also found a significant interaction between the Right region during both Light present and absent conditions with STAI-Trait scores across all four components of interest. Pearson's correlation between the terms found a negative relationship during both Light present and absent conditions for the Right region. Indicating that participants who had more positive AMAs for Correct Rejections had lower scores on the STAI-Trait during both Light conditions for the Right region (see Appendix B, figures B.26 and B.27)

Repeated measures ANOVA found a significant main effect of Region. The AMA of Correct Rejections over the Right region were found to be significantly more positive than the Left region across all components of interest, all $F_{(1,23)}$ = 8.89, p = .007; there was no significant effect of Light and not interaction between the terms, all p > .05. The AMAs were found to be significantly more positive over the Right region than the Left region. This can be seen in the waveforms in Figures 5.30 to 5.32.

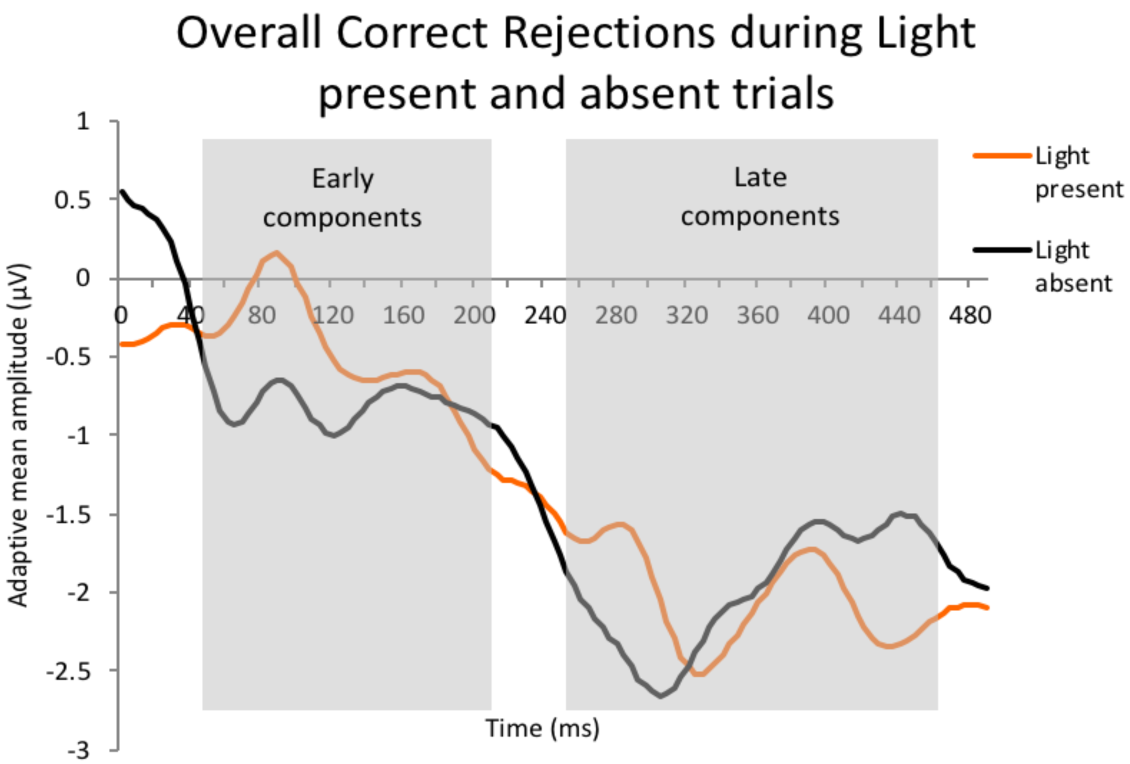


Figure.5.30. The figures show the ERP waveform during Light present and absent Correct Rejections, with the AMA for early and late ERP components over the Frontal regions. The more positive AMAs are present during Light present trials for early components and vary between Light present and absent trials for later components.

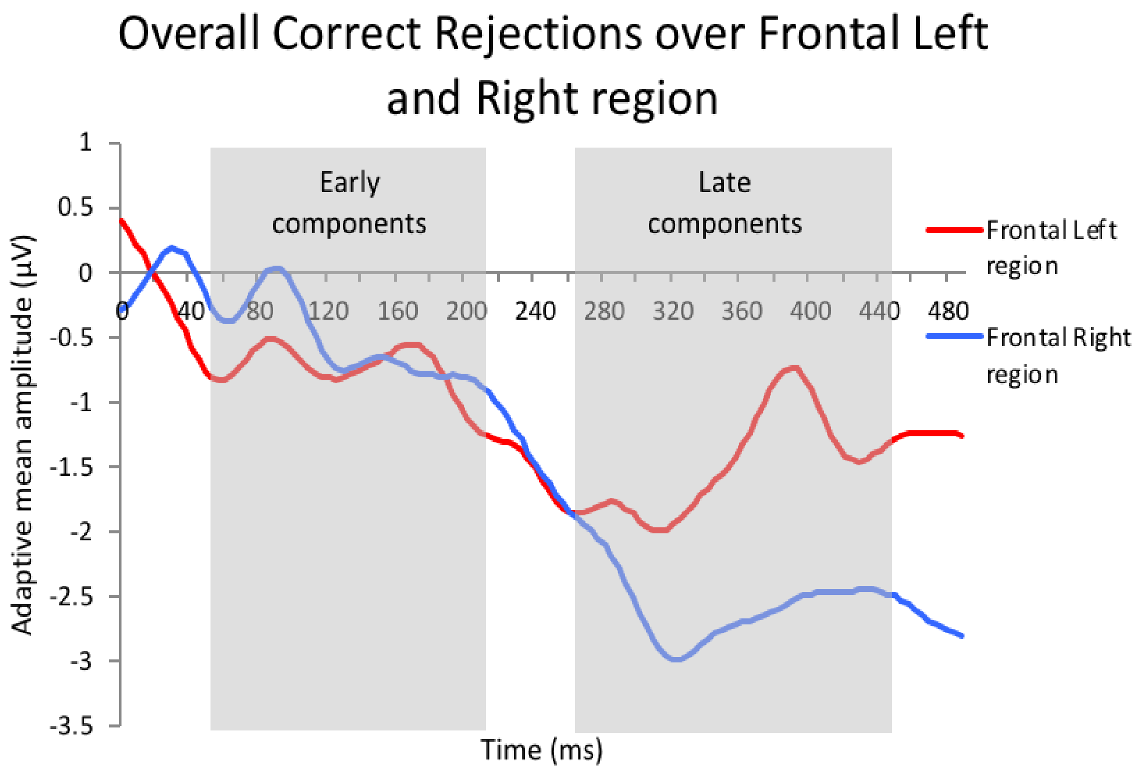


Figure.5.31. The figure shows the ERP waveform for the AMA of Correct Rejection over Left and Right Frontal regions. The AMA is more positive over primarily the Right region during the early components. The AMAs from Left region were more positive for later components.

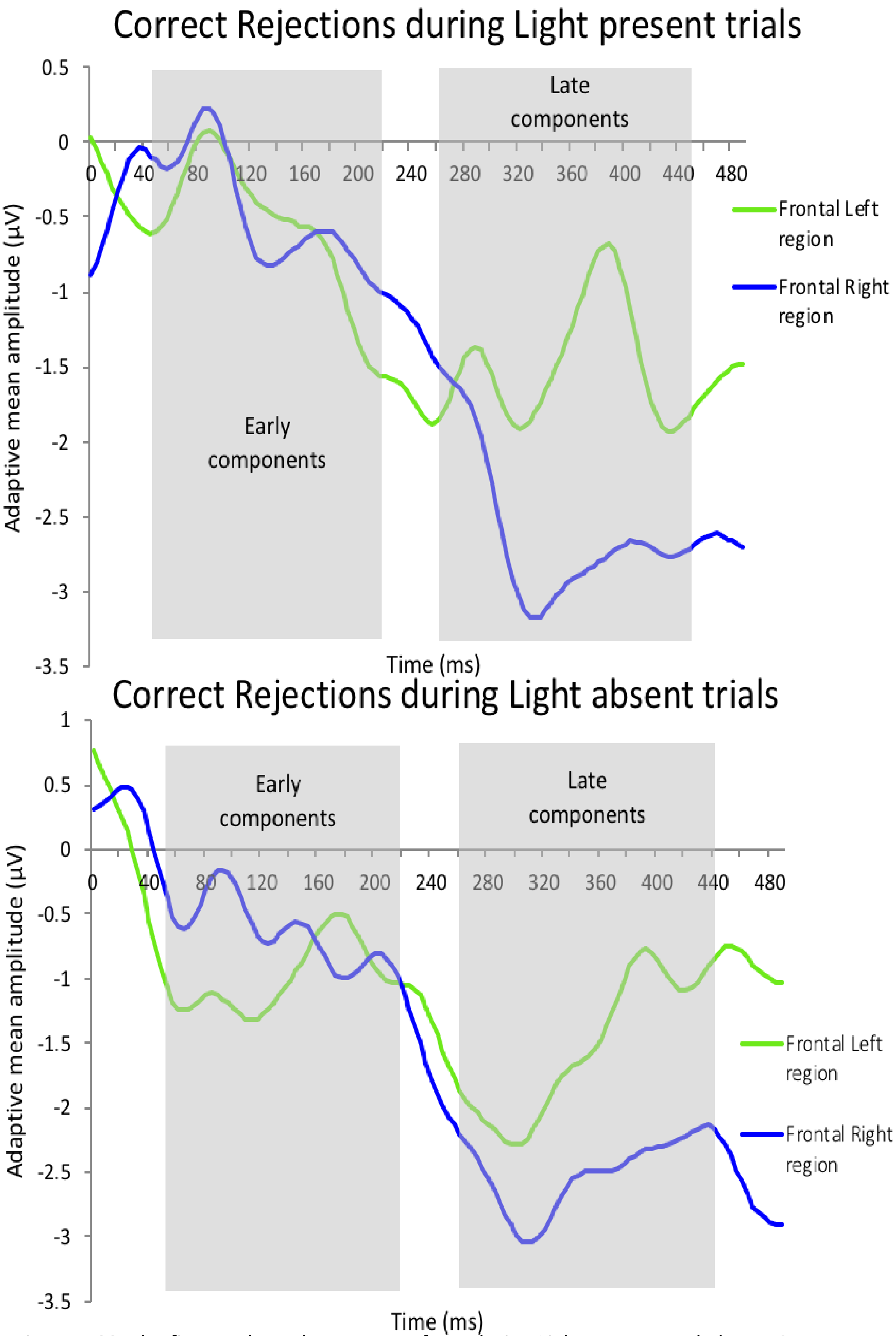


Figure.5.32. The figures show the ERP waveform during Light present and absent Correct Rejection, with the AMA for early and late ERP components over the Frontal regions. The AMA is predominantly more positive over the Right region for early components during Light present and absent conditions. The Left region had more positive AMA for the later components during Light present and absent conditions.

Summary

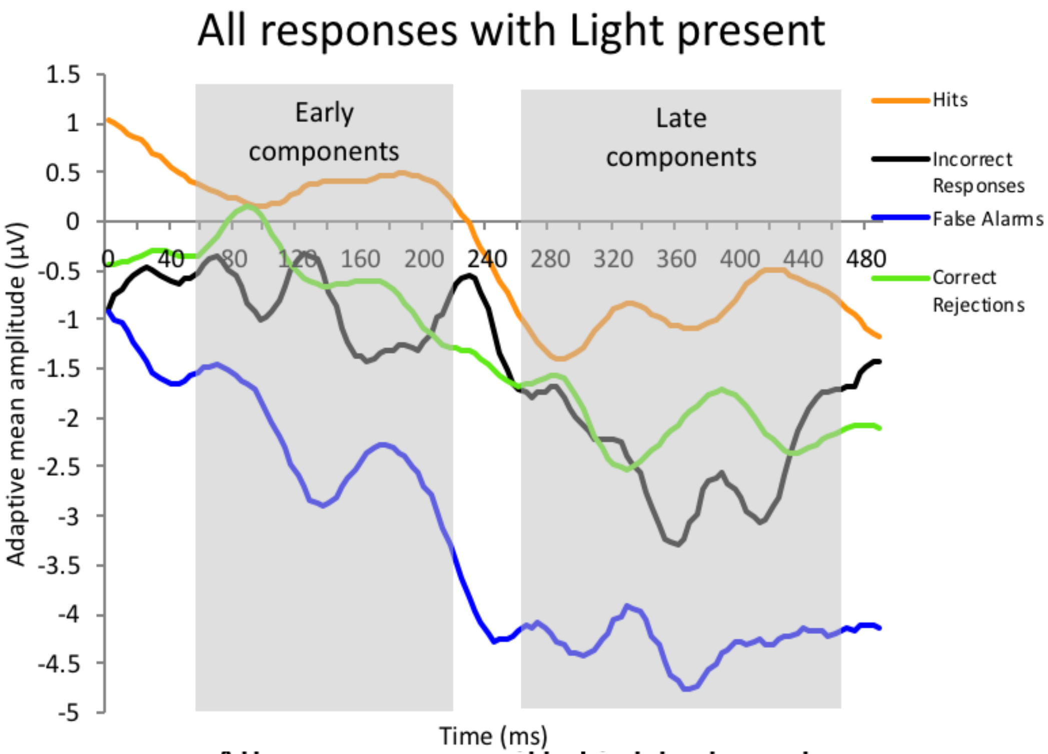
The AMA of Correct Rejections during both Light present and absent conditions over Left region and Right region during Light present only trials had a negative relationship with PHQ-15 scores across all four components of interest. Participants who reported having low somatosensory symptoms had more positive Correct Rejection AMAs during both Light conditions over the Left region and during Light present only trials over the Right region.

The AMA of Correct Rejections over Left and Right regions during both Light conditions was also found to have a negative relationship with SDQ-20 scores across all four components of interest. The Somatoform Dissociation Questionnaire 20 (SDQ-20) measures an individual's tendency to experience pseudo-neurological symptoms. Therefore, participants who were less likely to experience pseudo-neurological symptoms had a more positive AMA of Correct Rejections over all Frontal regions during both Light conditions across all four components of interest.

The AMA of Correct Rejections over Right region during both Light conditions had a negative relationship with HAI-Short scores across all four components of interest. The Health Anxiety Inventory short (HAI-short) is a reliable measure to indicate if participants are suffering from a range of health anxieties including symptoms characteristic of clinical hypochondriasis. Therefore, participants with low levels of health anxieties had a more positive AMA of Correct Rejections for all components of interest from all Frontal regions during both Light conditions.

The AMAs of Correct Rejections over both Frontal regions was found to have a significant negative relationship with the State-Trait Anxiety Inventory (STAI) during both Light conditions across all four components of interest. The STAI-State was used to measure current anxiety of participants at the time of the data collection. The negative relationship indicates that those participants who were not as anxious (low scorers on STAI-State) had more positive AMA for Correct Rejections for all components of interest over both Frontal regions during both Light conditions. The STAI-Trait scale was also found to have a significantly negative relationship with the AMA of Correct Rejections over the Right region during both Light conditions with all components of interest. Therefore, those who scored low on the STAI-Trait, indicate not experiencing any negative feelings/emotions at the time of data collection, had more positive AMA for Correct Rejections over the Right region during both Light conditions. The AMAs of Correct Rejections were found to be greater over the Right region than the Left region for all components of interest.

The Adaptive Mean Amplitude (AMA) for Hit, Incorrect Response, False Alarm and Correct Rejections were compared with each other within each Light condition across all four components of interest from the Frontal region. This was conducted to see how the AMA differed within each Light condition between Hits, Incorrect Responses, False Alarms and Correct Rejections (see figure 5.33, table 5.9 to 5.12 for the paired samples t-test).



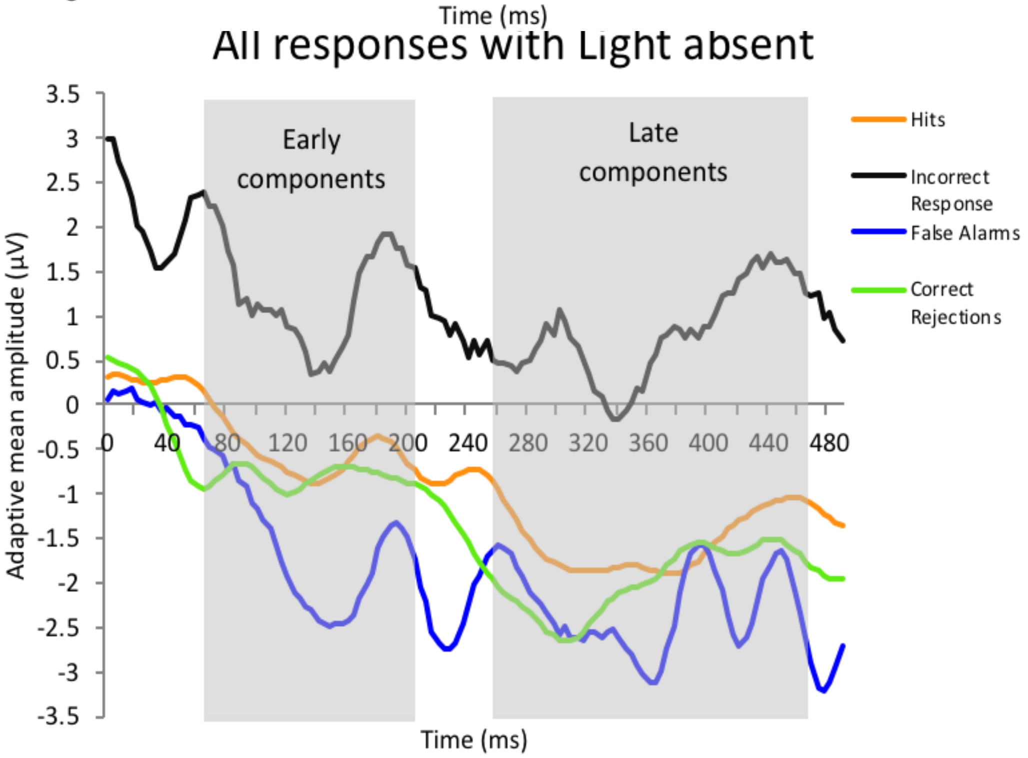


Figure.5.33. The figures show the ERP waveform for Hit, Incorrect Response, False Alarm and Correct Rejections during Light present and absent conditions for the AMA of early and late ERP components over the Frontal regions.

Table.5.9. Paired samples t-test comparing between the AMA of P120 during Light present and absent conditions and Hits, Incorrect Responses, False Alarms and Correct Rejections.

		P120				
Light		*M*	*SD*	*df*	*t*	*p*
Present	Incorrect Response X Hit	-944.73 -1566.22	1451.01 2617.99	23	1.21	.24
	False Alarm X Hit	-924.97 -1566.22	1928.35 2617.99	23	1.45	.16
	Correct Rejection X Hit	-1528.74 -1566.22	2440.48 2617.99	23	0.55	.59
	False Alarm X Incorrect Response	-924.97 -944.73	1928.35 1451.01	23	0.06	.95
	Incorrect Response X Correct Rejection	-944.73 -1528.74	1451.01 2440.48	23	1.23	.23
	False Alarm X Correct Rejection	-924.97 -1528.74	1928.35 2440.48	23	1.55	.13
Absent	Incorrect Response X Hit	-773.19 -1571.65	1804.63 2560.25	23	1.77	.089
	False Alarm X Hit	-765.67 -1571.65	1783.09 2560.25	23	1.80	.085
	Hit X Correct Rejection	-1571.65 -1594.39	2560.25 2634.95	23	0.44	.66
	False Alarm X Incorrect Response	-765.67 -773.19	1783.09 1804.63	23	0.03	.98
	Incorrect Response X Correct Rejection	-773.19 -1594.39	1804.63 2634.95	23	1.74	.10
	False Alarm X Correct Rejection	-765.67 -1594.39	1783.09 2634.95	23	1.78	.089

Table 5.9 shows that P120 AMAs during Light present conditions were not significantly different between the terms. P120 AMAs during Light absent conditions were also not significantly different, thought three of the terms had a trend towards being significantly different. The P120 AMA of Incorrect Responses and False Alarms were trending to be significantly more positive than the P120

AMA of Hits. P120 AMA of False Alarms was also trending to being significantly more positive than the P120 AMA of Correct Rejections.

Table.5.10. Paired samples t-test comparing between the P160 AMA during Light present and absent conditions and Hits, Incorrect Responses, False Alarms and Correct Rejections.

		P160				
Light		*M*	*SD*	*df*	*t*	*p*
Present	Incorrect Response X Hit	-945.59 -1566.13	1451.30 2617.35	23	1.21	.24
	False Alarm X Hit	-925.18 -1566.13	1928.82 2617.35	23	1.45	.16
	Correct Rejection X Hit	-1528.51 -1566.13	2440.05 2617.35	23	0.55	.57
	False Alarm X Incorrect Response	-925.18 -945.59	1928.82 1451.30	23	0.06	.95
	Incorrect Response X Correct Rejection	-945.59 -1528.51	1451.30 2440.05	23	1.23	.23
	False Alarm X Correct Rejection	-925.18 -1528.51	1928.82 2440.05	23	1.55	.13
Absent	Incorrect Response X Hit	-773.59 -1571.78	1804.68 2560.65	23	1.77	.089
	False Alarm X Hit	-765.54 -1571.78	1783.69 2560.65	23	1.80	.085
	Hit X Correct Rejection	-1571.78 -1594.36	2560.65 2634.76	23	0.44	.67
	False Alarm X Incorrect Response	-765.54 -773.59	1783.69 1804.68	23	0.03	.98
	Incorrect Response X Correct Rejection	-773.59 -1594.36	1804.68 2634.76	23	1.74	.10
	False Alarm X Correct Rejection	-765.54 -1594.36	1783.69 2634.76	23	1.78	.089

Table 5.10 shows that P160 AMAs during Light present conditions were not significantly different between the terms. P160 AMAs during Light absent conditions were also not significantly different, thought three of the terms had a trend towards being significantly different. The P160 AMA of Incorrect Responses

and False Alarms were trending to be significantly more positive than the P160 AMA of Hits. P160 AMA of False Alarms was also trending to being significantly more positive than the P160 AMA of Correct Rejections.

Table.5.11. Paired samples t-test comparing between the P360 AMA during Light present and absent conditions and Hits, Incorrect Responses, False Alarms and Correct Rejections.

		P360				
Light		*M*	*SD*	*df*	*t*	*p*
Present	Incorrect Response X Hit	-944.97 -1566.46	1451.47 2618.04	23	1.21	.24
	False Alarm X Hit	-925.47 -1566.46	1929.56 2618.04	23	1.45	.16
	Correct Rejection X Hit	-1528.70 -1566.46	2440.12 2618.04	23	0.55	.59
	False Alarm X Incorrect Response	-925.47 -944.97	1929.56 1451.47	23	0.06	.96
	Incorrect Response X Correct Rejection	-944.97 -1528.70	1451.47 2440.12	23	1.23	.23
	False Alarm X Correct Rejection	-925.47 -1528.70	1929.56 2440.12	23	1.55	.13
Absent	Incorrect Response X Hit	-773.50 -1572.23	1804.99 2560.82	23	1.76	.089
	False Alarm X Hit	-765.80 -1572.23	1784.54 2560.82	23	1.80	.085
	Hit X Correct Rejection	-1572.23 -1594.42	2560.82 2634.31	23	0.43	.67
	False Alarm X Incorrect Response	-765.80 -773.50	1784.54 1804.99	23	0.03	.98
	Incorrect Response X Correct Rejection	-773.50 -1594.42	1804.99 2634.31	23	1.74	.10
	False Alarm X Correct Rejection	-765.80 -1594.42	1784.54 2634.31	23	1.78	.088

Table 5.11 shows that P360 AMAs during Light present conditions were not significantly different between the terms. P360 AMAs during Light absent

conditions were also not significantly different, thought three of the terms had a trend towards being significantly different. The P360 AMA of Incorrect Responses and False Alarms were trending to be significantly more positive than the P360 AMA of Hits. P360 AMA of False Alarms was also trending to being significantly more positive than the P360 AMA of Correct Rejections.

Table.5.12. Paired samples t-test comparing between the P400 AMA during Light present and absent conditions and Hits, Incorrect Responses, False Alarms and Correct Rejections.

		P400				
Light		*M*	*SD*	*Df*	*t*	*p*
Present	Incorrect Response X	-944.37	1451.41	23	1.21	.24
	Hit	-1566.65	2618.74			
	False Alarm X	-925.24	1929.09	23	1.45	.16
	Hit	-1566.65	2618.74			
	Correct Rejection X	-1528.72	2440.00	23	0.55	.59
	Hit	-1566.65	2618.74			
	False Alarm X	-925.24	1929.09	23	0.06	.96
	Incorrect Response	-944.37	1451.41			
	Incorrect Response X	-944.37	1451.41	23	1.24	.23
	Correct Rejection	-1528.72	2440.00			
	False Alarm X	-925.24	1929.09	23	1.55	.13
	Correct Rejection	-1528.72	2440.00			
Absent	Incorrect Response X	-771.85	1805.13	23	1.78	.089
	Hit	-1572.13	2560.70			
	False Alarm X	-765.24	1783.72	23	1.80	.085
	Hit	-1572.13	2560.70			
	Hit X	-1572.13	2560.70	23	0.43	.67
	Correct Rejection	-1594.35	2634.07			
	False Alarm X	-765.24	1783.72	23	0.02	.98
	Incorrect Response	-771.85	1805.13			
	Incorrect Response X	-771.85	1805.13	23	1.74	.09
	Correct Rejection	-1594.35	2634.07			
	False Alarm X	-765.24	1783.72	23	1.78	.088
	Correct Rejection	-1594.35	2634.07			

Table 5.12 shows that P400 AMAs during Light present conditions were not significantly different between the terms. P400 AMAs during Light absent conditions were also not significantly different, thought three of the terms had a

trend towards being significantly different. The P400 AMA of Incorrect Responses and False Alarms were trending to be significantly more positive than the P400 AMA of Hits. P400 AMA of False Alarms was also trending to being significantly more positive than the P400 AMA of Correct Rejections.

Discussion

Signal detection analysis showed that the percentage of False Alarm Rates was greater in Light present trials (see table 5.3) it was not found to be significantly different between light conditions. There was an indication that SDQ-20 may account for some of the False Alarm rates, which could suggest that there is a connection between sensitivity to experience bodily symptoms with reports of False Alarms (Brown et al., 2010; McKenzie et al., 2010; Katzer et al., 2011; McKenzie et al., 2012; Poliakoff et al., in prep).

Participants' sensitivity indices (*d'*) were similar across Light conditions, which is reflected by the greater number of Hit Rates. The analysis of performance across blocks suggests it is not to do with repetition; as participants did not show any progressive improvements in Hit Rates. The SSAS, which measures the tendency to notice and experience vague sensory events as unpleasant, scores have a positive relationship with *d'* scores. This would indicate that those with heightened sensitivity to experience external stimuli as unpleasant were able to easily distinguish between the tactile stimuli.

Participants were also not randomly just responding 'strong' for all trials as their response bias (*c*) was significantly different across Light conditions, and a trend towards significance of Light absent trials being greater than Light present trials, this tells us that participants were more likely to shift their bias to respond with 'strong' when the Light was present than when Light was absent. This trend in the bias towards saying 'strong' in Light present trials is also evident from the larger percentage of Hit Rates and False Alarm Rates (see table 5.3). Individual differences of the tendency to experience pseudo neurological symptoms, as measured by questionnaire SDQ-20, was found to significantly account for partial response bias (*c*) scores.

The impact of individual differences, as accounted for by SDQ-20 and SSAS do provide a relationship with behavioural and ERP data. This strengthens the findings of the study as individual differences in sensitivity to external (exteroceptive) and internal (introceptive) factors do play a role on an individual's susceptibility to experience pseudo-neurological events.

The ERP components for this study were found to be within the expected time frame of between 100ms to 450ms as earlier somatosensory evoked potential EEG studies indicated (Michie, Bearpark, Crawford, Glue, 1987; Eimer and Driver, 2000; Eimer and Forster, 2003; Zopf et al. 2004; Schubert et al. 2008; Yamaguchi and Knight, 1991; Zhu, Disbrow, Zumer, McGonigle, Nagarajan, 2007). The present study found similar findings in timings of ERP components as that of Poliakoff et al's (in prep) investigation with SSDT; which is a slightly different to the SSDiT.

The present ERP data that shows both early and late components during erroneous responses (False Alarms and Incorrect Responses) could be evidence of sensory information being processed (early components) and the later components relating to decision making mechanisms such as the error predication type mechanisms during misperceptions of tactile sensory information (de Lafuente and Romo, 2005, 2006; Michie et al. 1987; Eimer and Driver, 2000; Eimer and Forster, 2003; Zopf et al. 2004; Schubert et al. 2008). Furthermore, previous ERP studies have shown that the scalp topography identified the early sensory components (usually between 50 – 180msec) arise over somatosensory areas and show reversal across central sulcus; later cognitive components (300-400ms) are found to be present over different regions of the scalp, including the Frontal, Parietal and Temporal areas, and that this activity is bilateral around medial and parietal areas (Ishibashi, Tobimatsu, Shigeto, Morioka, Yamamoto, Fukui, 2000; Cardini, Longo, Driver, Haggard, 2012). Additionally, other EEG somatosensory data has indicated larger activations over Posterior Medial and Parietal regions (Ishibashi et al., 2000; Cardini, Longo, Driver, Haggard, 2012). Upon visual inspection of both Parietal and Frontal regions of the present data, it appears that there is a presence of later ERP components throughout all of the response types. Over Parietal regions there are more visually defined components present at both early and late time points during erroneous responses (Incorrect response, figure 5.8 – 5.10; False Alarm, figure 5.11 – 5.13; for view in one figure see figure 5.17).

The Adaptive Mean Amplitudes (AMA) were found to be significantly more positive in the right Parietal region when tactile stimuli were correctly judged (Hits and Correct rejections) than with incorrect judgments (Incorrect Response and False Alarm). The AMAs over the Frontal region were significantly more positive over the Frontal Right region than the Frontal Left region for all components of interest for Hits, Incorrect Responses, False Alarms and Correct Rejections. The Parietal AMAs during Hits were significantly greater over the right parietal region. The Parietal AMAs of Hits (correct identification as 'strong') and Correct Rejections (correct identification as 'weak') for the Right Parietal region had a positive relationship with SDQ-20 scores in both Light conditions at each component of interest. This would indicate that the electrophysiological response over the

Parietal Right region to correctly identifying stimuli was greater during the four components of interest (P120, P160, P360 and P400) with participants who had a greater tendency to experience pseudo neurological symptoms (larger SDQ-20 score). The Parietal AMA of Hits was greater for all components of interest (both early and late components (table 5.9-5.12).

Interestingly, for the AMAs for Correct Rejections from the Frontal region had a significantly negative relationship with SDQ-20; participants who were less likely to experience pseudo-neurological symptoms had a more positive AMA over all Frontal regions during both Light conditions across all four components of interest. No other relationship was found with SDQ-20 and the Frontal Region AMA of Hits, Incorrect Responses or False Alarms.

The Frontal Regions AMA of Correct Rejections had significantly negative relationships with all questionnaires. Hits and Correct Rejections did have a significant negative relationship with STAI-State and Trait scores. This indicates that those participants who were not as anxious (low scorers on STAI-State) had more positive AMA for Correct Rejections for all components of interest over both Frontal regions during both Light conditions. Those who scored low on the STAI-Trait, indicate not experiencing any negative feelings/emotions at the time of data collection, had more positive AMA for Correct Rejections over the Frontal Right region during both Light conditions. Furthermore, the Health Anxiety Inventory short (HAI-short) had a significantly negative relationship with the Frontal region AMA of Correct Rejections. The HAI-short is a reliable measure to indicate if participants are suffering from a range of health anxieties including symptoms characteristic of clinical hypochondriasis. Therefore, participants with low levels of health anxieties had a more positive AMA of Correct Rejections for all components of interest from all Frontal regions during both Light conditions. The Frontal AMA of Correct Rejections had a negative relationship with PHQ-15 scores across all four components of interest. Participants who reported having low somatosensory symptoms (low PHQ-15 score) had more positive Correct Rejection AMAs during both Light conditions over the Front Left region and during Light present only trials over the Front Right region.

PHQ-15 scores were also found to have a significantly negative relationship with Frontal region AMAs of Incorrect Responses. Participants who reported having low somatosensory symptoms (low PHQ-15 scores) had a more positive Incorrect Response AMA during both Light conditions over the Right Frontal region. Similar to Incorrect Responses, the Frontal region AMA of False Alarms also had a negative relationship with PHQ-15; participants who reported having low somatosensory symptoms had a more positive False Alarm AMA during both Light conditions over both Left and Right Frontal regions.

Later ERP components (around P300, P400) have been associated with decision mechanisms that may have arisen due to the attention given to the stimuli (visual and weighted by the task at hand; participants gave to the site of stimulation (Bruyant, Garcia-Larrea, Maugier, 1993; Kida, Nishihira, Hatta, Wasaka, 2003). For the SSDiT paradigm participants view their left index finger and during trials. The focus participants give to the site of stimulation can vary between individuals. Some people are more susceptible to task-irrelevant sensory noise when attending to low-level threshold sensory stimuli. Participants were instructed to attend to the tactile stimulus as they are conducting discrimination judgements. However, as the SDQ-20 questionnaire has shown, a relationship between high SDQ0-20 scorers, and greater False Alarm rates exists as those participants are more likely to experience illusory somatosensory illusory effects; especially during Light present trials. These errors could be occurring due to the early processing of non-relevant sensory information being erroneously perceived as relevant and affecting the later processing of attended sensory stimuli. This erroneous incorporation of early sensory information could indicate that there is a form of feedback and feed forward mechanisms, supporting the proposed theory of MUS by Brown (2004). The ERP findings of this present investigation along with those of past findings do indicate top-down modulation being present during the SSDiT affecting bottom-up sensory information of the tactile stimuli.

The findings from the present ERP investigation into the SSDiT and information from previous ERP SSDT investigation by Poliakoff et al. (in prep) show that there is strong evidence of top-down reliance with the generation of illusory somatosensory sensations. Poliakoff et al. (in prep) further concluded that the significance at the later time point is indicative of attention possibly projecting the signal to sensory areas (Burton et al., 1999) through the paracingulate gyrus/sulcus and the frontal pole.

The importance of interoceptive (top-down) and exteroceptive (bottom-up) modulation during the SSDiT needs to be explored in more detail. The next stage would be to understand the extent prediction errors and bias of expectation has on the illusory effects of the SSDiT. To help understand the extent of reliance of top-down modulation of bottom-up sensory information during the SSDiT the MIRAGE augmented reality system will be used to manipulate a live video stream of participants' real hand while undertaking the SSDiT. Bottom-up distorted visual information of the hand (noise) would impact the signal detection data for the SSDiT of each condition. For the illusory effects of the SSDiT to be present participants' must incorporate the distorted image and would affect participants' responses.

Chapter six

An investigation of the effect of visual distortion on bottom-up and top-down modulation during the SSDiT

It is understood that both interoception (awareness of stimulus/self from within one's body) and exteroceptive (awareness of stimulus from outside of one's body/from the environment) plays a part with experiencing multisensory illusory sensations. These multisensory processes take place at different stages of processing and can be affected different cognitive processes such as attention and memory (Talsma, 2015). The processing relationship between different internal mechanisms (not just sensory) processing must be dynamic in order for to maintain a balanced representation for the bodily self (Seth, 2013; Tsakiris, 2017). To help bridge theories of perceptual processing, aspects of both interoception and exteroceptive mechanisms have been unified by the use of predictive coding theory.

The unified theory of bodily self states that incoming sensory data (bottom up) are compared with internal models (top-down) held by the body. The integration between sensory systems occurs due to top-down information actively maintaining a mental model of the environment based on the concepts of environmental probabilities (Talsma, 2015). Prediction errors occur when the incoming data does not match the internally held predictions. A dynamic evaluation system must be working to adjust predictions of the self, based on the actual sensory information, which would also adjust initial sensory processing (Talsma, 2015). This would mean that the image held of the bodily self would also need to be flexible (Seth & Critchley, 2013; Seth, 2013; Apps & Tsakiris, 2014; Talsma, 2015; Tsakiris, 2017). The individual's sensory information is processed in a probabilistic manner, by adapting a model that best fits the image of the self, which is most likely to be 'me' (Seth & Critchley, 2013; Seth, 2013; Apps & Tsakiris, 2014).

Integration of top-down (estimated predictions of the body) with uni-modal bottom-up (prediction errors) would create the probabilistic representations of self (Apps & Tsakiris, 2014; Moutoussis, Fearon, El-Deredy, Dolan, & Friston, 2014; Tsakiris, 2017). The signals and predictions from different modalities would be utilised to reduce/account for errors detected in another modality, such as amodal assumptions (predictions). This hierarchical model would therefore, integrate interoceptive and exteroceptive pathways for there to be a body self representation (Seth, 2013; Moutoussis et al., 2014). Predictive coding model would see continuous interaction in the form of prediction errors at each level of perceptual representation (via uni-modal processing and bottom-up data). Data processing within this model would go through active inference, a feedback and feed forward mechanism between internal predictions of stimuli from different modalities (top-down) and early uni-modal (bottom-up) sensory processing (Kennett, Taylor-Clarke, Haggard, 2001; Taylor-Clarke, Kennett, & Haggard, 2002; Busse, Roberts, Crist, Weissman, Woldorff, 2005; Lloyd et al., 2008; Mirams et al. 2010; Van der Burg, Talsma, Olivers, Hickey, Theeuwes, 2011; Seth, 2013; Moutoussis et al., 2014; Talsma, 2015; Tsakiris, 2017). Predictions already held (and subsequent prediction errors) or newly modified predictions would vary in their level of reliability depending on the quality of incoming sensory signals (bottom-up). Sensory signals compatible with few potential predictions would have high precision and would consist of low noise (higher reliability; Apps & Tsakiris, 2014; Tsakiris, 2017).

The SSDiT presents participants with a tactile pulse paired with simultaneous light present or absent trials. The illusory sensations from the SSDiT are reported more during light present trials. Participants are asked to view their stimulated finger and only report the intensity of the tactile pulse they feel. Predictions based on this question would result in top-down expectations of the stimuli. Participants maybe erroneously accept the uni-modal (bottom-up) visual noise of the light information into their probability predictions of the self (top-down) during the tactile discrimination task; resulting in bottom-up information altering top-down interpretations, resulting in a False Alarm. As False Alarm rate differ between each trial and vary between participants, the incorporation of these prediction errors into generating a representation of self must also reflect a mechanism of active inference. This mechanism of being able to process interoceptive and exteroceptive information to eliminate prediction errors maybe affected by the prior experience of the participant, their individual differences to process sensory information. The level of sensitivity and awareness one is to exteroceptive and interoceptive information may result in them not being able to 'filter' the visual noise of the simultaneous light presentation from the tactile pulse and other visual information regarding the site of stimulation. Viewing the sight of stimulation has been found to affect tactile detection (Harris, Arabzadeh, Moore, Clifford, 2007; Kennett et al., 2001; Taylor-Clarke et al., 2002).

Harris, Arabzadeh, Moore, Clifford (2007) investigated how non-informative vision of the site of stimulation affects tactile detection during a two-alternative forced-choice (2-AFC) detection and discrimination task. During experiment 1 – 4 the vibration device and hand were hidden from the participants view by a mirror. The mirror showed the participants' left hand reflect to appear as the right hand or the mirror was rotated to show an opaque surface. During the fifth experiment participants were able to view their right hand and the vibrating device or were covered by a curtain. Participants had to report which of two temporal intervals contained a vibration (detection task), or which interval contained the stronger of the two vibrations (discrimination task). Participants were presented with a single vibration occurring during one of the two intervals. Participants verbally reported which interval contained the vibration. Amplitude discrimination thresholds were measured in experiment 2 and 4. Participants were presented with two randomised vibrations, the base vibration was 20µm and the comparison amplitude was always higher. Experiment 5 replicated experiments 1 – 4 as a within participants design. All experiment 5 procedures were the same as those of 1 - 4 except vision was manipulated by placing a black cloth for the no vision conditions. Harris et al. (2007) found that viewing the site of stimulation would impair participants' detection and discrimination of near-threshold tactile stimuli; this is different to previous findings (Kennett et al., 2001; Taylor-Clarke et al., 2002). Furthermore, vision of site of stimulation also improved participants' discrimination between above threshold stimuli. This enhancement effect was also found when viewing different sizes of the site of stimulation, an increase in visual size of the site of stimulation resulted in greater sensitivity to the tactile stimuli (Kennet et al., 2001). Harris et al.’s (2007) additional finding of non-informative vision impairing the discrimination of near threshold tactile stimuli could be due to several factors. Vision of site of stimulation can shift receptive fields from receptor-centred representations to object-based representations (Kennett et al., 2001; Taylor-Clarke et al., 2004). This would result in visual receptors being active, reducing the initial level of activation needed for identifying tactile sensations. Furthermore, the tactile stimuli presentation for Harris et al.’s (2007) experiment 5, in which they found this impairment effect, was for one second for each of the two presentations in the discrimination task; the duration was 150ms for Kennett et al. (2001) and Tylor-Clarke et al.’s (2002) studies. This exposure to suprathreshold (larger amplitude) tactile stimulus may have resulted in the summation of receptors to the more robust stimulus, resulting in the loss in sensitivity for near-threshold stimuli and an improvement to discriminate the suprathreshold tactile stimuli (Harris et al., 2007).

Kennett et al. (2001) investigate how viewing site of stimulation can affect tactile perception during a two-point discrimination task. Participants were lightly tapped on their right arm by either one stimulus or two simultaneous spatially separated stimuli; the distance between the stimuli was changed according to how they were performing (closer together or further apart). Participants were asked to verbally respond to when they could distinguish between one and two tactile stimuli. This was done for four different experimental conditions: visible, participants were able to view their arm and site of stimulation; magnified, a x2.5 magnification of the visible condition; visibility of neutral object, a white plastic cylinder was place outside the box where the viewed condition would be (no arm was visible); darkness, participants were not able to view the site of stimulation (the inside of the box was not illuminated). Kennett et al. (2001) found that participants' sensitivity to detect the tactile stimuli was greater during visible conditions than in darkness, their threshold was lower (mean distance between stimulation was lower) during visual condition. Performance was not improved by viewing a neutral object at the arm's location. However, tactile sensitivity was further enhanced when viewing a magnified view of the arm. Kennett et al. (2001) suggest that this visual enhancement of touch may point to online reorganisation of tactile receptive fields and occurs via feedback from uni-modal areas in the brain. Top-down modulation maybe affected by bottom-up sensory information. These results could provide evidence to cross-modal effect of vision influencing small tactile sensory detection, via feedback to early somatosensory processing (Driver et al., 2000; Kennett et al., 2001; Seth, 2013; Moutoussis et al., 2014; Talsma, 2015; Tsakiris, 2017).

The susceptibility of participants to experience these illusory effects has been in part to correlate with their susceptibility to experience somatoform sensations. McKenzie and Newport (2015) investigated whether individuals with MUS traits would be more susceptible to visual illusions inducing tactile sensations on the skin when none are presented. Participants were seating and viewed a real time video of their own hand, or a digitally altered live view of their hand with darker luminance or an effect of static (pixilation) on it (crawling skin illusion). They recorded participants' subjective reports of strength for the physical sensations during each of the visual conditions on a numerical scale and compared their subjective reports to their individual measure of somatoform dissociation (SDQ-20). They found that participants who had a greater SDQ-20 score were more susceptible to somatic sensations across all visual conditions and felt less ownership towards their viewed hand. These findings suggest that high scoring SDQ-20 individuals would report more False Alarm Rates (Nijenhuis et. al., 1996; Brown et al., 2010; Poliakoff et al., Submitted; Chapter 5). McKenzie and Newport (2015) analysed their data further by removing the reports of the higher SDQ-20 participants during the crawling skin condition. They found that during the baseline no visual manipulation condition also had higher ratings of illusory sensations. This may be due to these participants having a greater baseline sensitivity level due to interceptive noise being misinterpreted and reporting false feelings of sensations. The researchers concluded that their findings do strengthen the notion that MUS occur due to increased reliance on top-down processing when interpreting bottom-up sensory information (McKenzie et al., 2014; Mirams et al., 2010. Brown, 2004).

The SSDiT is a technique that has shown to present somatosensory illusory effects. Participants' view their left index finger (site of stimulation) during SSDiT trials, and as research has shown, attention to site of stimulation can enhance detection and discrimination of tactile stimuli. Furthermore, ERP-SSDiT data (Chapter 5) suggests that there are two separate mechanisms that are working to generate/maintain these illusory effects. The current study aimed to investigate whether the illusory effects found in the SSDiT are due to the influence of pre-held perceptual concepts or beliefs (i.e. top-down factors) affecting how the bottom-up sensory information is processed; could it occur due to competing beliefs that lead to the misperception of tactile stimuli. The present study aimed to investigate how manipulation of bottom-up sensory could affect participants' tendency to False Alarm on the SSDiT, by augmenting the view of stimulation sight. Creating augmented visual 'information' at the site of stimulation would help further the understanding of how illusory sensation could be generated and maintained. The present study would use the skin crawling (pixelated) MIRAGE illusion to manipulate bottom-up sensory information to investigate how this would affect the SSDiT data.

The unified theory of the self can be used to account for the relationship between interoceptive and exteroceptive representations of one's body (Seth & Critchley, 2013; Seth, 2013; Talsma, 2015; Apps & Tsakiris, 2014; Tsakiris, 2017). The prediction errors formed by the pixelated visual condition would need to be reduced and participants would have to adopt their existing percept of self to be able to accept this new model as their own. If they did not do this their susceptibility to report illusory sensations during the SSDiT would be expected to be reduced. However, if the False Alarm rate was higher or similar to that of no visual manipulation, one could assume that participants adapted their internal model to accept what they see. When visual information (bottom-up) no longer matches the then most current model of the self, these outdated beliefs would lead to more errors. As a result, pre-held concept (top-down) would be updated to a model that has less errors at the time (e.g., which prediction error best fits the concept of the self). As the findings of McKenzie and Newport (2015) have suggested, those who score higher on the SDQ-20 would experience illusorily sensations due to the visually pixelated image they see, would this sensory information (visual noise) affect the illusory enhancement effect of the SSDiT on participants' signal detection data (Hit and False Alarm rates, sensitivity indices [*d′*] and response bias [*c*]). False Alarm rates during the pixelated and no visual MIRAGE conditions would help indicate the level of body ownership; for the illusory effect of the SSDiT to be present participants must incorporate the visual manipulations as their own limb. Furthermore, if these visual conditions affect participants' sensitivity indices, they could be lower due to the visual noise of the Pixelated (static) visual condition; this could result in a more conservative response bias. Furthermore, how would sensitivity indices differ between each visual condition, understanding more about what aspects of the SSDiT affect different participants in different ways, how much does view of stimulation site affect individuals' sensitivity to experience the illusory effects of the SSDiT? How would visibility to Normal SSDiT visual conditions differ to when participants are presented with distorted visual conditions, would this additional distorted body image affect participants' False Alarm Rates. Observing how participants' signal detection data differs between visual conditions in relation to their ability to experience somatoform symptoms may be able to provide a greater understanding of how MUS may experience visuo-tactile illusory effects.

Method

Design

A 2 [Strength of pulse (Strong, Weak)] x2 [Light (present, absent)] x3 [Visual Condition (Vision, No vision and Pixelated)] within-participants design was used. Participants' responses [Response (Strongest, Strong, Weak, Weakest)] were recorded as a judgement of the tactile pulse strength they felt. Experimental trials were pseudo randomised following the Vision condition (Vc), between No Vision condition (NVc) and Pixelated Vision conditions (PVc); participant key presses were rotated between thresholding and main experiment response keys.

Participants

30 participants (9 Male), mean age 21 years (SD = 3.08) took part in this study. All participants were right-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). All participants had normal or corrected-to normal vision and none reported any sensory deficits. Full informed consent was obtained from each participant, after written and verbal explanations of the tasks were provided. All procedures were approved by the University of Nottingham Malaysia Campus Research Ethics Committee. Participants were recruited at the University of Nottingham Malaysia Campus, and received a course credit or RM5 in return for their participation.

To account for the strong relationship between sensitivity of experiencing bodily symptoms with reports of False Alarm (Brown et al., 2010; McKenzie et al., 2010; Katzer et al., 2011; McKenzie et al., 2012; Poliakoff et al., submitted), five questionnaires (SDQ-20, SSAS, PHQ-15, HAI-short, STAI) were used to determine participants' level of sensitivity to internal and external factors. The scores from these questionnaires were then be used as covariates to determine if the results found can be attributed to individual differences of sensitivity (see table 6.1 for the means of the questionnaires; see Chapter 2.1.2 for full details of the questionnaires).

Table.6.1. Mean and range of scores across all questionnaires (± 1 SD).

	SDQ 20	SSAS	PHQ 15	HAI Short	STAI - State	STAI - Trait
Mean	22.30	28.93	5.83	31.93	35.67	37.97
(SD)	(4.41)	(5.61)	(3.46)	(5.66)	(8.99)	(9.27)
Range	20 – 41	15 – 37	1 – 14	23 – 49	22 – 55	21 – 57

Stimulus and Materials

Presentation of stimuli and instructions were controlled by a HP desktop running Windows 7 enterprise 32bit operating system with a HP Compaq LE1902x 18.5 inch LED backlit LCD monitor. Participants responded by pressing keys on a standard QWERTY HP keyboard. The instructions and onscreen prompts were adapted to be visible in the gap between the MIRAGE viewing screen and the top of the MIRAGE system, there is a large rectangular opening on both participant and experimenter sides; the viewing area on the participants side is where they look down at their video hand (see figure 6.3 for participant view). The prompt screen was placed directly behind participants' left hand, as with the SSDiT experimental set ups used in the previous chapters.

SSDiT

See Chapter 2, for detailed SSDiT equipment information. See figure 6.2 and 6.3 below for the experimental set up with the SSDiT stimulus array within the MIRAGE. A fixation mark was placed above the Tactor where participants were told to look when prompted to do so during trials. A fixation mark was used so participants would have something to look towards during all visual manipulations. In the previous SSDiT setups, participants were instructed to look at their finger when the Green arrow appeared. However, the wording had to be changed for the experiment as their hand was not always visible, therefore participants were instructed to look towards the fixation mark when the green arrow appeared, thus keep their gaze consistent within all visual conditions; the marker was placed directly above the Tactor and was not touching their finger or the Tactor. A digital audio player (iPod Nono) with Philips SHP 1900 stereo over ear headphones were used to play white noise to participants during thresholding and experimental trials; this was to mask the sound of the Tactor and any background noises. Participants were asked if they could hear any external noise while the white noise played, if they did the volume was increased slightly until they could not hear any ambient sounds. The white noise was turned off during breaks.

MIRAGE

The visual manipulations were created and conducted using the MIRAGE augmented reality system (Newport et al., 2010; University of Nottingham) via a bespoke program (LabView: National Instruments 2012 www.ni.com/data-acquisition). See chapter 2.3 for full MIRAGE equipment information. The Vision condition (Vc, Figure 6.1.a) consisted of participants viewing an unaltered live video image of their arm/hand and SSDiT stimulus array. The No Vision condition (NVc, figure 6.1.b) consisted of participants viewing a masked video image of their hand/arm that was black (matching the background) and participants were only able to see the live stimulus array (the LED light) with fixation mark. The Pixelated Vision condition (PVc, figure 6.1.c) consisted of a pixilation effect occurring over the masked off area, which was only applied to the participants' hand/arm area that they could view in the MIRAGE system. The live video image is presented from the same perspective of where the real had would be (from the participants' perspective).

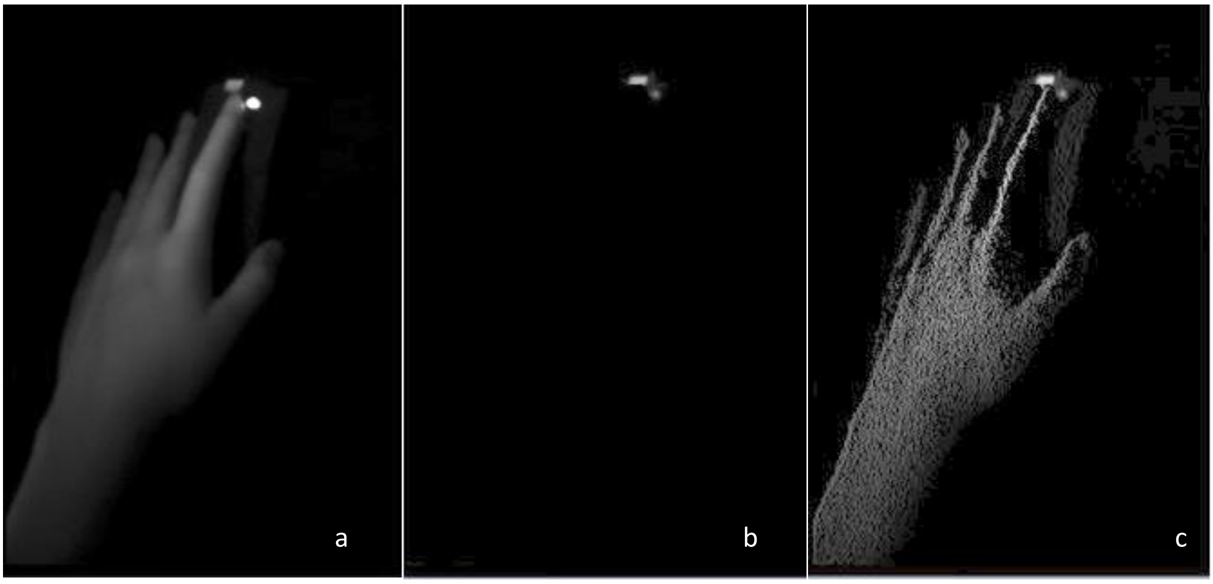


Figure.6.1. Showing the three different Visual conditions: a, Vision (Vc); b, No Vision (NVc); c, Pixelated Vison (PVc). These images are presented from the participants' perspective, as they would have seen it. The images have been brightened to show the visual differences between the conditions in printed form.

Procedure

Participants were seated at the MIRAGE system and were asked to place their left hand into the MIRAGE system. They were instructed to move their fingers while they looked down to view their video hand (see figure 6.3 for participants view of their hand); there were no visual manipulations present during this period. Participants gave verbal feedback to an adapted Acclimatisation questionnaire (Newport et al. 2010), which consisted of six items asking questions such as 'It seemed like the image of the hand was my own' and 'It seemed like the image of the hand belonged to me'. This was only used to assess the extent participants believing the live video image they saw was truly their actual real had, and was not used for further analysis.

Participants did this for two minutes and were asked the Acclimatisation questions. This procedure was conducted to i) familiarise the participants of what their hand would look like and ii) to confirm that participants did accept the live video view of their hand to be true and to be theirs. After this acclimatisation period participants placed the headphones on and their left index finger was attached to the Tactor using a double-sided adhesive circle (see figure 6.2 for SSDiT stimulus array and participants' left index finger placement on the Tactor), this was to minimise movement during the experiment. During all thresholding and experimental trials participants listened to white noise through a digital audio player (iPod Nano) with Philips SHP 1900 stereo over ear headphones; this was to mask the sound of the Tactor and any background or experimentally informative noises. Participants were asked if they could hear any external noise while the white noise played, if they did the volume was increased slightly until they could not hear any ambient sounds. Participants could have a short rest between each block of trials, during which time the white noise was turned off.

Thresholding

Each participant underwent a thresholding procedure before starting the experiment. A green arrow cue on the monitor was presented at the start of each trial, prompting the participant to look at the fixation mark above their left index finger on the MIRAGE video display.

The thresholding procedure consisted of participants being presented with a block of 13 trials, consisting of 10 tactile (touch) present and 3 touch absent randomly presented trials, with each trial lasting 1020ms. An on screen green arrow indicated the start of each trial, prompting the participant to look at their left index finger. There was a 500ms wait before the onset of stimuli from the cue: during touch present trials a 20ms tactile stimulus was delivered to the participants' left index finger, followed by a 500ms wait; touch absent trials were the same as touch present trials except there was no tactile stimuli presentation during the 20ms and an empty trial was presented lasting the same duration of 1020ms (see figure 6.4 for the experimental flow diagram depicting these timings). After each of these trials participants were prompted on the monitor to indicate whether they had felt a tactile pulse by pressing one of two keys on the number pad of the keyboard, "Y" for yes and "N" for no. Stickers with these letters printed on were placed on number '3' and '9' to denote the 'Yes' and 'No' response; the keyboard was rotated by 90 degrees from the normal functional orientation to make it easier for participants to press these keys. At the end of each block the experimenter was presented with the total correct (yes) responses and the tactile intensity was adjusted according to the staircase method described above. Participants had to responded 'Yes' on 40% to 60% of touch present trials (correctly report 4 to 6 tactile present trials) during a thresholding block, if they failed to report the desired number of touch present trials the intensity of the tactile stimulus was adjusted by turning the Tactor dial at the front of the TactAmp in small increments to change the amplitude of the output signal in the Tactor; clockwise to increase and anticlockwise to decrease amplitude after which a new threshold block would commence. Participants were required to respond 'Yes' on 40% to 60% of touch present trials during three consecutive thresholding blocks to be considered as having found their 50% threshold level. Participants only progressed to the experimental blocks after they had met these thresholding requirements. Over course of the experimental session the threshold level for a participant can change due to fatigue and tactile drift (McKenzie et al., 2010). Therefore, a further thresholding procedure was used at the mid-point of the experiment to make sure that participants were within the 50% threshold level.

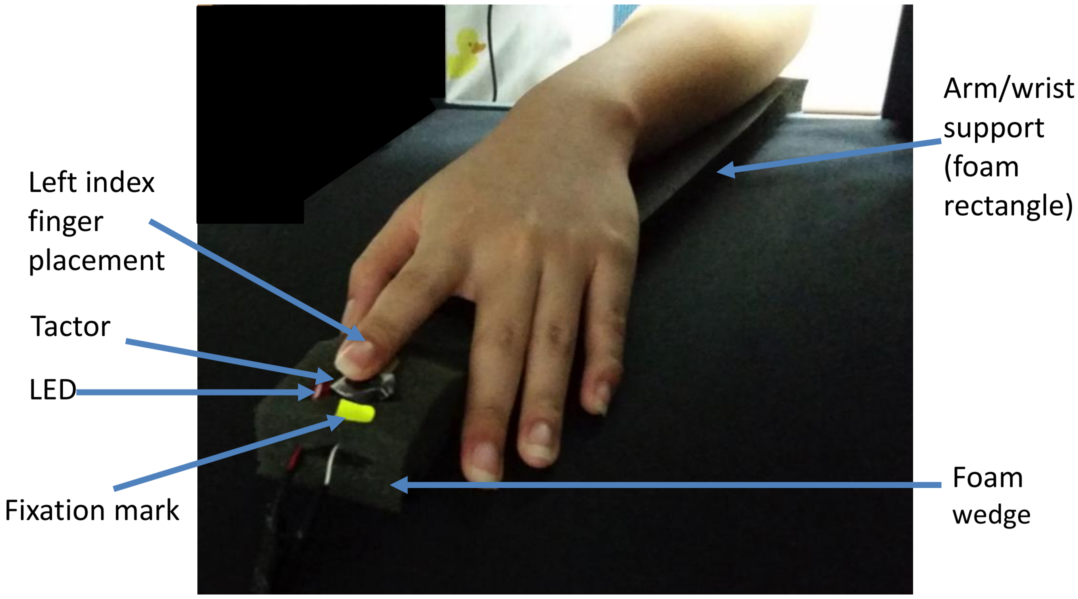


Figure.6.2. SSDiT stimulus array set up within the MIRAGE system.

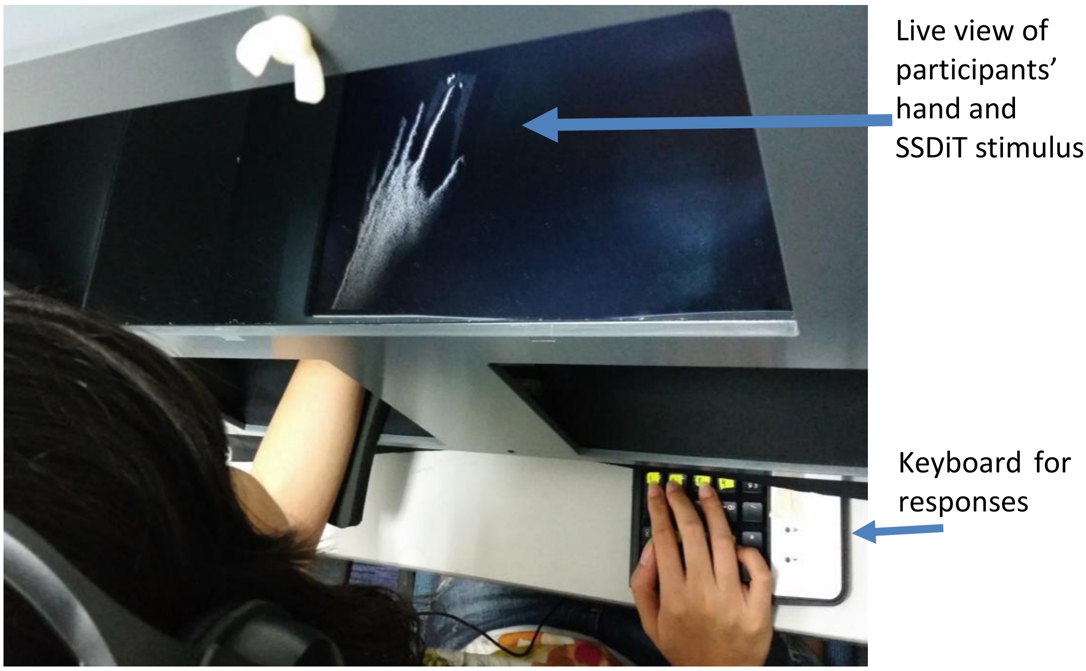


Figure.6.3. Experimental setup of SSDiT and MIRAGE from the participant side.

SSDiT Experiment

Each of the three visual experimental conditions (Vision, Vc; No Vision, NVc; Pixelated Vision, PVc) consisted of 160 trials (a total of 480 over all 3 visual conditions). Each of these 160 trials consisted of two blocks of blocks 80 trials; these consisted of 40 Light present and 40 Light absent trials for both Strong and Weak tactile stimuli strengths (see figure 6.4 for diagram of experimental design). These were presented in a pseudo-randomised order within each visual condition experimental session. Participants were asked to report the intensity of the tactile pulse they felt by pressing one of four numerical keys: 'Strongest; 'Strong; 'Weak; 'Weakest'. All participants underwent the Vision condition (Vc) first and then visual experimental blocks were alternated between No Vision (NVc) and Pixelated Vision (PVc) conditions between each participant. Participants had a break when the visual conditions were changed, during which time the white noise sound was turned off and the view of their hand was disabled (MIRAGE view screen was off). This was to reduce any residual effects of the previous visual manipulation and to help reduce any fatigue. During this time participants were asked how they felt as the examiner applied/setup the next visual condition manipulation on the experimental computer.

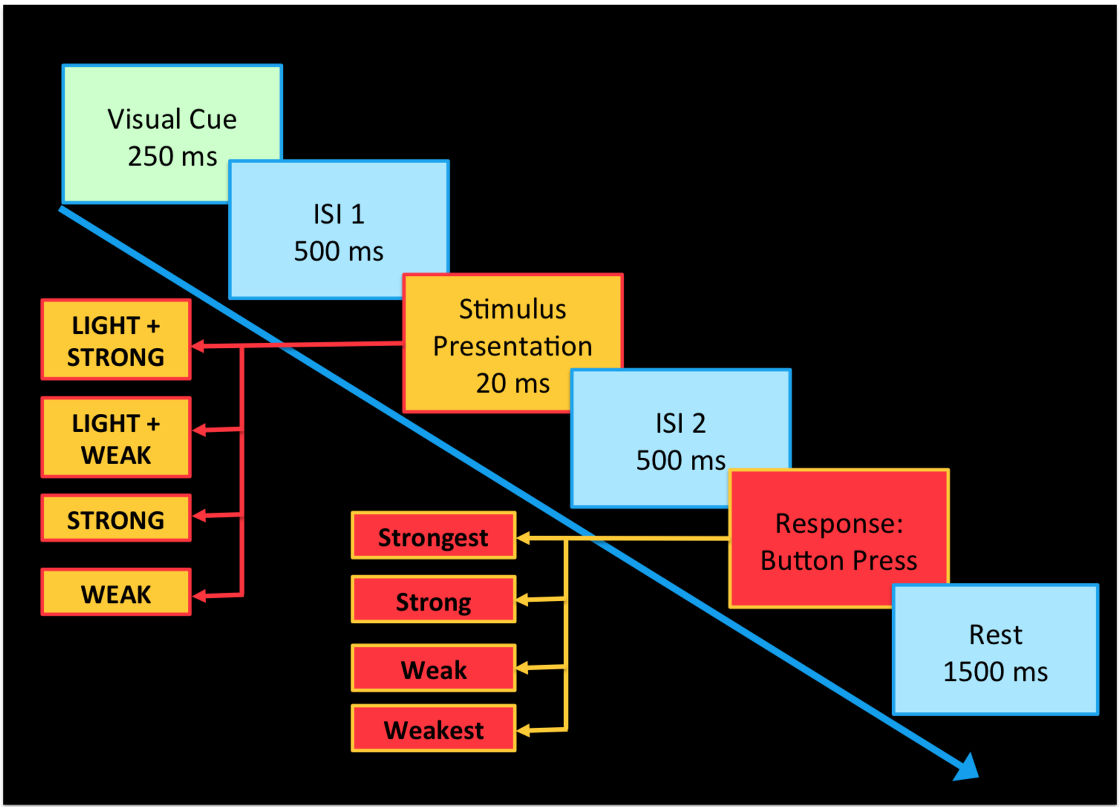


Figure.6.4. Experimental design of the SSDiT. Stimuli consisted of one of condition from 2 Tactile Strength (Strong, Weak) and Light (present or absent) being presented for 20ms before participants responded with one key response out of the four possible choices (Strongest, Strong, Weak, Weakest).

Results

To determine the chance of correct responses to the tactile judgements during each Visual manipulation the cumulative probability was calculated from the signal detection data for each of the three Visual conditions (Vision - Vc; No Vision - NVc; and Pixelated Vison – PVc). To understand how sensory information (augmented Visual conditions) affected participants' responses on the SSDiT, the raw data was converted to signal detection coding (Hit, Incorrect response, False Alarm, Correct rejection) and then signal detection analysis was conducted with each of the three Visual conditions separately.

Univariate ANOVA was conducted with the SSDiT signal detection data [Hit and False alarm rates, Sensitivity indices (*d'*) and Response bias (c)], with SDQ-20, SDQ-15, SSAS and HAI questionnaires used as covariates. When they were of significance, post-hoc Pearson's Correlations were conducted and reported. If there were no significant findings with covariates on the signal detection data a 2 [Light (Present, Absent)] x3 [Visual Condition (Vc, NVc, PVc)] repeated measures ANOVA was conducted; post-hoc analysis for this data will be stated where applicable. Comparisons were also made between the three Visual conditions (Vc, NVc, PVc), to determine if there were any differences between the signal detection data of the bottom-up visual manipulations; paired samples t-tests of the Hit and False Alarm Rates, *d'* and *c* between the each of the three Visual Conditions (Vc, NVc, PVc) were conducted. The cumulative probability results will be presented by the Visual condition as they we want to show how the Visual conditions affected participants' responses. The Signal detection results will be presented by Hit Rates, False Alarm Rates, Sensitivity indices (*d'*) and Response bias (*c*) as each of these components were analysed for all three Visual conditions (Vc, NVc, PVc).

Somatic Signal Discrimination Task (SSDiT):

SSDiT - Detection of Stimuli

In order to conduct single detection analysis all participants' responses were collapsed and detection theory coding was applied to the data, as shown in table 6.2.

Table.6.2. How participants' responses were collapsed, and detection theory coding was applied. A Hit was when participants correctly identified Strong tactile stimuli. False Alarm is when participants erroneously reported Weak stimuli as Strong. An Incorrect Response is when a Strong tactile pulse was incorrectly reported as Strong. A Correct Rejection is when participants correctly reported Weak stimuli.

Participant Response		Stimuli	
		Strong + Light	Weak + Light
		Strong	Weak
Strongest Strong	Strong	Hit	False Alarm
Weak Weakest	Weak	Incorrect Response	Correct Rejection

SSDiT Signal detection analysis

Signal detection analysis was also used to explore the discrimination of strong from weak vibrations. The hit rate was the number of strong tactile pulses correctly identified as strong, divided by the total number of strong vibrations detected (i.e., participants said 'strong' too). The false alarm rate was the total number of weak vibrations incorrectly identified as strong over the total number of weak vibrations detected (i.e., participants said 'weak' too). As with the detection analysis, a correction factor was applied to all data to compensate for cells with '0' responses (Snodgrass and Corwin 1988). The cumulative probabilities were used to calculate sensitivity (*d'*) for the strong and weak stimuli strong d' = z (cumulative probability of responding correctly to strong) – z (probability incorrectly to strong); (weak d' = z (cumulative probability of responding correctly to weak) – z (probability incorrectly to weak), (Macmillan and Creelman 2005). Table 6.3 below provides the percentage Hit and False Alarm Rates, *d'* and *c* for light present and absent conditions.

Table.6.3. Shows the Hit Rates (%), False Alarm Rates (%), d' and c, for light present and absent condition (± 1 SD) across all Visual Conditions of the MIRAGE.

		Hit Rates	False Alarm Rates	*d'*	*c*
Vc					
	Light Present	80.88 (0.18)	9.11 (0.14)	2.89 (0.95)	0.19 (0.53)
	Light Absent	77.89 (0.22)	6.02 (0.11)	2.83 (0.87)	0.43 (0.58)
NVc					
	Light Present	82.76 (0.21)	4.55 (0.08)	3.17 (1.01)	0.35 (0.48)
	Light Absent	70.49 (0.27)	3.09 (0.04)	2.81 (1.08)	0.62 (0.56)
PVc					
	Light Present	81.06 (0.18)	6.18 (0.12)	2.90 (0.92)	0.40 (0.51)
	Light Absent	68.29 (0.26)	3.90 (0.06)	2.59 (1.01)	0.69 (0.56)

Comparisons were also made by conducting paired samples t-tests of the Hit and False Alarm Rates, d' and c between the each of the three Visual Conditions (Vc, NVc, PVc), these will be present towards the end of each subsection.

Hit Rates

The covariates were not found to be of significance with Hit Rates, therefore a 2 [Light (Present, Absent)] x3 [Visual Condition (Vc, NVc, PVc)] repeated measures ANOVA was conducted, Greenhouse-Geisser correction are stated where applicable.

Visual Condition was found to be of significance with Hit Rates, $F_{(1.43, 41.34)} = 4.89$, $p = .02$. Pairwise comparisons (Bonferroni) found that the Hit Rates during the Pixelated Vision (M = 0.75, SD = 0.22) condition were significantly lower than those during the Vision (M = 0.81, SD = 0.20) condition, $p = .002$. The No Vision (M = 0.77, SD = 0.24) condition was not significantly different to the Vision and Pixelated Vision conditions, $p > .31$. Light Condition was also of significance with greater mean Hit Rates during Light present (M = 0.83, SD = 0.19) trials being greater than Light absent (M = 0.72, SD = 0.25) trials, $F_{(1,29)} = 20.95$, $p < .001$.

A significant interaction effect between Visual Condition and Light was found, $F_{(2, 58)} = 3.45$, $p = .04$. A one-way ANOVA was conducted with Hit Rates of each Visual condition and Light, post-hoc paired samples t-test are included where applicable:

For the Vision condition there was no significant difference between Light present (M = 0.85, SD = 0.18) and absent (M = 0.78, SD = 0.22), $F_{(1,58)} = 1.85$, $p = .18$. For the No Vision condition there was a trend towards a significant difference between Light present (M = 0.83, SD = 0.21) and absent (M = 0.71, SD = 0.27), $F_{(1,58)} = 3.79$, $p = .056$. Post-hoc analysis found that the Hit Rates were greater during Light present trials, $t_{(29)} = 3.93$, $p < .001$. Pixelated Visual condition was found to be significantly different between Light present (M = 0.81, SD = 0.18) and absent (M = 0.68, SD = 0.26) trials, $F_{(1,58)} = 4.89$, $p = .03$. Paired samples t-test found that Hit Rates were significantly greater during Light present trials, $t_{(29)} = 4.37$, $p < .001$.

Vision conditions and Hit Rates

Comparisons were also made by conducting paired samples t-tests of the Hit rates between each of the three Visual Conditions (Vc, NVc, PVc), results shown in table 6.4.

Table.6.4. Shows the t-values of comparisons made between Vision, No Vision and Pixelated Vision conditions for Hit Rates during Light present and absent trials (* indicates significant values).

Light condition	*Visual condition*	*M*	*SD*	*df*	*t*	*p*
Present	Vision x No Vision	0.85 0.83	0.18 0.21	29	0.80	.43
	Vision x Pixelated Vision	0.85 0.81	0.18 0.18	29	2.09	.045*
	No Vision x Pixelate Vision	0.83 0.81	0.21 0.18	29	0.73	.47
Absent	Vision x No Vision	0.78 0.71	0.22 0.27	29	2.10	.045*
	Vision x Pixelated Vision	0.78 0.68	0.22 0.26	29	3.92	< .001*
	No Vision x Pixelated Vision	0.71 0.68	0.27 0.26	29	1.10	.28

The Hit Rates were significantly greater within the Vc than during the PVc during Light present and Light absent trials. There were significantly greater Hit Rates within the Vc as compared with the NVc during Light absent trials.

False Alarm Rates

SSAS was found to be of significance with False Alarm Rates during Pixelated Vision condition with Light present trials, $F_{(1,28)} = 5.70$, $p = .02$. A trend to significance of covariate HAI was found with False Alarm Rates during the Pixelated Vision condition with Light present trials, $F_{(1,28)} = 3.46$, $p = .073$. Another trend to significance with SDQ-20 was found with False Alarm Rates during Light absent trials during the Vision Condition, $F_{(1,28)} = 3.63$, $p = .067$. Pearson's Correlation analysis was conducted on the significant data to see the relationship between the questionnaire data and these False Alarm Rates. Pearson's Correlation found a positive relationship between high SSAS scorers having greater False Alarm Rates during Light present trials in the Pixelated Vision condition, $r = .41$, $p = .02$.

A 3 [Visual Condition (Vc, NVc, PVc)] x 2 [Light (Present, Absent)] repeated measures ANOVA was conducted, Greenhouse-Geisser correction are stated where applicable.

Visual Condition was found to be of significance with False Alarm Rates, $F_{(1.16,33.70)} = 4.18$, $p = .04$. Pairwise comparisons (Bonferroni) found that there was a trend towards lower False Alarm Rates during the Pixelated Vision ($M = 0.05$, $SD = 0.09$) condition than those during the Vision ($M = 0.08$, $SD = 0.13$) conditions, $p = .059$. The No Vision ($M = 0.04$, $SD = 0.06$) condition was not significantly different to the Vision and Pixelated Vision conditions, $p > .14$. There was a trend to significant main effect of the Light Condition with False Alarm Rates during Light present ($M = 0.07$, $SD = 0.12$) trials being greater than Light absent ($M = 0.04$, $SD = 0.07$) trials, $F_{(1,29)} = 3.61$ $p = .07$. There were no significant interactions between the terms, $F_{(2,58)} = 1.52$, $p = .23$.

Vision conditions and False Alarm Rates

Comparisons were also made by conducting paired samples t-tests of the False Alarm Rates between each of the three Visual Conditions (Vc, NVc, PVc), which are presented in table 6.5.

Table.6.5. Shows the t-values of comparisons made between Vision, No Vision and Pixelated Vision conditions for False Alarm Rates during Light present and absent trials (* indicates significant values).

Light condition	*Visual condition*	*M*	*SD*	*df*	*t*	*p*
Present	Vision x No Vision	0.09 0.05	0.14 0.08	29	2.43	.02*
	Vision x Pixelated Vision	0.09 0.06	0.14 0.12	29	2.60	.01*
	Pixelated Vision x No Vision	0.06 0.05	0.12 0.08	29	1.30	.21
Absent	Vision x No Vision	0.06 0.03	0.11 0.04	29	1.66	.11
	Vision x Pixelated Vision	0.06 0.04	0.11 0.06	29	1.76	.09*
	Pixelated Vision x No Vision	0.04 0.03	0.06 0.04	29	0.90	.38

False Alarm Rates were significantly greater during the Vision condition in comparison to the No Vision and Pixelated Vision conditions for Light present trials. The False Alarm Rates were also significantly greater during the Vision condition than with the Pixelated Vision condition with Light absent trials.

Sensitivity indices (d')

There was only a trend to significance found between SSAS and sensitivity indices (*d'*), $F_{(1,28)}$ = 3.76, p = .06. No other questionnaires were found to be of significance with sensitivity indices (*d'*), therefore a 3 [Visual Conditions (VC, NVc, PVc)] x 2 [Light (Present, Absent)] repeated measures ANOVA was conducted.

Visual Condition was found to be of significance with *d'*, $F_{(2, 58)}$ = 3.37, p = .04. Pairwise comparisons (Bonferroni) found that the *d'* during the Pixelated Vision (M = 2.74, SD = 0.96) conditions were significantly lower than the *d'* during the No Vision (M = 2.99, SD = 1.05) conditions, p = .02. The mean *d'* was not significantly different to the Vision (M = 2.86, SD = 0.91) condition, p > .63. Light Condition was also of significance with mean *d'* during Light present (M = 2.99, SD = 0.96) trials being greater than Light absent (M = 2.74, SD = 0.98) trials, $F_{(1,29)}$ = 9.55, p =.004. There was no significant interaction effect between the Visual Condition and Light, $F_{(2,58)}$ = 2.68, p = .08.

Vision conditions and Sensitivity indices (d')

Comparisons were also made by conducting paired samples t-tests of the sensitivity indices (*d'*) between each of the three Visual Conditions (Vc, NVc, PVc), which are presented in table 6.6.

Table.6.6. Shows the t-values of comparisons made between Vision, No Vision and Pixelated Visual Conditions for sensitivity indices (*d'*) during Light present and absent trials (* indicates significant values).

Light condition	*Visual condition*	*M*	*SD*	*df*	*t*	*p*
Present	No Vision x	3.17	1.01	29	2.35	.03*
	Vision	2.89	0.95			
	Pixelated Vision x	2.90	0.92	29	0.03	.98
	Vision	2.89	0.95			
	No Vision x	3.17	1.01	29	2.21	.04*
	Pixelated Vision	2.90	0.92			
Absent	Vision x	2.83	0.87	29	0.15	.89
	No Vision	2.81	1.08			
	Vision x	2.83	0.87	29	2.44	.02*
	Pixelated Vision	2.59	1.00			
	No Vision x	2.81	1.08	29	2.65	.01*
	Pixelated Vision	2.59	1.00			

Sensitivity indices (*d'*) were significantly greater during No Vision conditions than with Vision and Pixelated Vision conditions during Light present trials. Also, Vision and No Vision conditions had significantly greater sensitivity indices than those during the Pixelated Vision conditions during Light absent trials.

Response bias (c)

There was only a trend to significance found between HAI and response bias (*c*), $F_{(1,28)} = 3.90$, $p = .058$. No other questionnaires were found to be of significance with Response bias (*c*), therefore a 3 [Visual Condition (Vc, NVc, PVc)] x 2 [Light (Present, Absent)] repeated measures ANOVA was conducted, Greenhouse-Geisser correction are stated where applicable.

Visual Conditions were found to be of significance with the mean response bias (*c*), $F_{(1.44, 41.81)} = 6.72$, $p = .007$. Pairwise comparisons (Bonferroni) found that the response bias (*c*) during the Pixelated Vision (M = 0.54, SD = 0.54) conditions were significantly greater than the response bias (*c*) during the Vision (M = 0.31, SD = 0.56) conditions, $p < .001$. The mean *c* was not significantly different between No Vision (M = 0.49, SD = 0.52) conditions and Vision or Pixelated Vision conditions, $p > .13$. Light Condition was also of significance with the mean response bias (*c*) with Light absent (M = 0.58, SD = 0.56) trials being greater than Light present (M = 0.31, SD = 0.51) trials, $F_{(1,29)} = 31.71$, $p < .001$. There was no significant interaction effect between the Visual Condition and Light, $F_{(1.68, 48.65)} = 0.27$ $p = .76$.

Vision conditions and Response bias (c)

Comparisons were also made by conducting paired samples t-tests of the response bias (*c*) between each of the three Visual Conditions (Vc, NVc, PVc), which is presented in table 6.7.

Table.6.7. Shows the t-values of comparisons made between Vision, No Vision and Pixelated Visual Conditions for response biases (*c*) during Light present and absent trials (* indicates significant values).

Light condition	*Visual condition*	*M*	*SD*	*df*	*t*	*p*
Present	No Vision x Vision	0.35	0.48	29	1.95	.06*
		0.19	0.53			
	Pixelated Vision x Vision	0.40	0.51	29	3.21	.003*
		0.19	0.53			
	Pixelated Vision x No Vision	0.40	0.51	29	0.58	.56
		0.35	0.48			
Absent	No Vision x Vision	0.62	0.56	29	2.07	.048*
		0.43	0.58			
	Pixelated Vision x Vision	0.69	0.56	29	2.05	< .001*
		0.43	0.58			
	Pixelated Vision x No Vision	0.69	0.56	29	1.00	.33
		0.62	0.56			

Response biases (*c*) were significantly greater during the No Vision and Pixelated Vision conditions than with the Vision condition during Light present and absent trials.

Discussion

Looking at each Visual condition separately, the signal detection data does show similar findings of the previous chapters and studies (Poliakoff et al., submitted). With Light present conditions eliciting greater False Alarms than with trials with no Light. The augmented visual conditions by the MIRAGE affected participants' sensitivity indices (*d'*) and response criterion (*c*). The large *d'* values indicate that participants found it easier to discriminate between tactile strength. Lower response criterions (*c*) would indicate that participants were slightly conservative with their judgements. Participants were the least liberal (as indicated by greater response bias) during the Pixelated Visual condition as compared to the Vision condition; they were not significantly different to those of the No Visual Condition. This indicates that the static visual noise of the Pixelated condition could have been interpreted as the task being slightly more difficult and therefore participants were not sure of what they were feeling. To the extent that response criterions (*c*) during Pixelated Visual conditions were not dissimilar to that of the No Vision Conditions. The presence of the Light reduced participants' response criterion (*c*) during all visual conditions, however *d'* was only significantly greater during the No Vision and Pixelated Visual conditions. This may provide an insight into how participants are affected by top-down and bottom-up sensory information processing. Participants' would hold a predicted view of themselves and their hand. During the Pixelated and No Vision conditions of the MIRAGE, there would be an increase in prediction errors as the reliability reduces of bottom-up sensory data due to the noise from the MIRAGE visual conditions. This bottom-up sensory data would not match with those of top-down precepts; however, the most compatible prediction errors would have been accepted to become their updated belief (Apps & Tsakiris, 2014; Tsakiris, 2017).

McKenzie and Newport (2015) indicted those individuals who exhibit MUS like traits would be affected by the static visual conditions of the visual illusion. Though this investigation did not find a relationship with the SDQ-20, the SSAS was found to have a positive relationship with False Alarm rates during the Pixelated (static) Visual Condition with Light present trials. Brown et al. (2007) found during a tactile detection task that participants who showed a greater tendency to experience somatoform symptoms (measured by the SSAS), showed a greater shift in their attention to the tactile stimuli. This shift occurred when participants were exposed to another external body stimulus that they considered as threatening/potentially harmful to themselves. This would explain the relationship between SSAS and participants who had greater False Alarm Rates during the Pixelated Visual conditions with the Light present, they may have perceived the pixelated (static) effect of the visual condition as unpleasant or even as a threating experience, causing them to become hyper focused on task at hand, and misinterpreted the tactile stimuli more so than when there was no visual noise (threat) during the No Vision condition. To ensure that the False Alarm rate does not reduce over time due to participant factors (e.g., participants becoming accustomed to the tactile stimulus), all participants underwent a second thresholding procedure at the midway point. Furthermore, the order of presentation of No Vision and Pixelated Vision conditions were counterbalanced to reduce any order effects.

It may be plausible to suggest that the illusory effects of the SSDiT were 'diluted' by the visual manipulations applied via the MIRAGE system. Taking each of the visual conditions separately, the signal detection data within each of the Visual Conditions does show the presence of the illusory effects of the SSDiT, however, they are not as robust as they have been during the previous chapters. However, all participants underwent the Vision condition first. Comparing performance during the No Vision against the Vision, it is evident that Hit Rates were not different, which is surprising, as previous studies have found that attending to the site of stimulation increases participants ability in detecting tactile stimuli. However, for this investigation, participants were able to view the site of stimulation. The illusory effect of the SSDiT could account for why there is a greater Hit and False Alarm Rate during Light present trials. The sensitivity indices (*d'*) and response criterion (*c*) for the No Vision condition indicate participants were able to distinguish between tactile stimuli fairly confidently (larger mean *d'*) during Light present conditions than in absent. This larger *d'* would indicate that participants' response bias (*c*), how they internally shift their criterion of the tactile discrimination task, to be slightly more liberal (greater Hit and False Alarm rates), however response biases (*c*) were found to be significantly greater, which suggests that participants were less liberal, during Light absent trials; which as table 6.3 shows, did not elicit higher Hit and False Alarm rates. This would move against what Harris et al. (2007) found, that viewing site of stimulation would improve participants' discrimination between two tactile stimuli. In the present study, participants are not significantly different in correct discrimination of tactile stimuli between Vision and No Vision conditions of the site of tactile stimulation.

Mirams et al. (2010) investigated how viewing the hand affected participants’ SSDT performance in two conditions: non-informative vision of the hand and no vision of the hand. Mirams et al. (2010) found more False Alarms in light present trials during the vision condition compared to light present trials in the no vision condition. This result is also indicated in the present chapter. Specifically, there are greater False Alarm rates during Light present trials in the Vision condition compared to the Pixelated and No Vision conditions; however, the False Alarm rates in the No Vision and Pixelated Vision conditions were not significantly different. The present study found that the Light present responses were more liberal during the Vision condition whereas the responses in the two distorted visual conditions were less liberal; as indicated by response criterion (*c*). However, Mirams et al. (2010) found that Hit rates, sensitivity (*d’*) and response criterion (*c*) were not affected by vision of the hand. These findings could suggest that viewing the body increases somatic interference, which could occur due to a raised awareness of internal bodily sensations (Mirams et al., 2010). Additionally, the present observed findings could be due to a summation of somatic interference between the SSDiT and the MIRAGE visual manipulations.

The multisensory aspects of the visual manipulations would indicate that the internal representation of self would be updated by bottom-up data (exteroceptive) to reduce any prediction errors. These errors would have arisen due to the unexpected visual information (Pixilated and No visual conditions). What participants would expect was not what they actually saw. The reliability to the perceptual error correction may account for why the effects of the SSDiT were not as robust. Perceptual prediction mechanism would have perceived the visual noise of the LED flash as being applicable to multiple prediction models, and therefore the weight of it being reliable to one model is reduced. This would then result in SSDiT LED data being dismissed as bottom-up erroneous data. The prediction mechanism would associate the LED as part of the visual noise (pixelated and no vision) of the MIRAGE and therefore deem the LED flash as noise and resulting in it being discounted within other sensory precepts. This would account to the illusory effects of the SSDiT not being as robust during the MIRAGE's visual manipulations, and also why there was no significant difference between Pixelated Vision and No Visual conditions.

Furthermore, not all SSDiT LED data would have been discounted, if so there would be no illusory reports presented during this experiment. Participants could have become hyper-vigilant to why they cannot view their hand, they therefore attend more to the bottom-up stimuli of the SSDiT resulting in a twofold conflict between top-down and bottom-up sensory information: i) the actual underlying mechanisms of the SSDiT (as discussed in Chapter 4) relating to early sensory and later decision making mechanisms, competition between bottom-up and top-down processing that maybe responsible for the illusory effects of the SSDiT occurring; and ii) the erroneous data (noise) of a person's actual limb location not matching with where their body schema (perceptual representation of self) is expecting there to be one. This would indicate that there top-down and bottom-up modulation is of a multi-modal construct, interacting with different sensory modality processing. This would strengthen the notion that prediction errors can influence the perceptual prediction of another sensory modality

(Kennett, Taylor-Clarke, Haggard, 2001; Taylor-Clarke, Kennett, & Haggard, 2002; Busse, et al., 2005; Lloyd et al., 2008; Mirams et al. 2010; Van der Burg et al., 2011). The signal detection data for the Pixelated Vision condition in comparison to the Vision condition, see table 6.3, Hit Rates were lower during the Pixelated Vision condition than the Vision condition and more so with Light absent trials. The main difference between Vision and Pixelated Vision conditions is the visual noise created by the Pixelated Vision conditions 'static' effect. Participants continued to exhibit the illusory effects of the SSDiT within the Pixelated Vision condition, as their mean Hit and False Alarm Rates were enhanced during Light present trials (see *table 6.3*). However, when compared with the Vision condition there was only a trend to significant differences between the two visual manipulations with regards to False Alarm Rates. SSAS (Somatosensory Amplification Scale, Barsky et al., 1988) was found to have a positive relationship with False Alarm Rates during Light present trials within the Pixelated Vision conditions. This indicates those with a greater tendency to amplify ambiguous sensory information and perceive them as an unpleasant experience had greater False Alarm Rates during Light present trials in the Pixelated Vision conditions. This positive relationship was also found in previous chapters in relation to False Alarm Rates during Light present trials, however during this investigation it is only evident during the Pixelated Vision condition. This would imply that participants with greater SSAS scores were affected by the visual 'noise' of the Pixelated Vision 'static effect' body image, to the extent to which they would focus more on the judgement task at hand resulting in slightly lower False Alarm Rates than the Vision condition, but greater than those reported during the No Vision conditions.

Participants' sensitivity indices (*d'*) were not significantly different between Pixelated Vision and Vision conditions during Light present trials. Which implies that participants were able to equally distinguish Strong and Weak tactile pulses between these conditions. However, *d'* was significantly lower during Light absent trials within the Pixelated Vision than during the Vision condition. This indicates that participants were more likely to incorrectly judge the tactile strength, resulting in fewer Hit Rates, as is shown in Table 6.3. Hit Rates for Light absent trials within the Pixelated Vision condition were the lowest out of all of the Visual Conditions. Though, the False Alarm Rates during the Light absent Pixelated Vision conditions were greater than those of the No Vision conditions. This would indicate that even though participants experienced illusory sensations during the SSDiT, the Visual Conditions also increased illusory tactile enhancements. The low Hit Rates and greater False Alarm Rates during Light absent trials in comparison to No Vision condition shows that no view of site of stimulation generated greater Hit Rates than when participants had a disrupted view of their actual body image. Similar to why the No Vision condition was not different to Vision conditions, the Pixelated Vision condition has noise present in the form of moving static pixels, which could have caused a reduced enhancement effect on tactile stimuli judgements.

The illusory effects of the SSDiT were present during the Light present trials but there were greater False Alarm rates during Light absent trials during Pixelated Vision than No Vision conditions, the visual static pixilation could have caused participants to misinterpret the actual tactile strength due to participants being influenced by the illusory effects of the pixelated video representation of their hand. This would strengthen the theory that over focus on external stimuli to the body can result in the formation of illusory sensations (Brown, 2004; Brown et al., 2007). Furthermore, reflected by participants' sensitivity indices (*c*) are significantly greater with both No Vision and Pixelated Vision conditions than the Vision condition. Pixelated Vision conditions' sensitivity indices (*c*) were greater during both Light conditions than those of Vision condition. Response criterion (*c*) values indicate that participants adopted a more liberal response strategy during Light absent trials within the Pixelated Vision conditions, which would be reflected by greater Hit and False Alarm Rates, however this is not the case. There are fewer Hit Rates and slightly greater False Alarm Rates during the no light condition of the Pixelated Vision condition in comparison to the No Vision condition. The visual distortion of the moving pixels (static effect) caused participants to adopt a more liberal response criterion (*c*) but did not affect their *d'*; it can be said that participants must have experienced an illusory enhancement effect of the visual pixilation of their hand, resulting in them to False Alarm more during Pixelated Vision conditions than No Vision Light absent trials.

Looking at the comparison between No Vision and Pixelated Vision conditions to Vision conditions, it is clear that participants were affected by not being able to view the site of stimulation (No Vision) and also external sensory noise being perceived as 'harmful' or in a negative manner results in participants experiencing visual illusory effects that affected their tactile discrimination ability; the latter is evident from the difference in SSDiT performance between the No Vision and Pixelated Vision conditions. There is evidence of participants experiencing disturbances in their body representations during this experiment (between No Vision and Pixelated Vision conditions), similar to what McKenzie and Newport (2015) found. They concluded that the visual distortion effects created by the Pixelated Vision supports the proposed connection between MUS and disrupted body representation. Anecdotal expressions by the participants during the experiment was of surprise that they could not see their hand during No Vision conditions and reported that the Pixelated Vision condition gave them a tingling sensation towards the end of the experimental block.

Previous studies have identified that participants would perceive a threat to representation of their limb even when it does not follow expected top-down knowledge of what the arm representation must be, if the perceived limb had a disconnected wrist, threats to the hand would not elicit significant SRCs, however the disconnected had was connected by a wire to the forearm participants would incorporate that limb as a whole and a threat to the hand would result in significant SRCs (Tieri, Tidoni, Pavone, Aglioti, 2015). From the present SSDiT MIRAGE study, if participants embodied the No Vision and Pixelated Vision conditions we would expect to see the illusory effects of the SSDiT present, which we do find, however the enhancement effect of tactile discrimination appears to have been reduced as compared with the Vision condition. Therefore, participants must have accepted the distorted representation of their hand as 'matching' that of their body schema, during Pixelated Vision conditions. The effects of the visual distortion must have affected participants' peripersonal space, this is known as the space directly surrounding our bodies (Rizzolatti, Fadiga, Fogassi, & Gallese, 1997; see Holmes and Spence, 2004 and for a review). Furthermore visuotactile enhancement has been known to occur when participants view of their hand with the ‘moving static’ Pixelated Vision conditions may have caused them to perceive this visual noise as a threat to their peripersonal space, with a defensive like mechanism causing participants to become hyper vigilant to this visual noise resulting in a distracted attention to the SSDiT discrimination task; therefore resulting in fewer Hit Rates, but greater False Alarm Rates than the No Vision conditions.

During the No Vision condition the lack of an expected view of the limb could have been perceived as a removal form expected body schema, and therefore the visually defined peripersonal space boundaries were not as clear, resulting in participants being confused between the top-down and bottom-up information processing. These changes in perceived body representation can causes confusion that can be shown as degradation in tactile acuity and sensitivity (D’Amour et al., 2015); furthermore, participants must have also been affected by the SSDiT paradigm as during these visual disruptions to the body schema, participants did show illusory enhancement effects which would account for the mismatch results (Botvinick and Cohen, 1998; Cardini et al., 2013; see Moseley et al., 2012 for review; Medina & Coslett, 2010).

Chapter seven

General Discussion

This thesis set out to understand the mechanisms of the illusory enhancement effects of the SSDiT. The SSDiT (discrimination task) is an adapted form of the SSDT (detection task; Lloyd et al., 2008). The SSDT is known to illicit an illusory sensation of touch during tactile absent trials when light was presented. The SSDT was originally created to recreate MUS like symptoms with healthy participants to understand why they occur. According to Brown's (2004) integrative conceptual model of MUS, illusory somatosensory symptoms are caused by the disruption between conscious and preconscious processing of stored information; where symptom-focused attention is a key component of creation of and the maintenance of these illusory symptoms. The SSDT has been found to be a robust paradigm in recreating these illusory effects within healthy participants, and has been extensively investigated (Lloyd et al., 2008; Mirams et al., 2010; Mirams et al., 2012; McKenzie et al., 2010; Brown et al., 2010). The SSDiT was developed to investigate the illusory enhancement effect of simultaneous light presentation with tactile stimuli (Poliakoff et al, submitted). The series of investigations presented in this thesis aimed to understand the mechanisms of the SSDiT and why discrimination judgements are affected by the presence of a light.

Discussion of Chapter 3: An investigation of how sensitivity to the illusory effects of the SSDiT relate to those felt during the SSDT.

This study aimed to investigate if False Alarm rates during the SSDiT relate to the False Alarm rates on the SSDT. To determine participants' ability to discriminate between different tactile strengths (SSDiT) is related to their ability to detect a tactile stimuli (SSDT). False Alarm rates have shown to be greater during the Light present condition during previous investigations, therefore it was expected that they would be greater during both tasks during light present conditions. Furthermore, False Alarm rates between the two tasks would have a significant relationship with Light present conditions, as the both tasks only differ by the type of judgement participants would be conducting. The sensory processing would be the same for both tasks. Results were as we expected on both the tasks, the SSDT having greater Hit Rates and False Alarm rates during Light Present trials (Lloyd et al., 2008; Mirams et al., 2010; McKenzie et al., 2010). The SSDiT results show that simultaneous presentation of light with tactile stimuli did result in a subjective enhancement of tactile strength, resulting in greater False Alarm rates during Light present trials (Lloyd et al., 2008; Poliakoff et al., submitted). The two tasks (SSDT and SSDiT) were expected to have a significant relationship between the False Alarm rates during Light present trials. It was thought the incorrect detection (False Alarm) of tactile stimuli (SSDT) during Light present conditions would be related to the incorrectly perceived tactile strength during the discrimination task (SSDiT). Both tasks investigate bottom-up sensory processing but have different top-down factors that could affect their judgements.

There was no relationship between the False Alarm rates in the two tasks, which could suggest that the effect of the Light on signal intensity and response bias may be mediated by different mechanisms that occur at different stages of processing.

Participants' tendency to False Alarms during the SSDT could be the result of top-down processing affecting bottom-up sensory processing. This rise in False Alarms may occur due to the top-down mechanisms, such as attention and expectation of the task and tactile stimuli affecting the later stages of processing Poliakoff et al., (submitted). Furthermore, participants' misperceptions of feeling a tactile pulse when one was not present or perceiving tactile strength to be stronger than it actually was, could occur due to the influence of external sensory noise (e.g. simultaneous light present condition) affecting the top-down mechanisms such as expectation (Lloyd et al., 2008; Karol and EL-Deredym 2011; Poliakoff et al., submitted). Signal detection theory provides an indication of participants' response bias (*c*) and sensitivity indices (*d'*). Sensitivity indices (*d'*) can be taken as a score which indicates how easily two tactile signals were distinguishable; if they were distinctly different their means would be further apart (larger *d'*), if they were not so different their means would be closer (smaller *d'*). How sensitive an individual is to this task would in turn affect the way they would gauge their confidence in being able to make the judgements; this would affect how many hits and misses participants made during the task. Response bias/criterion (*c*) is an indicator of the strategy that participants adopt in order to gauge how to make their judgement. A liberal strategy of always saying 'Yes' (SSDT) or 'Strong' (SSDiT) would be indicated by a lower or more negative response bias (c; expect greater Hit and False Alarm Rates); a conservative strategy of always saying ‘No’ or ‘Weak’ would be indicated by a larger or more positive response bias (c; expect greater misses and correct rejections).

There were no differences between the sensitivity indices (*d’*) and Light conditions, however, there were lower response bias (*c*) during Light present conditions for both the SSDT and SSDiT, indicating that participants were more likely to judge tactile stimuli as being present when one was not present (SSDT) or as ‘strong’ even if it was ‘weak’ (SSDiT). This shift in response bias during Light present conditions indicates that participants were affected by the presence of the Light condition, but their sensitivity indices (*d’*) was not affected between Light conditions. Therefore, the presence of Light seems to affect the bottom-up processing of the tactile stimuli. This misperception could be the result of memory of early sensory events being affected by later decision making mechanisms. The real tactile sensation and sensory noise from the task irrelevant light could be causing the illusory enhancement effects.

Discussion of Chapter 4: Effects of order of judgement on two forced-choice SSDiT.

Two forced-choice (2FC) tasks has found participants tend to show an enhancement in ability to discriminate between two separate tactile stimuli (Kennett et al., 2001; Taylor-Clarke et al., 2002). To see whether working memory (short term memory, STM) contributes to these enhancement effects found during 2FC tasks. To understand how memory (working memory, WM) plays a role within the SSDiT, a 2FC-SSDiT was conducted. By conducting a 2FC-SSDiT, the impact of memory on the standard SSDiT paradigm would be more apparent, as participants' focus between first and second pulses would have an impact on their ability to make False Alarms depending on which pulse they were judging.

The aim was to compare participants' responses between two judgement order groups (JOG), those who judged the first pulse and second pulse for both Comparator Strengths (Weak and Strong). Participants were presented with two consecutive stimuli presentations. Each of the stimuli presentations (first and second) was composed of the standard SSDiT stimulus. Each group had different target stimuli (the condition they were in, i.e. first pulse target was the first presentation and the second pulse was their comparator and the opposite for second pulse judgement group). Therefore, the main focus on first pulse judgement group was on the first presentation of stimuli with comparison to the second presentation that followed; and for second pulse judgement group their main focus was on the send stimuli presentation with comparison to the first presentation that preceded it. The stimuli were composed of two tactile comparator strengths, which were presented depending on the judgement question asked; the final data was separated by Comparator strength, as they were not counterbalanced.

It was expected that False Alarm rates during Light present trials would have been present across both first and second judgements groups, with the first pulse judgement groups False Alarm responses being slightly greater than those in the second pulse judgement group. This would be due to the first judgement group being presented with their target stimulus first. The participants in the first pulse judgement group (first JOG) know they are expected to judge the target pulse (first stimulus presentation) with the second presentation (comparator) and answer the judgement question to the tactile sensation they perceived. Therefore, the first JOG's target stimulus information (bottom-up) must be maintained in memory in order for discrimination judgements (top-down) to be conducted.

There were mixed findings with the effect of Light on participants' judgements between first and second judgement groups on the 2FC-SSDiT. The Hit Rates during Comparator and Target Light absent conditions were lower with those who had higher SDQ-20 scores. Conversely, the second pulse judgement group had greater Hit Rates during Comparator Light present trials. Hit Rates were greater during Strong Comparator first pulse judgements than second pulse judgements. False Alarm rates were significantly greater during Target Light present trials during Weak Comparator conditions for both judgement groups. Overall the False Alarm rates were significantly greater during first pulse judgements than with second pulse judgements with Strong Comparator trials.

The Sensitivity indices (*d')* were greater (more positive) during second pulse judgements with all Comparator and Target Light stimuli pairings; this is reflected by the lower False Alarm Rates during second pulse judgements. The Strong Comparator strengths' sensitivity indices (*d'*) indicate that participants were able to differentiate between the two stimulus signals when the Comparator light was absent. Sensitivity indices (*d'*) of participants during Strong Comparator second pulse judgement group were better able to distinguish between the Target (second pulse) and Comparator (first pulse) when the Target Light was absent.

Weak Comparator response biases (*c*) during second pulse judgements were found to have a significant positive relationship with questionnaire SSAS during Comparator Light absent and Target Light present trials. The Somatosensory Amplification Scale (SSAS) measures the tendency to notice and experience vague sensory events as unpleasant. This would indicate that those who score higher on the SSAS, greater tendency to notice and experience vague sensory experiences as, had greater (more positive) response biases (*c*) within the second pulse judgement group. Response bias (*c*) for the second pulse judgement group indicated that participants adopted a more liberal criterion, during Comparator Light absent trials. This is reflected by the greater number of False Alarm rates during Target Light present trials. This is also reflected during second pulse judgement group with Hit rates being significantly greater during Target Light present trials.

Interestingly, Strong Comparator trials with Comparator Light present trials were found to be less negative, they were less liberal, than during Comparator Light absent trials. This was also found with the Response bias (*c*) being less negative during Target Light absent conditions during both first and second pulse judgements, unlike those of the Weak Comparator conditions; they were less liberal during both judgement groups. Overall the response biases (*c*) were less negative/closer to zero during second pulse judgement group, which is the opposite to that of the findings of the Weak Comparator conditions. The less conservative criterion during second pulse judgements is also reflected by there being greater False Alarm rates during first pulse judgement group than in the second.

The signal detection data indicates that participants did experience misperceptions (as evident by Weak Comparator False Alarm rates). The Target (the stimulus they were judging) for the first pulse judgement order group was the first pulse and their Comparator (stimulus that the target would be compared with) was the second pulse. For those in the second pulse judgement order group, the Target was the second pulse and their Comparator was the first pulse.

The findings from this experiment could be due to a thresholding issue. The thresholding procedure used (adapted staircase method from Lloyd et al., 2008; Poliakoff et al, submitted; originally from Cornsweet, 1962) is a validated and well-established method to assess sensory thresholds at the time of data collection. It has come to light that there is a better method that can be adopted for thresholding participants than the one used throughout this thesis (which is discussed in the limitations section of this chapter).

A possible explanation as to why there was a large difference between the two judgement groups could be down to the only actual difference between the tasks and what effect this would have on the 2FC-SSDiT. This difference is the actual temporal difference between which stimulus pulse participants judged. Sensory processing/encoding occurs early and this sensory information is then projected to other areas related to perceptual processing. Perceptual processing is thought to be where patterns are recognised to from new sensory information and recalled from the existing representation in longer-term memory (Jolicoeur and Dell'Acqua, 1998).

The signal detection data for participants within the first judgement group does not look dissimilar to that of previous findings (Chapter 3, SSDiT). Participants within the first JOG may have been influenced by the illusory sensations elicited during the Comparator trials, as the time to process this information was relatively shorter than that of Target stimuli. This would indicate that there was a later decision-making mechanism that was not able to fully process the detected sensory information, resulting in a greater number of False Alarm rates; this aspect of the data would be similar to previous SSDiT findings). Target sensory information for first judgement group, had a minimal significant effect during the signal detection analysis, this could this be due to there being greater time for encoding to occur. There were fewer errors during first pulse judgements, which would account towards the greater Hit Rates. The earlier Target trials may have had a reduced illusory capacity due to decay of the sensory signal or due to a later decision-making mechanism that enabled participants to make a more confident decision when judging the Target with the Comparator strength. However, the results presented indicate that False Alarm rates differed by the presence of a simultaneous Light presentation either during the Comparator Light or Target Light. Weak first pulse judgements with Target Light present trials along with Strong first pulse judgements with Comparator Light present and with Target Light absent trials resulted in significantly greater False Alarm rates. This fluctuation in False Alarm rates and Light presence is also evident with sensitivity indices (*d'*) and response bias (*c*). It could be plausible in suggesting that not only was there interference order of Target and Comparator stimulus presentation, but that there was also an illusory effect present from the complete processing of the Target (First Presentation, FP) giving results that were not as robust as expected but also exhibited signs of an illusory mechanism occurring.

Conversely, the findings from second pulse judgements is the reverse to that of first pulse judgements. Due to the shorter processing time of second pulse judgements Target (Second Presentation, SP) sensory information would not have fully undergone encoding. The second pulse judgement group participants may have had a longer time to process Comparator (FP) stimuli, similar to the first pulse judgements Target (FP) sensory information. Resulting in the second judgement groups participants moving further on from the earlier sensory processing to a later decision-making process and for the illusory sensory information to decay, which would result in fewer False Alarm Rates. Additionally, second pulse judgement participants may have been influenced by the illusory sensation experienced during the Target (SP) trials. False Alarm rates during second pulse trials were greater during Weak trials with Comparator Light absent trials and in Target Light present trials; and with Strong trials when Comparator Light was present and when the Target Light was absent. Within both Weak and Strong Comparator trials in both first and second pulse judgement groups the Light conditions of both Comparator and Target had a significant affect with participants' sensitive indices (*d'*) and response bias (*c*). Weak Comparator second pulse judgements had greater sensitive indices (*d'*) during Comparator and Target Light absent trials (easier to discriminate with no light condition). The response bias during Weak second pulse judgements was more negative (more liberal) during Comparator Light absent trials. Participants were directed by the judgement question to the second pulse during second pulse JOG trials. This may have enabled Target (SP) being held in working memory long enough to affect participants' responses, as latent illusory effects could have disrupted their judgements. Participants may have been conflicted by the Target Light, which caused them to shift their response bias (*c*) depending on what the Comparator was. The Target during the second pulse judgement group may have acted as an inhibitor of this later mechanism.

With the present study there are two stimuli presentations, both a form of the original SSDiT. This would result in there being two sets of illusory mechanisms occurring. The observed findings from the second pulse JOG could be the result of conflicting SSDiT illusory mechanisms occurring simultaneously. Therefore, the illusory enhancement effects (False Alarm Rates) of the Light on tactile stimuli during the SSDiT may be due multiple sensory information overwhelming the short-term capacity for consolidation (STC) to take place. Responses would be less accurate due to the later perceptual encoding system not being able to fully process the early sensory information as the ‘attention’ of the encoding process might be disrupted by a feedback mechanism that helps maintain the sensory information so that it is not degraded during encoding (Jolicoeure and Dell’Acqua, 1998; Kennett et al., 2001; Taylor-Clarke et al., 2001). The type of sensory stimulus can affect the time taken for consolidation to occur. The rate of consolidation is considered to be very quick, however it can be affected by the accumulated decision mechanisms that would also be working (Vogel et al., 2006). This along with Theeuwes’ (2010) theory could help explain these findings. The weighted sensory stimuli of the 2FC-SSDiT would require a feedback mechanism (top-down modulation) for the judgement to be conducted on the bottom-up sensory information. This top-down processing would occur after participants initially detect the stimulus of the presentation (pulse/light), and as this processing is accompanied by a question there would be a feedback mechanism that discriminates between the two pulses that were delivered (Theeuwes, 2010). The feedback process would fit with the encoding aspect as Vogel et al. (2006) and Jolicoeure and Dell'Acqua (1998) have suggested. This feedback mechanism (top-down modulation) could recall all sensory information that pertain to the judgement question and recalls both tactile and visual stimuli as they both occurred at the same time. Due to the limiting capacity of consolidation, the tactile sensory memory maybe influenced by the visual sensory noise of the task-irrelevant light; resulting in participants having a False Alarm.

Interoceptive and exteroceptive mechanisms are known to contribute to experiencing multisensory sensations (Talsma, 2015). Multisensory processing must occur instantly and simultaneous across different sensory modalities for the presence of light to have an affect on Hit and False Alarm rates, sensitivity indices (*d'*) and response bias (*c*). Therefore, these processes must occur at different times due to their time of detection, affecting different cognitive processes at a later stage such as attention and memory (Talsma, 2015). Incoming sensory data (bottom up, early sensory processing) are compared with internal models (top-down, later decision processing) held by the body. The integration between sensory systems occurs due to top-down information actively maintaining a mental model of the environment based on the concepts of environmental probabilities (Talsma, 2015). The behavioural findings from the 2FC-SSDiT were not sensitive enough to draw firm conclusions as to the temporal effects of the task.

Discussion of Chapter 5: An ERP investigation of cross-modal enhancement using the SSDiT.

This was the first time an ERP investigation into the SSDiT had been conducted; this was a very exploratory investigation. The findings from this study would provide insight into the time course of visuo-tactile illusory enhancement of touch sensations during the SSDiT and would also help identify why/who is more susceptible to experiencing bodily misperception. The behavioural data was as expected of that of previous chapters SSDiT findings, with Light present trials affecting participants judgement of near-threshold tactile stimuli. The ERP components of interest identified (P120, P160, P360, P400) did fall into the expected timeframes of between 100ms to 450ms as earlier somatosensory evoked potential EEG studies indicated (Michie, Bearpark, Crawford, Glue, 1987; Eimer and Driver, 2000; Eimer and Forster, 2003; Zopf et al. 2004; Schubert et al. 2008; Yamaguchi and Knight, 1991; Zhu, Disbrow, Zumer, McGonigle, Nagarajan, 2007). The SSDiT ERP components of interest were also similar to that of Poliakoff et al's (in prep) EEG investigation with SSDT. The ERP data found both early and late components during erroneous responses (False Alarms and Incorrect Responses). Early components could be evidence of early sensory information being processed, they are also thought to relate to perceptual attention (Eimer and Forster, 2003).

Visual inspection of both Parietal and Frontal regions, shows that there is a presence of later ERP components throughout all of the response types. Over Parietal regions there are more visually defined components present at both early and late time points during erroneous responses (Incorrect rejection and False Alarm). When tactile stimuli were correctly judged (Hits and Correct rejections) greater more positive AMAs were found in the right Parietal region than with incorrect judgments (Incorrect Response and False Alarm). The AMAs over the Frontal region were significantly more positive over the Frontal Right region than the Frontal Left region for all components of interest for Hits, Incorrect Responses, False Alarms and Correct Rejections. The Parietal AMAs during Hits were significantly more positive over the right parietal region.

The susceptibility of people to task-irrelevant sensory noise when attending to low-level threshold sensory stimuli differs greatly. Participants were instructed to attend to the tactile stimulus as they are conducting discrimination judgements. Several questionnaires were used to ascertain this (please see Chapter 5, Results for more details). The SDQ-20 questionnaire has shown a relationship between high SDQ0-20 scorers and greater False Alarm rates exists as those participants are more likely to experience illusory somatosensory illusory effects; especially during Light present trials. However, electrophysiological response over the Parietal Right region for correctly identifying stimuli was largest (greater AMA) during the all early and late components of interest (P120, P160, P360 and P400) with participants who had a greater tendency to experience pseudo neurological symptoms (larger SDQ-20 score). Conversely, participants who were less likely to experience pseudo-neurological symptoms (low SDQ-20 score) had a more positive AMA of Correct Rejections over all Frontal regions during both Light conditions across all early and late components of interest. The AMA of False Alarms over Frontal region had a negative relationship with PHQ-15 scores; participants who reported having low somatosensory symptoms had a more positive False Alarm AMA during both Light conditions over both Left and Right Frontal regions.

The observed later ERP components (P300, P400) have been associated with decision mechanisms that may occur due to the attention given to the site of stimulation (visual and weighted by the task at hand; Bruyant, Garcia-Larrea, Maugier, 1993; Kida, Nishihira, Hatta, Wasaka, 2003). The later components could also reflect non-sensory processing, such as the error predication type mechanisms (decision making mechanisms) during misperceptions of tactile sensory information (de Lafuente and Romo, 2005, 2006; Michie et al. 1987; Yamaguchi and Knight, 1991; Eimer and Driver, 2000; Eimer and Forster, 2003; Zopf et al. 2004; Zhu et al. 2007; Schubert et al. 2008). The erroneous incorporation of early sensory information could indicate that there is a form of feedback and feed forward mechanisms, supporting the proposed theory of MUS by Brown (2004). The ERP findings could indicate top-down modulation being present during the SSDiT affecting bottom-up sensory information of the tactile stimuli.

Interoceptive and exteroceptive mechanisms are known to contribute to experiencing multisensory sensations (Talsma, 2015). Multisensory processing must occur instantly and simultaneous across different sensory modalities. Therefore, these processes must occur at different times, affecting different cognitive processes at a later stage such as attention and memory (Talsma, 2015). Bottom-up early sensory information (incoming sensory data) would be compared with internal models (top-down, later decision processing) held by the body. The integration between sensory systems occurs due to top-down information actively maintaining a mental model (representation) of the environment based on the concepts of environmental probabilities (Talsma, 2015). These estimated predictions would be about how environmental factors can affect the body and would be constantly changing and updating depending on the new bottom up sensory information. For this type of constant dynamic updating, feedback and feed-forward, memory must play a role. The present ERP investigation shows that there are two distinct componential groups, early (sensory processing) and later (decision mechanisms), which reflects the relationship of exteroceptive and interoceptive mechanisms. This would strengthen the notion of a feedback mechanisms working during the SSDiT. Components of memory must also play a role in the SSDiT with experiencing illusory somatosensory sensations. Theeuwes (2010) put forward an explanation of how sensory information is processed, which could help understand why these misperceptions occur. An inability to reject erroneous sensory noise as relevant, therefore increasing prediction errors, maybe be reflected by the AMA during the later components of interest in the present ERP data. The task-irrelevant visual stimulus could be incorrectly adopted into the current held belief when the sensory information undergoing the feedback mechanism (in order to answer the question at hand) resulting in the misperception of tactile stimuli and affecting response bias, which is in keeping with previous findings (Calvert & Thesen, 2004; Koelewijn et al. 2010; Theeuwes, 2010; Katzer et al., 2012; Lloyd et al., 2008; Poliakoff et al., submitted). The role of interoceptive (top-down) and exteroceptive (bottom-up) modulation during the SSDiT was explored in the SSDiT MIRAGE experiment. This was conducted to understand the extent prediction errors and bias of expectation has on the illusory effects of the SSDiT.

Discussion of Chapter 6: An investigation of the effect of visual distortion on bottom-up and top-down modulation during the SSDiT.

The MIRAGE SSDiT experiment (Chapter 6) was conducted to understand how the modulations of top-down expectations/biases affect bottom-up sensory information during the SSDiT. To address the attentional focus of top-down modulation of expected visual information participants have of their hands, the appearance was manipulated by using visual augmentations implemented by the MIRAGE system. This would alter participants expected knowledge of what their hand looks like (visual conditions were, Vision [Vc], No Vision [NVc] and Pixelated Vision [PVc). This would then determine if/how much reliance there is on top-down modulation during the SSDiT especially during False alarm responses.

The presence of light did appear to elicit greater Hit and False Alarm Rates than light absent trials. The presence of the light also affected participants sensitivity indices (*d'*); Light present trials had greater *d'* than light absent trials. This is also reflected by a liberal response bias (*c*; value closer to zero) during light present trials. The presence of Light did effect participants' subjective sensitivity to the discrimination of the SSDiT.

However, MIRAGE augmented visual conditions (Vision, No Vision and Pixelated vision) did affect participants responses. Hit and False Alarm Rates during light present trials were greatest during the Vision condition than No Vision and Pixelated visual conditions. False Alarm rates during Light absent trials were only greater in the Vision Condition than those of the Pixelated vision condition. Participants found it easier to discriminate between tactile strength during Light present trials in the No Vision condition than Vision and Pixelated vision; the sensitivity indices (*d'*) were greater during No Vision condition. Interestingly, Light absent sensitivity indices (*d'*) indicate participants were better able to discriminate between tactile strengths during the Vision and No Vision conditions (greater sensitivity indices, *d'*) than the Pixelated condition. Additionally, the greater response biases (*c*; conservative strategy) during Light present and absent No vision and Pixelated vision conditions indicates that these visual manipulations caused participants to shift their response criterion (*c*), increasing Hit Rates and reducing False Alarm rates.

The manipulated visual distortions of No Vision condition and Pixelated Vision condition compared with the Vision condition clearly show that participants are affected by not being able to view the site of stimulation (No Vision condition). Additionally, external sensory noise could be perceived as 'harmful' or in a negative manner (as indicated by high False Alarm rates relationship with covariate SSAS) results in participants experiencing visual illusory effects that affected their tactile discrimination ability. Brown et al. (2007) found during a tactile detection task that participants who showed a greater tendency to experience somatoform symptoms (measured by the SSAS), showed a greater shift in their attention to the tactile stimuli when they considered it as threatening/potentially harmful to themselves. Anecdotal expressions by the participants during the experiment in Chapter 6 was of surprise that they could not see their hand during No Vision conditions and reported that the Pixelated Vision conditions gave them a tingling sensation towards the end of the experimental block. The multisensory aspects of the visual manipulations would indicate that the internal representation of self would be updated by bottom-up data (exteroceptive) to reduce any prediction errors.

Participants over-focusing on external task irrelevant stimuli (i.e. the visual conditions for the MIRAGE SSDiT investigation) could have resulted in the formation of additional illusory sensations other than those of the SSDiT. The illusory effects of the SSDiT were present during the Light present trials but there were greater False Alarm rates during Light absent trials during Pixelated Vision than No Vision. The visual pixilation could have caused participants to misinterpret the actual tactile strength due to participants being influenced by the illusory effects of the pixelated video representation of their hand. This inability to ignore/filter out this visual stimulus noise strengthens the theory that over focusing on external body stimuli could result in the formation of illusory sensations (Brown, 2004; Brown et al., 2007).

The signal detection data from the No Vision and Pixelated Vision conditions from the SSDiT MIRAGE investigation (Chapter 6) may have resulted in participants experiencing a sense of loss for their hand and that it no longer exists within the participants' internal representation of their body due to the visual sensory noise elicited by the MIRAGE visual manipulations. Though anecdotal reports after the experiment indicated that participants did feel a tingling sensation after the pixelated visual condition; which may suggest participants only lost ownership over the visually represented had. McKenzie and Newport (2015) study identified those with greater susceptibility to experience somatoform illusory effects to be affected by the static visual illusion (Pixelated Vision), but further investigations into how these participants accept the visual depictions of their limbs would strengthen the SSDiT MIRAGE findings (Chapter 6). Additionally, Tieri, Tidoni, Pavone, Aglioti (2015) identified that participants would perceive a threat to representation of their limb even when it does not follow expected top-down knowledge of what the arm representation must be. If the perceived limb had a disconnected wrist, threats to the hand would not elicit significant skin conductance responses (SRCs; recorded physiological skin responses), however if the disconnected hand was connected by a wire to the forearm participants would incorporate that limb as a whole and a threat to the hand would result in significant SRCs (Tieri et al., 2015). This inability to remove erroneous stimulus information can be linked with the unified theory of bodily self.

The estimated predictions held, according to the unified theory of bodily self, would consist of how environmental factors can affect the body (Talsma, 2015). Misperceptions can occur during the generation and maintenance of these models which help maintain a stable representation of the self. Prediction errors occur when the incoming data does not match the internally held predictions. A dynamic evaluation system must be working to adjust predictions of the self, based on the actual sensory information, which would also adjust initial sensory processing (Talsma, 2015). This initial sensory information would be processed in a probabilistic manner, by adapting a model that best fits the image of the self at the time, which is most likely to be ‘me’ (Seth & Critchley, 2013; Seth, 2013; Apps & Tsakiris, 2014). The model of self is a multimodal concept, thought to be a hierarchical construct, consisting of higher level (top-down) beliefs and attitudes and lower level (bottom-up) bodily representations (Seth, 2013; Moutoussis et al., 2014; Tsakiris, 2017). This hierarchical model would therefore, integrate interoceptive and exteroceptive pathways for there to be a body self representation (Seth, 2013; Moutoussis et al., 2014). A feedback and feed forward mechanism would be present between the internal predictions of stimuli from different modalities (top-down) and early uni-modal (bottom-up) sensory processing of self constructs (Kennett, Taylor-Clarke, Haggard, 2001; Taylor-Clarke, Kennett, & Haggard, 2002; Busse, Roberts, Crist, Weissman, Woldorff, 2005; Lloyd et al., 2008; Mirams et al. 2010; Van der Burg, Talsma, Olivers, Hickey, Theeuwes, 2011; Seth, 2013; Moutoussis et al., 2014; Talsma, 2015; Tsakiris, 2017). Predictions already held (and subsequent prediction errors) or newly modified predictions would vary in their level or reliability depending on the quality of incoming sensory signals (bottom-up). Sensory signals compatible with few potential predictions would have high precision and would consist of low noise. The opposite would apply if sensory signals were compatible with many predictions, they would be deemed as being less reliable (greater noise) information or imprecise prediction errors and would be inhibited by a more reliable prediction (Apps & Tsakiris, 2014; Tsakiris, 2017). Erroneous acceptation of exteroceptive (bottom-up) information could result in the creation and maintenance of an inaccurate representation of the self; due to a failure in rejecting inaccurate predictions errors.

Based on these findings, if participants embodied the No Vision and Pixelated Vision conditions of the SSDiT MIRAGE task (Chapter 6), we would expect to find the illusory effects of the SSDiT present, which we do find, however the enhancement effect of tactile discrimination appears to have been reduced as compared with the Vision conditions. Therefore, participants must have accepted the distorted representation of their hand as 'matching' that of their body schema, during Pixelated Vision. The effects of the visual distortion must have affected participants' peripersonal space; this is known as the space directly surrounding our bodies (Rizzolatti, Fadiga, Fogassi, & Gallese, 1997; see Holmes and Spence, 2004 and for a review). Furthermore visuo-tactile enhancement has been known to occur when participants view of their hand with the Pixelated Vision condition may have caused them to perceive this visual noise as a threat to their peripersonal space, with a defensive like mechanism causing participants to become hyper vigilant to this visual noise resulting in a distracted attention to the SSDiT discrimination task; resulting in fewer Hit Rates, but greater False Alarm Rates than the No Vision condition. This hyper vigilance to visual noise maybe account for the participants incorrectly incorporating prediction errors into their top-down (body schema) resulting in the not so robust illusory effect of the SSDiT being reported. The findings of the No Vision condition can also be accounted for by the unifying bodily theory of the self, where the prediction errors were failed to be rejected due to the lack of an expected view of the limb could have been perceived as a removal form expected body schema, and therefore the visually defined peripersonal space boundaries were not as clear.

Implications of findings

Overall the main aim of this thesis was to understand the mechanisms underpinning the illusory reports of the SSDiT. The ERP results as well as the behavioural data indicate that these illusory somatoform distortions occur due to the cross-modal processing of task irrelevant sensory noise. Two distinct mechanisms have been identified to contribute to these illusory sensations. An early sensory processing mechanism (bottom-up modulation) and a later decision based mechanism (top-down modulation). The preceding experimental chapters have outlined how distinctly different mechanisms of early sensory processing and later decision mechanisms can cause the illusory sensations reported during the SSDiT. The limited capability of short term working memory in being able to process bottom-up sensory information along with later perceptual decision mechanisms of encoding information could account for these illusory sensations. The task-irrelevant stimuli (i.e. the light) of the SSDiT must be being processed along with the desired tactile stimulus during working memory encoding mechanism. However, there is also modulation of top-down knowledge that affects the 'assessment' of the earlier sensory (bottom-up) information. Top-down modulation was found to affect the False Alarm rate of participants as a result of external body stimulus manipulations and removal of prior knowledge (Chapter 6) of site of stimulation did cause disruption to bottom-up sensory information as participants' ability to False Alarm was affected. The illusory sensations from the SSDiT are reported more during light present trials. Participants are asked to view their stimulated finger and only report the intensity of the tactile pulse they feel.

Predictions based on this question would result in top-down expectations of the stimuli. Participants may erroneously accept the uni-modal (bottom-up) visual noise of the light information into their probability predictions of the self (top-down) during the tactile discrimination task; resulting in bottom-up information altering top-down interpretations, resulting in a False Alarm. As False Alarm rate differ between each trial and vary between participants, the incorporation of these prediction errors into generating a representation of self must also reflect a mechanism of active inference. This mechanism of being able to process interoceptive and exteroceptive information to eliminate prediction errors maybe affected by the prior experience of the participant, their individual differences to process sensory information. The level of sensitivity and awareness one is to exteroceptive and interoceptive information may result in them not being able to 'filter' the visual noise of the simultaneous light presentation from the tactile pulse and other visual information regarding the site of stimulation.

Limitations of studies

In Chapter 5 (EEG), participants seem to have higher Hit Rates. This pattern of result may be due to the large number of trials per experimental block that resulted in too many correct identifications of the stimulus. Although, it is difficult to create a more balanced number of trials that elicit an ideal level of Hit Rates and False Alarm rates, future studies could attempt to increase the number of trials that may result in greater False Alarms. Additionally, the thresholding methods used throughout this thesis were thought to be an adequate means to obtain the motor thresholds of each participant. However, a different dynamic staircase thresholding method could provide a more accurate measure of participants' sensory thresholds. Taylor and Creelman (1967) developed the Parameter Estimated by Sequential Test (PEST) staircase method. They developed a thresholding procedure where by participants thresholds are adjusted and assessed between successive trials. The PEST method can determine if the current tactile presentation is at threshold or above or below it by adjusting subsequent tactile magnitudes based on the response of the previous trial. These adjustments are made based on the three rules set of PEST: condition for changing stimulus magnitude; incremental stimulus magnitude; finally condition of termination. These processes would be fully automated by use of a computer script that would indicate how each of the three rules (above) are to be met. This would then automatically implement the tactile magnitude step up if too many incorrect responses or step down if too many correct responses or complete the thresholding procedure as the predetermined criteria/rules have been met. The present thresholding method needed experimenter intervention to adjust the tactile intensity on the TactAmp, and need the correct intensity sound files to be loaded. During the PEST method, the tactile intensity would be automatically changing, a dynamic process during the actual thresholding task. The PEST method would also allow for a large number of trials to be conducted in a reasonable amount of time, which would increase the accuracy of participants' sensory thresholds and reduce the likelihood of participants anticipating the trials.

To help understand the findings of this ERP study more analysis would need to be conducted in determining the localization of the recorded ERP signals, by the use of low-resolution brain electromagnetic tomography (LORETA). LORETA is an offline (after data collection) mathematical modelling tool used to determine which cortical structures generated the source of the recorded surface ERPs. LORETA was not utilised for the present ERP investigation, as the tools were not available for this type of analysis to be conducted. Though LORETA uses mathematical modelling it would only provide an estimate of the EEG source location. A more robust technique to investigate cortical regions of activation would be to use functional magnetic resonance imaging (fMRI) to determine exactly which cortical regions are active during the SSDiT, this has not been done before. A functional investigation with ERP would help provide a better understanding of the cortical structures involved in the SSDiT; such as using Magneto encephalography (MEG).

By using the questionnaires, it was hoped that a deeper understanding of why these illusory tactile sensations occur more in some people compared to others. Brown (2004) theorised that over internalisation of external stressors and over focus on these factors could result in the manifestation of these illusory symptoms that subjectively were overwhelming in their existence. However, this relationship was not as robust in this thesis, there appeared to be no consistent relationship between participants responses on the questionnaires and their performances on the tasks, which was unexpected. Participants scoring for the SDQ-20 followed that of Nijenhuis (2003) taking into consideration that our sample was not from a clinical population, the low scores were taken as being 22 or lower and the high scorers were taken as being 28 or higher (Brown et al., 2010; Maaranen et al., 2005). The questionnaire scores of the present in this thesis may have not been defined enough to show significance of SDQ-20 groups. This could be due to the range of low and high scorers pooling closer to the maximum (low group 22) or minimum (high group 28). The scope of the difference may have been too weak to show as significant during covariate analysis. It is not clear what the range of Brown et al. (2010) participant scorers were, though they did have a very large sample size of 80 (40 low and 40 high scorers); the sample size of each experimental chapter was around 30. Future experiments can take this into consideration when using questionnaires as covariates.

To further strengthen the measure of internal awareness and interoceptive sensitivity an Interoceptive Accuracy (IAcc) task can be used. By measuring the IAcc of each participant the reliance on self-reporting questionnaires can be strengthened. It has been found that individuals with higher interoceptive accuracy would experience a greater illusory sensation. A measure of IAcc would be to use a heartbeat detection task, if they have greater accuracy in detecting heartbeats they have a higher IAcc and therefore more likely to experience illusory sensations (Suzuki et al., 2013; Aspell et al., 2013). The precision of the heartbeat task (IAcc) can also be connected to the exteroceptive awareness in relation to the self (Fotopoulou, 2013; Friston, 2010; Seth, 2013) which would also help strengthen the findings of Chapter 6 with the use of the MIRAGE.

Future directions

Future research can focus on perception of the body (body schema) in relation to illusory misperceptions in clinical and non-clinical populations by using different investigative methodologies (e.g., fMRI, Diffusion Tensor Imaging [DTI] Tractography, EEG, TMS, and the MIRAGE system) to understand why these sensations are expressed and what could be the aetiology of these sensations. Understanding how different cortical sensory pathways (white matter tracts) connect between different sensory modalities may help with understanding why neurological damage can result in illusory sensation. Investigating the impact of psychological stress with cortical functioning may also help in understanding how one's state of mind can affect the susceptibility in experiencing illusory somatosensory events and how this may affect top-down modulation; with future hope of developing effective interventions to reduce the impact of these illusory sensations.

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Appendices

Appendix A

Appendix B

Appendix A

Parietal region analysis tables and plots

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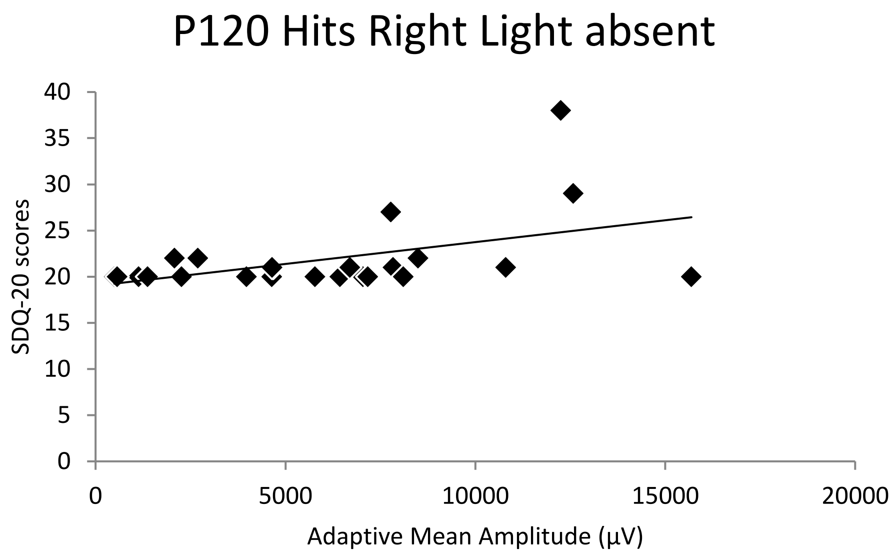
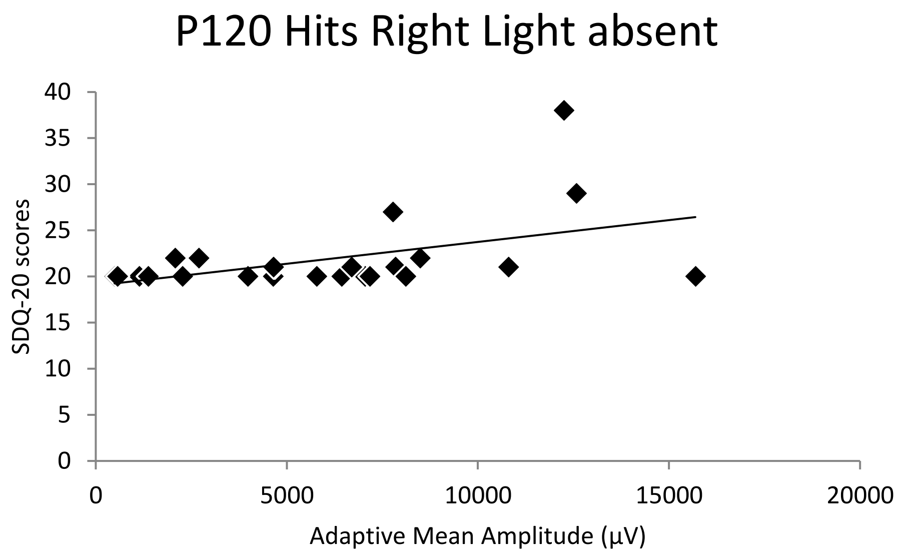
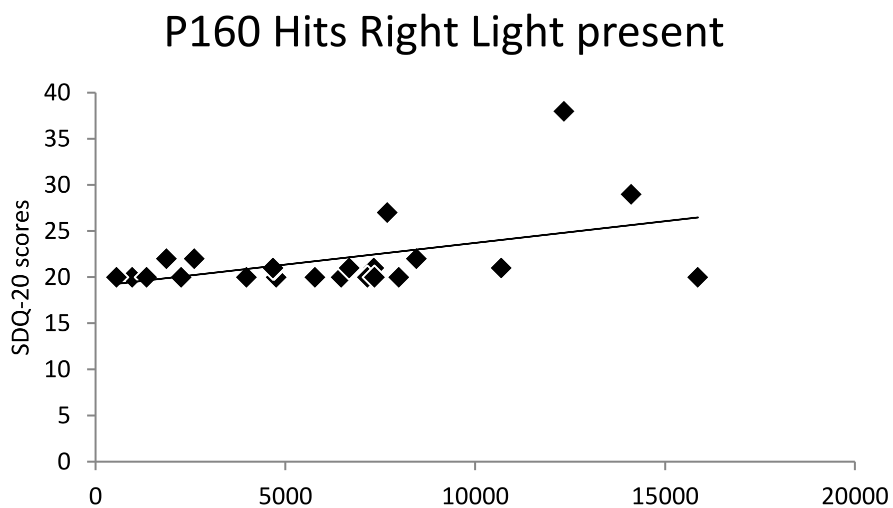
Hits

Table A.1. Parietal Region ANCOVA - Univariate and Pearson's correlation results across all components for Hits with SDQ-20 (*denotes significance).

			Univariate Analysis of Variance		Pearson's Correlation	
Component	**Region**	**Light**	F	p	r	p
P120	Left	Present	3.75	.066		
		Absent	3.55	.07		
	Right	Present	6.55	.02*	.48	.02*
		Absent	6.09	.02*	.47	.02*
P160	Left	Present	3.75	.066		
		Absent	3.55	.07		
	Right	Present	6.55	.02*	.48	.02*
		Absent	6.09	.02*	.47	.02*
P360	Left	Present	3.75	.066		
		Absent	3.55	.07		
	Right	Present	6.55	.02*	.48	.02*
		Absent	6.08	.02*	.47	.02*
P400	Left	Present	3.75	.066		
		Absent	3.55	.07		
	Right	Present	6.55	.02*	.48	.02*
		Absent	6.08	.02*	.47	.02*







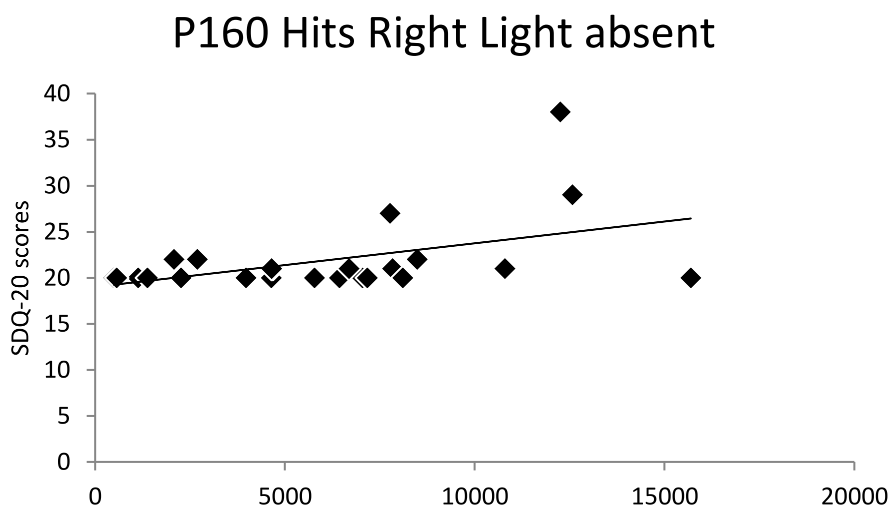


Figure. A.1. Showing the relationship between the AMA of Hits for P120 and P160 during Light absent and present trials with the SDQ-20 (with trend line of best fit). There is a positive relationship between SDQ-20 and the AMA of Hits during both Light conditions; those who scored higher on the SDQ-20 had greater Hit AMA.

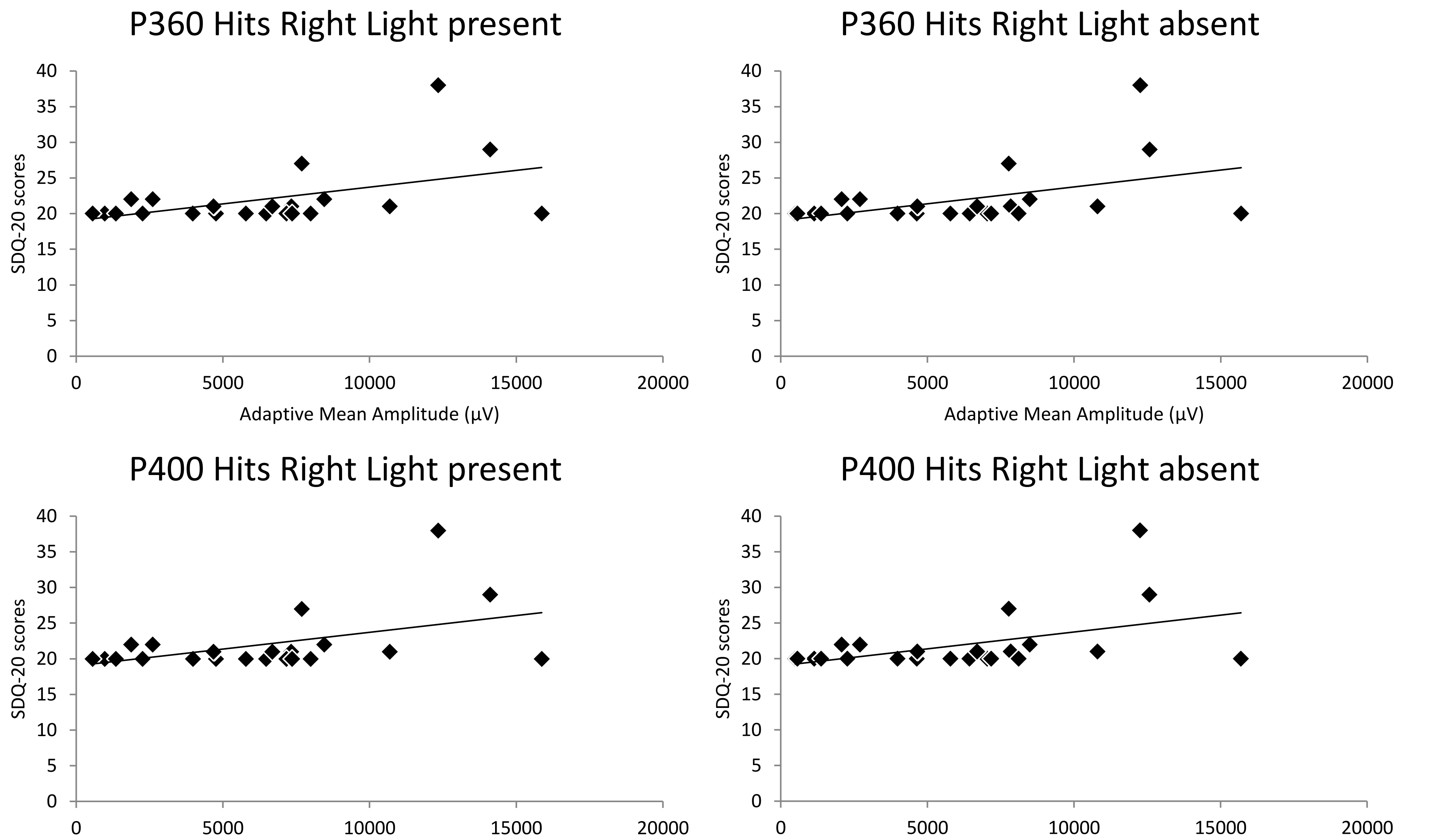


Figure.A.2. Showing the relationship between the AMA of Hits for P360 and P400 during Light absent and present trials with the SDQ-20 (with trend line of best fit). There is a positive relationship between SDQ-20 and the AMA of Hits during both Light conditions; those who scored higher on the SDQ-20 had greater Hit AMA.

False Alarms

Table.A.3. Parietal region selection ANCOVA - Univariate and Pearson's correlation results across all components for False Alarms with SDQ-20 (*denotes significance).

			Univariate Analysis of Variance		Pearson's Correlation	
Component	**Region**	**Light**	F	p	r	p
P120	Left	Present	4.46	.046*	.41	.046*
		Absent	5.20	.03*	.44	.03*
	Right	Present	4.90	.04*	.43	.04*
		Absent	5.711	.03*	.45	.03*
P160	Left	Present	4.46	.046*	.41	.046*
		Absent	5.21	.03*	.44	.03*
	Right	Present	4.90	.03*	.43	.04*
		Absent	5.71	.03*	.45	.03*
P360	Left	Present	4.46	.046*	.41	.046*
		Absent	5.20	.03*	.44	.03*
	Right	Present	4.89	.04*	.43	.04*
		Absent	5.71	.03*	.45	.03*
P400	Left	Present	4.46	.046*	.41	.046*
		Absent	5.20	.03*	.44	.03*
	Right	Present	4.89	.04*	.43	.04*
		Absent	5.71	.03*	.45	.03*

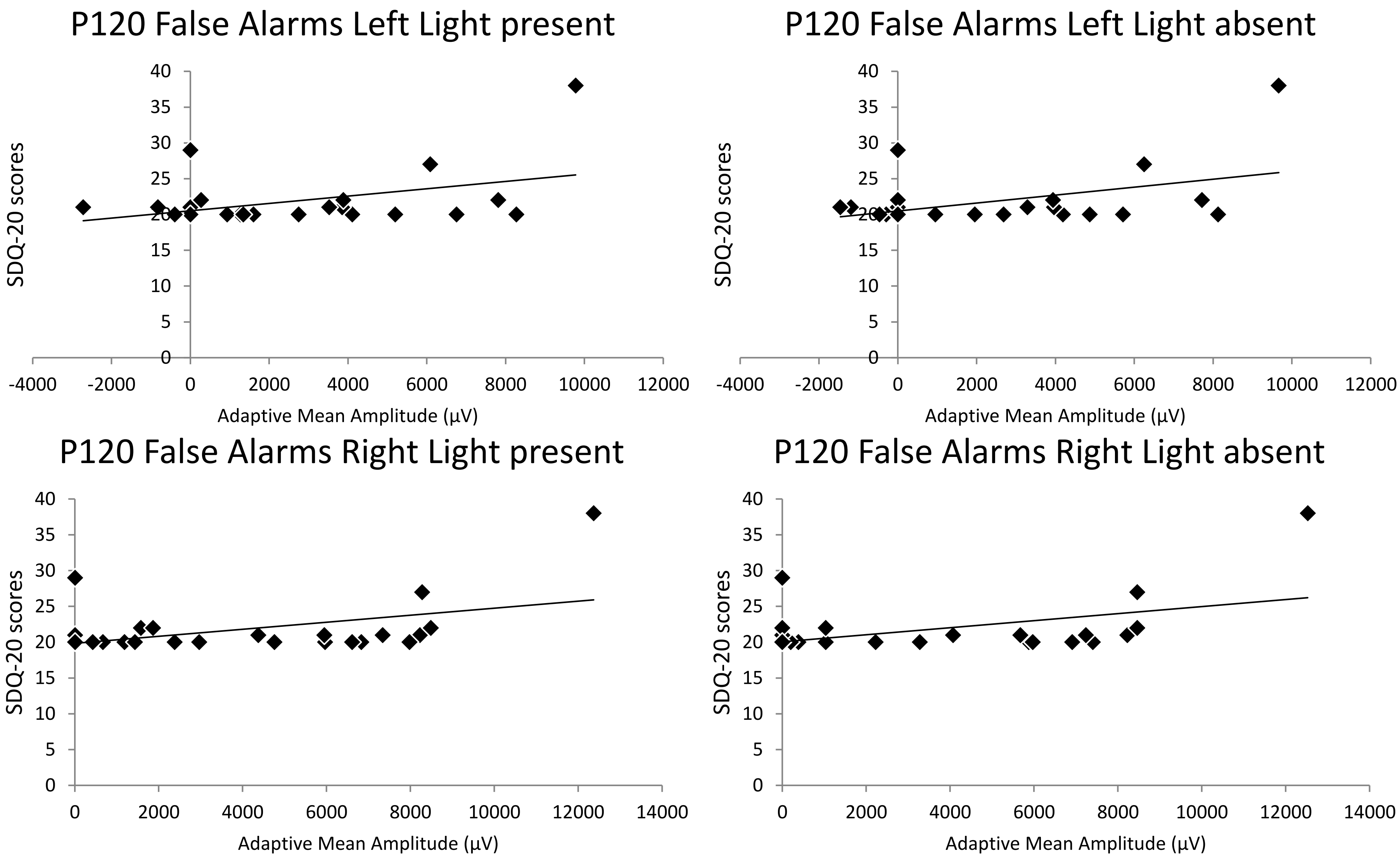


Figure.A.3. Showing the relationship between the AMA of False Alarms for P120 during Light present and absent trials with the SDQ-20 over Left and Right electrode selections (with trend line of best fit). There is a positive relationship between SDQ-20 and the AMA of False Alarms during both Light conditions and over the left and right electrodes; those who scored higher on the SDQ-20 had greater False Alarm AMAs.

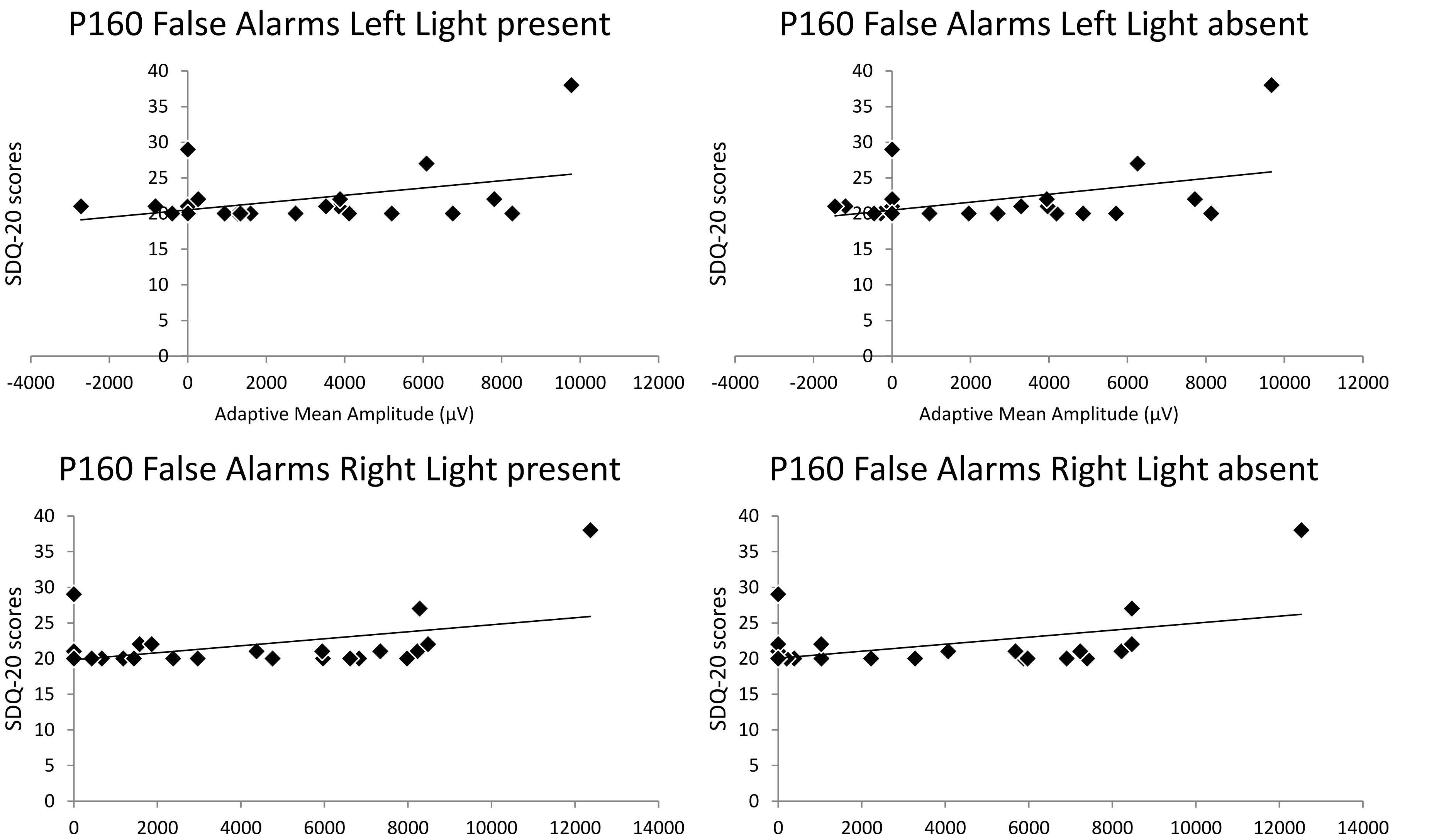


Figure.A.4. Showing the relationship between the AMA of False Alarms for P160 during Light present and absent trials with the SDQ-20 over Left and Right electrode selections (with trend line of best fit). There is a positive relationship between SDQ-20 and the AMA of False Alarms during both Light conditions and over the left and right electrodes; those who scored higher on the SDQ-20 had greater False Alarm AMAs.

Correct Rejections

Table.A.4. Parietal region ANCOVA - Univariate and Pearson's correlation results across all components for Correct Rejections with SDQ-20 (*denotes significance).

			Univariate Analysis of Variance		Pearson's Correlation	
Component	**Region**	**Light**	F	p	r	p
P120	Left	Present	3.13	.09		
		Absent	3.87	.06		
	Right	Present	5.62	.03*	.45	.03*
		Absent	6.40	.02*	.48	.02*
P160	Left	Present	3.13	.09		
		Absent	3.87	.06		
	Right	Present	5.62	.03*	.45	.03*
		Absent	6.40	.02*	.48	.02*
P360	Left	Present	3.13	.09		
		Absent	3.86	.06		
	Right	Present	5.62	.03*	.45	.03*
		Absent	6.40	.02*	.48	.02*
P400	Left	Present	3.13	.09		
		Absent	3.87	.06		
	Right	Present	5.61	.03*	.45	.03*
		Absent	6.40	.02*	.48	.02*

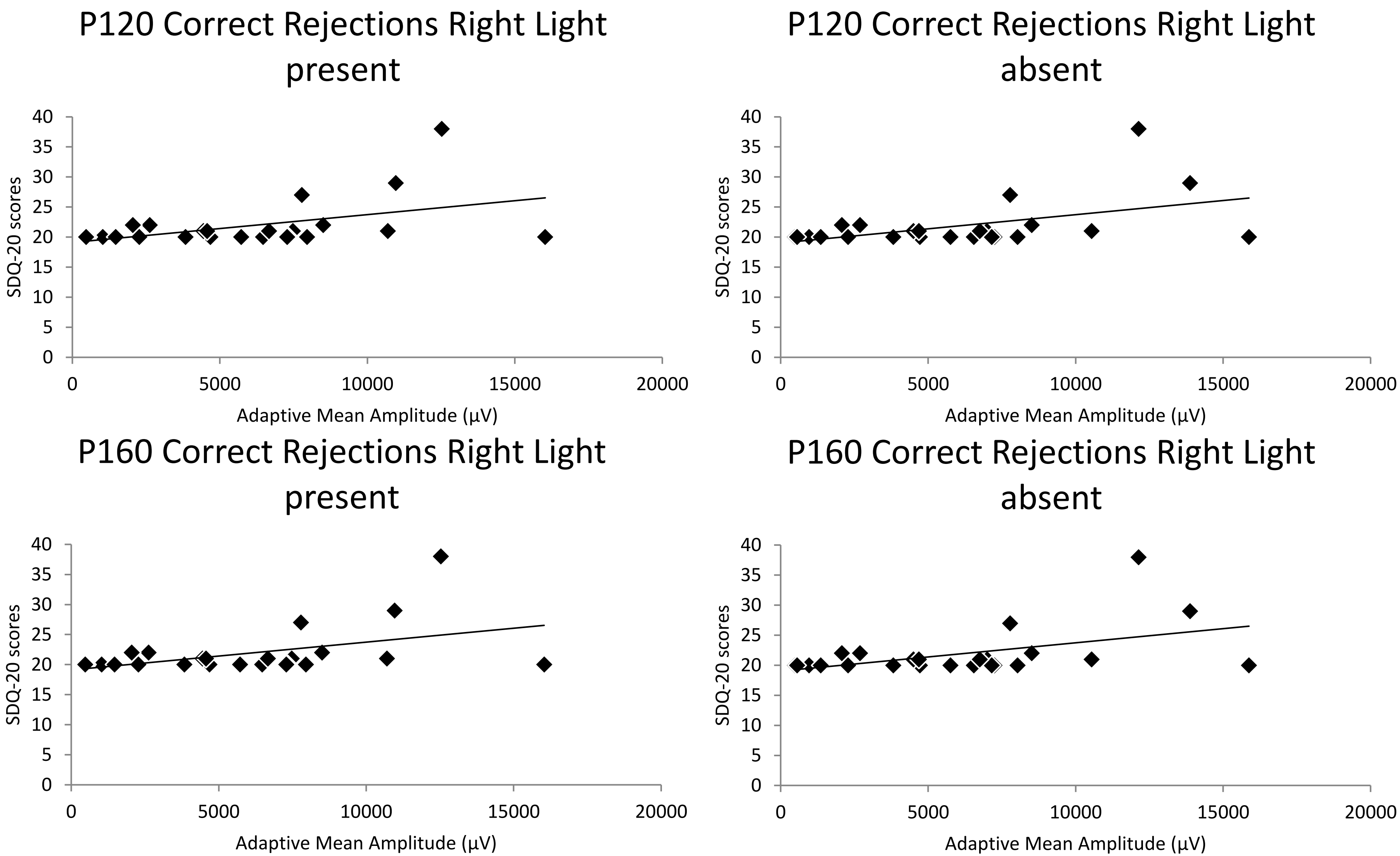


Figure.A.5. Showing the relationship between the AMA of Correct Rejections for P120 and P160 during Light absent and present trials with the SDQ-20 (with trend line of best fit). There is a positive relationship between SDQ-20 and the AMA of Hits during both Light conditions; those who scored higher on the SDQ-20 had greater Correct Rejection AMA.

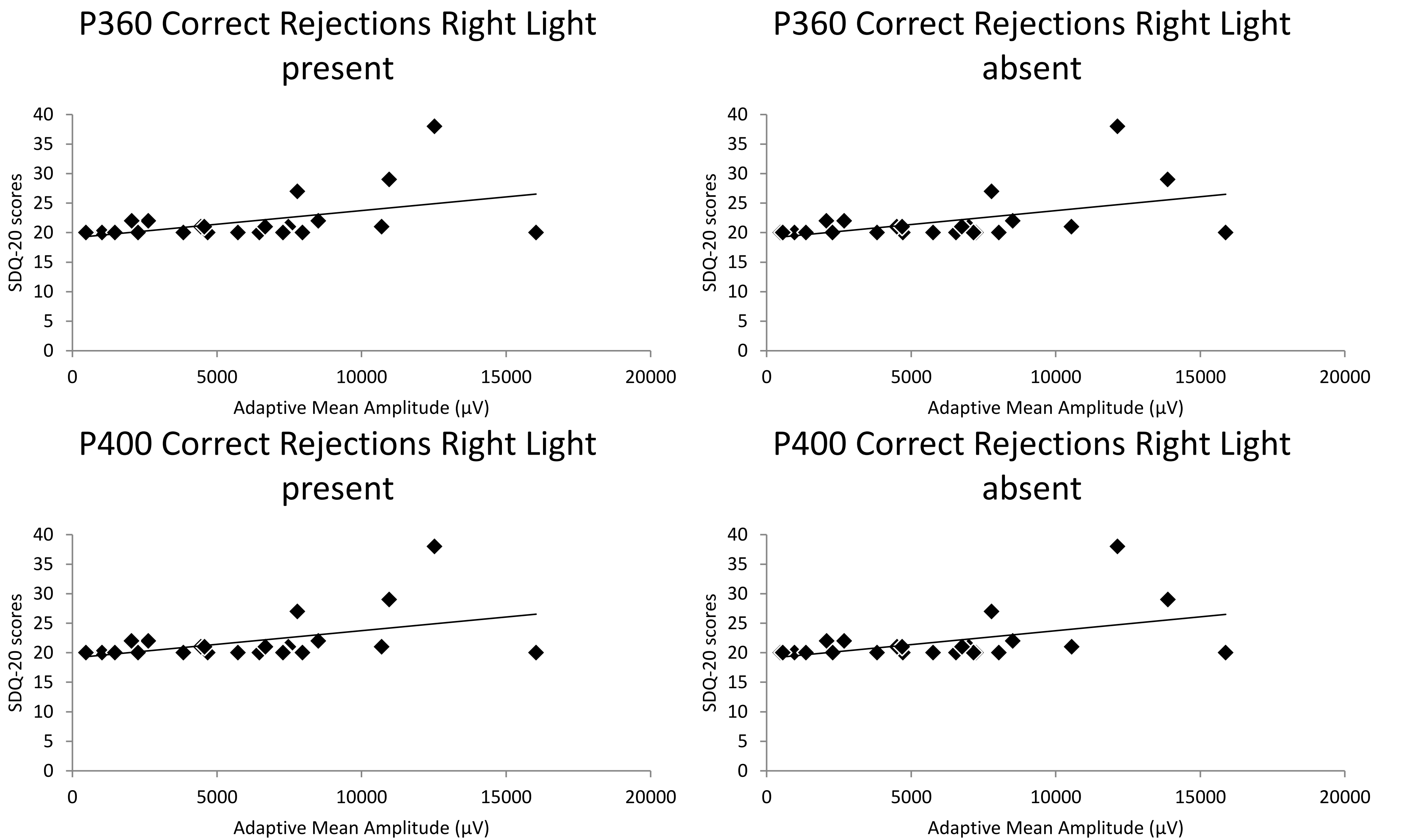


Figure.A.6. Showing the relationship between the AMA of Correct Rejections for P360 and P400 during Light absent and present trials with the SDQ-20 (with trend line of best fit). There is a positive relationship between SDQ-20 and the AMA of Hits during both Light conditions; those who scored higher on the SDQ-20 had greater Correct Rejection AMA.

Appendix B

Frontal Region analysis tables and plots

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Hits

Table.B.1. Frontal Region ANCOVA - Univariate and Pearson’s correlation results across all components for Hits with STAI-State (*denotes significance).

			Univariate Analysis of Variance		Pearson’s Correlation	
Component	**Region**	**Light**	F	p	r	p
P120	Left	Present	9.35	.006*	-0.55	.006*
		Absent	8.99	.007*	-0.54	.007*
	Right	Present	9.12	.006*	-0.54	.006*
		Absent	9.06	.006*	-0.54	.006*
P160	Left	Present	9.35	.006*	-0.55	.006*
		Absent	8.99	.007*	-0.54	.007*
	Right	Present	9.12	.006*	-0.54	.006*
		Absent	9.06	.006*	-0.54	.006*
P360	Left	Present	9.35	.006*	-0.55	.006*
		Absent	8.98	.007*	-0.54	.007*
	Right	Present	9.10	.006*	-0.54	.006*
		Absent	9.05	.006*	-0.54	.006*
P400	Left	Present	9.35	.006*	-0.55	.006*
		Absent	8.98	.007*	-0.54	.007*
	Right	Present	9.10	.006*	-0.54	.006*
		Absent	9.05	.006*	-0.54	.006*

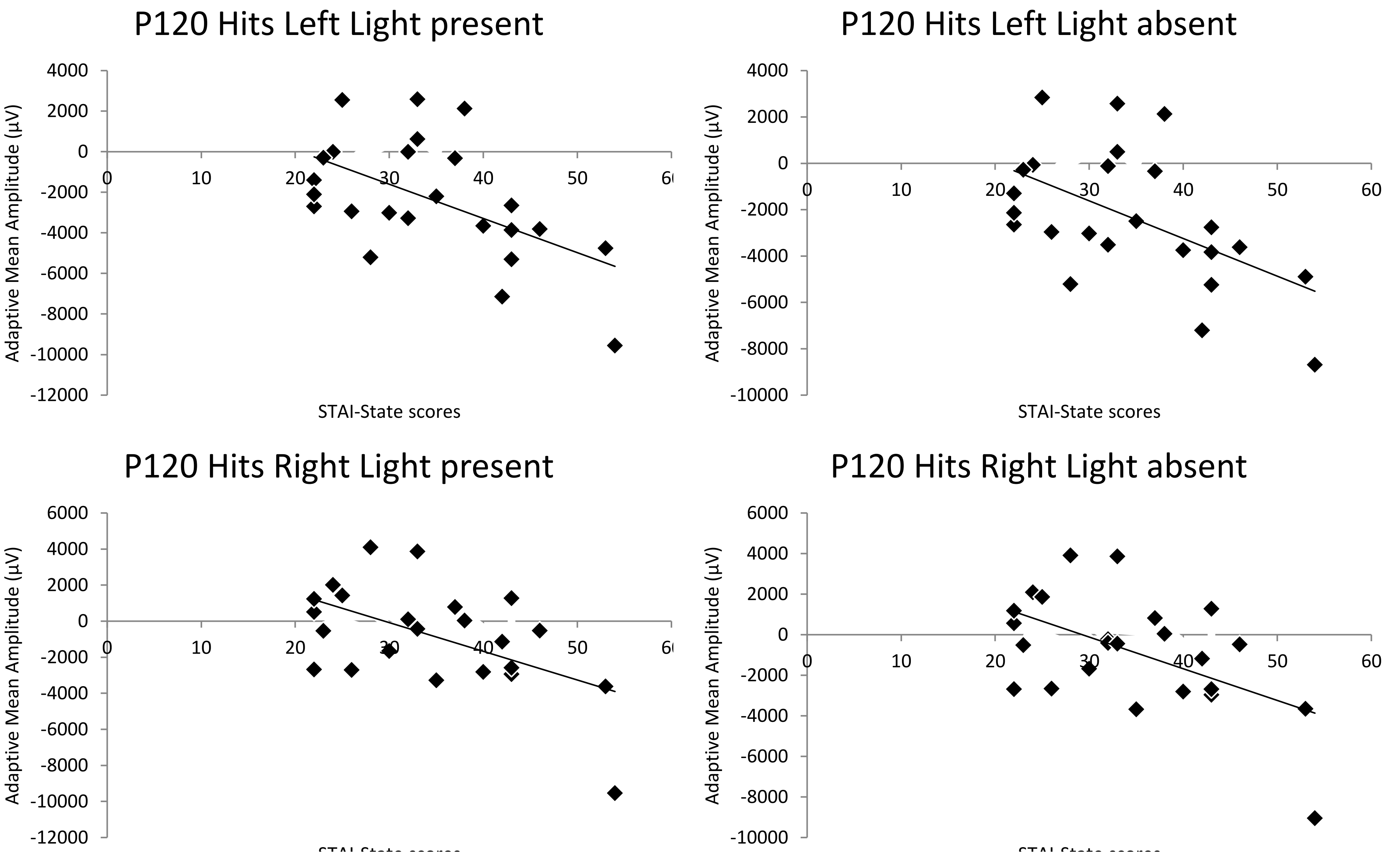


Figure B.1. Showing the relationship between the Frontal Left and Right region AMA of Hits for P120 during Light absent and present trials with STAI-State scores (with trend line of best fit). There is a negative relationship between STAI-State and the AMA of Hits during both Light conditions; those who had more positive AMAs for Hits had a lower score on the STAI-State.

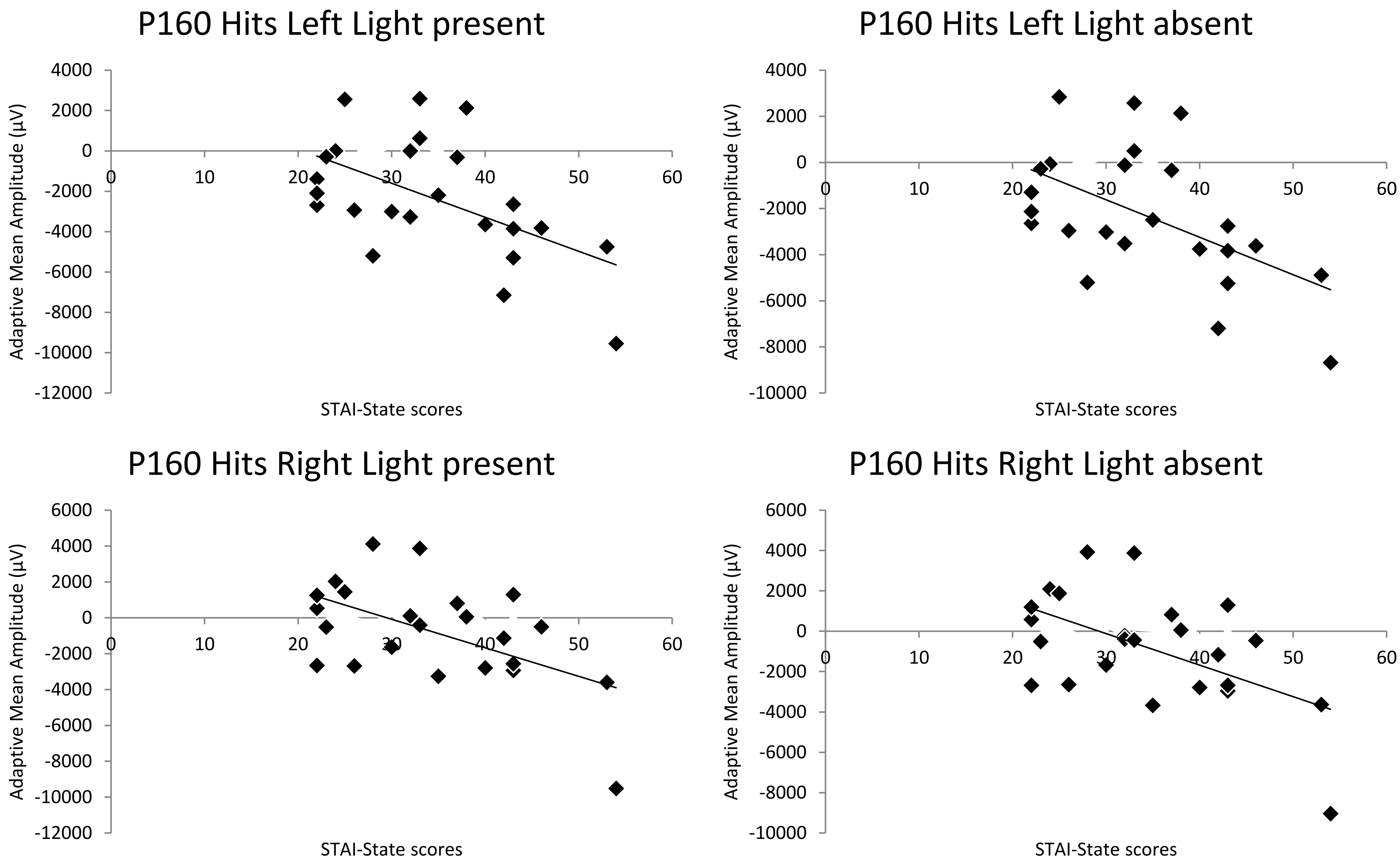


Figure B.2. Showing the relationship between the Frontal Left and Right region AMA of Hits for P160 during Light absent and present trials with STAI-State scores (with trend line of best fit). There is a negative relationship between STAI-State and the AMA of Hits during both Light conditions; those who had more positive AMAs for Hits had a lower score on the STAI-State.

Table.B.2. Frontal Region ANCOVA - Univariate and Pearson's correlation results across all components for Hits with STAI-Trait (*denotes significance).

			Univariate Analysis of Variance		Pearson's Correlation	
Component	**Region**	**Light**	F	p	r	p
P120	Left	Present	0.24	.63		
		Absent	0.20	.66		
	Right	Present	4.37	.048*	-0.41	.048*
		Absent	4.21	.052		
P160	Left	Present	0.24	.63		
		Absent	0.20	.66		
	Right	Present	4.37	.048*	-0.41	.048*
		Absent	4.21	.052		
P360	Left	Present	0.24	.63		
		Absent	0.20	.66		
	Right	Present	4.37	.048*	-0.41	.048*
		Absent	4.21	.052		
P400	Left	Present	0.24	.63		
		Absent	0.20	.66		
	Right	Present	4.36	.048*	-0.41	.048*
		Absent	4.21	.052		

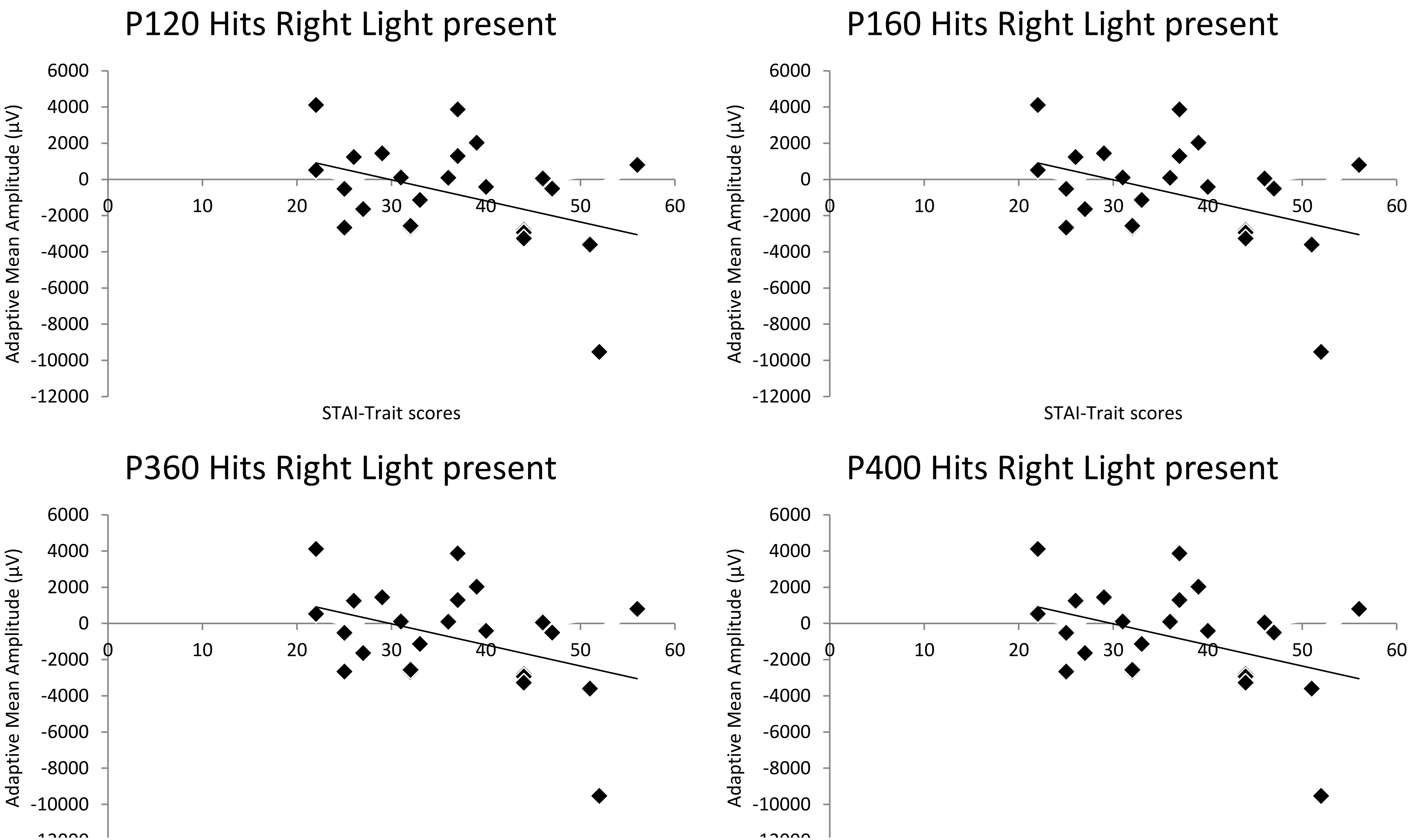


Figure B.5. Showing the relationship between the Frontal Right region AMA of Hits for P120, P160, P360 and P400 during Light present trials with STAI-Trait scores (with trend line of best fit). There is a negative relationship between STAI-Trait and the AMA of Hits during Right region and Light present conditions; those who had more positive AMAs for Hits had a lower score on the STAI-Trait.

Incorrect Response

Table.B.3. Frontal Region ANCOVA - Univariate and Pearson's correlation results across all components for Incorrect Responses with PHQ-15 (*denotes significance).

			Univariate Analysis of Variance		Pearson's Correlation	
Component	**Region**	**Light**	F	p	r	p
P120	Left	Present	2.00	.17		
		Absent	3.06	.09		
	Right	Present	4.90	.04*	-0.43	.04*
		Absent	4.45	.046*	-0.41	.046*
P160	Left	Present	2.00	.17		
		Absent	3.07	.09		
	Right	Present	4.89	.04*	-0.43	.04*
		Absent	4.45	.046*	-0.41	.046*
P360	Left	Present	2.00	.17		
		Absent	3.06	.09		
	Right	Present	4.90	.04*	-0.43	.04*
		Absent	4.46	.046*	-0.41	.046*
P400	Left	Present	2.00	.17		
		Absent	3.06	.09		
	Right	Present	4.91	.04*	-0.43	.04*
		Absent	4.46	.046*	-0.41	.046*

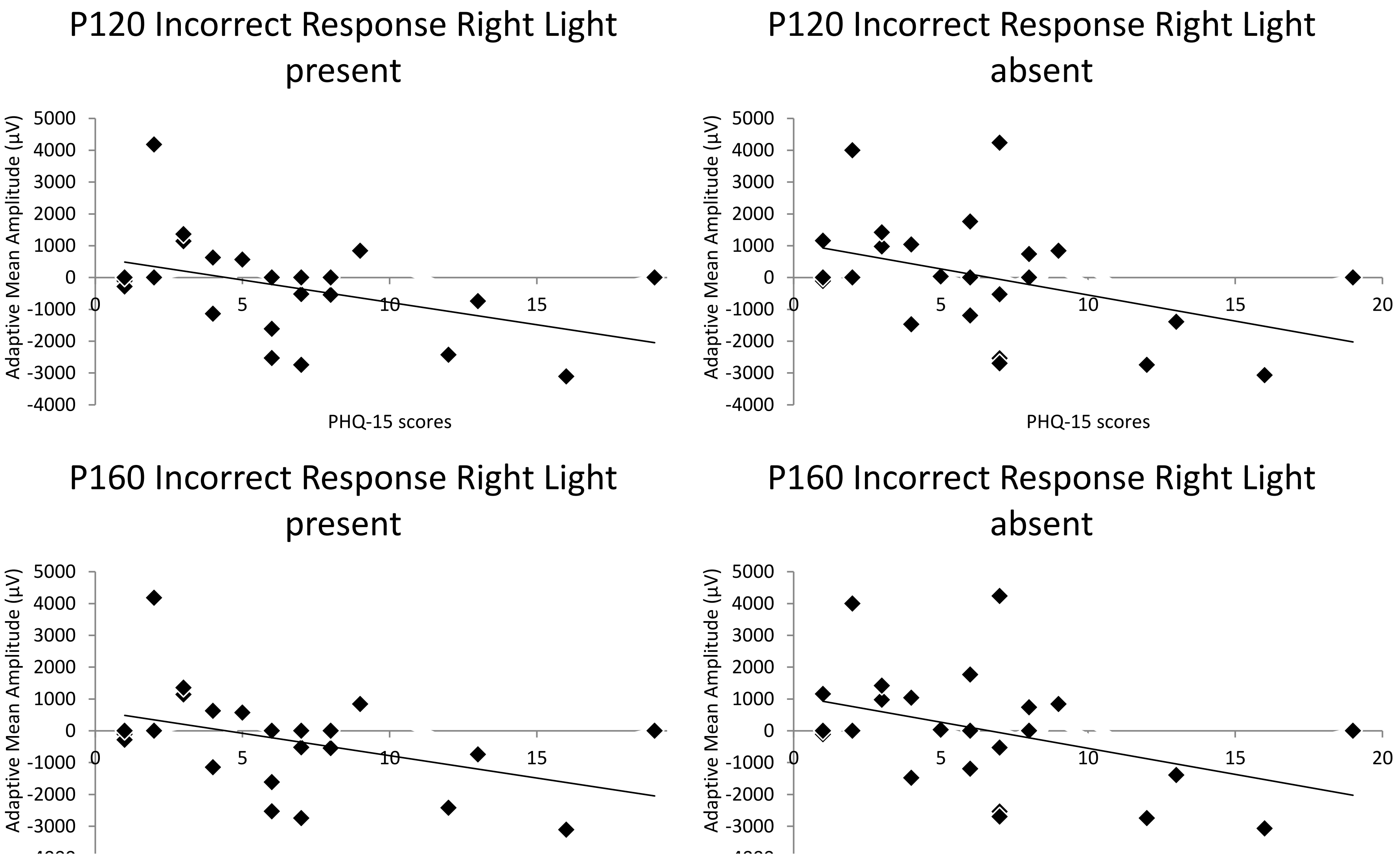


Figure B.6. Showing the relationship between the Frontal Right region AMA of Incorrect Responses for P120 and P160 during Light absent and present trials with PHQ-15 scores (with trend line of best fit). There is a negative relationship between PHQ-15 and the Right region AMA of Incorrect Responses during both Light conditions; those who had more positive AMAs for Incorrect Responses had a lower score on the PHQ-15.

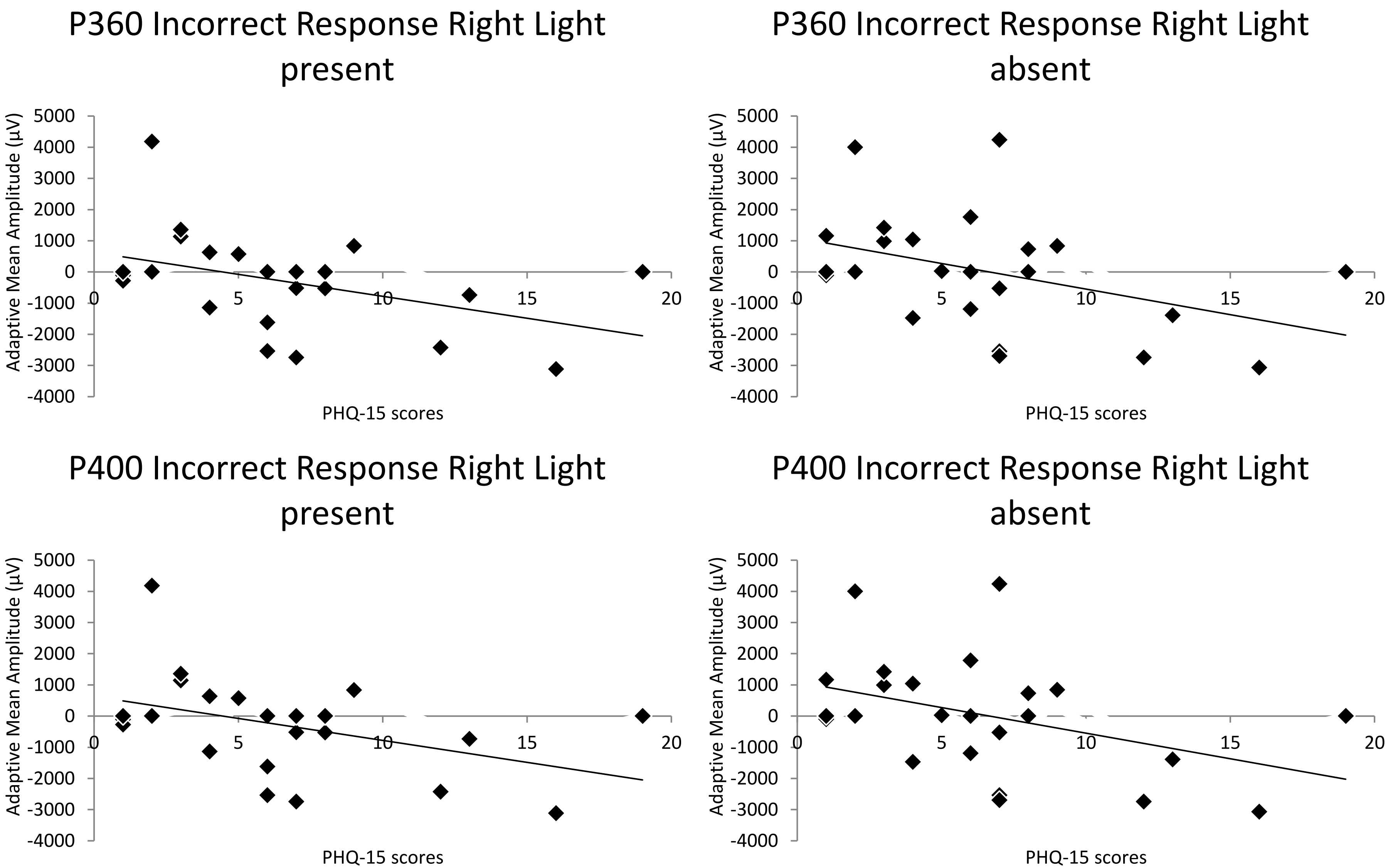


Figure B.7. Showing the relationship between the Frontal Right region AMA of Incorrect Responses for P360 and P400 during Light absent and present trials with PHQ-15 scores (with trend line of best fit). There is a negative relationship between PHQ-15 and the Right region AMA of Incorrect Responses during both Light conditions; those who had more positive AMAs for Incorrect Responses had a lower score on the PHQ-15.

False Alarms

Table.B.4. Frontal Region ANCOVA - Univariate and Pearson's correlation results across all components for False Alarms with PHQ-15 (*denotes significance).

			Univariate Analysis of Variance		Pearson's Correlation	
Component	**Region**	**Light**	F	p	r	p
P120	Left	Present	9.34	.006*	-0.55	.006*
		Absent	7.58	.01*	-0.51	.01*
	Right	Present	7.87	.01*	-0.51	.01*
		Absent	7.93	.01*	-0.52	.01*
P160	Left	Present	9.34	.006*	-0.55	.006*
		Absent	7.57	.01*	-0.51	.01*
	Right	Present	7.87	.01*	-0.51	.01*
		Absent	7.93	.01*	-0.52	.01*
P360	Left	Present	9.34	.006*	-0.55	.006*
		Absent	7.59	.01*	-0.51	.01*
	Right	Present	7.88	.01*	-0.51	.01*
		Absent	7.95	.01*	-0.52	.01*
P400	Left	Present	9.34	.006*	-0.55	.006*
		Absent	7.58	.01*	-0.51	.01*
	Right	Present	7.88	.01*	-0.51	.01*
		Absent	7.93	.01*	-0.52	.01*

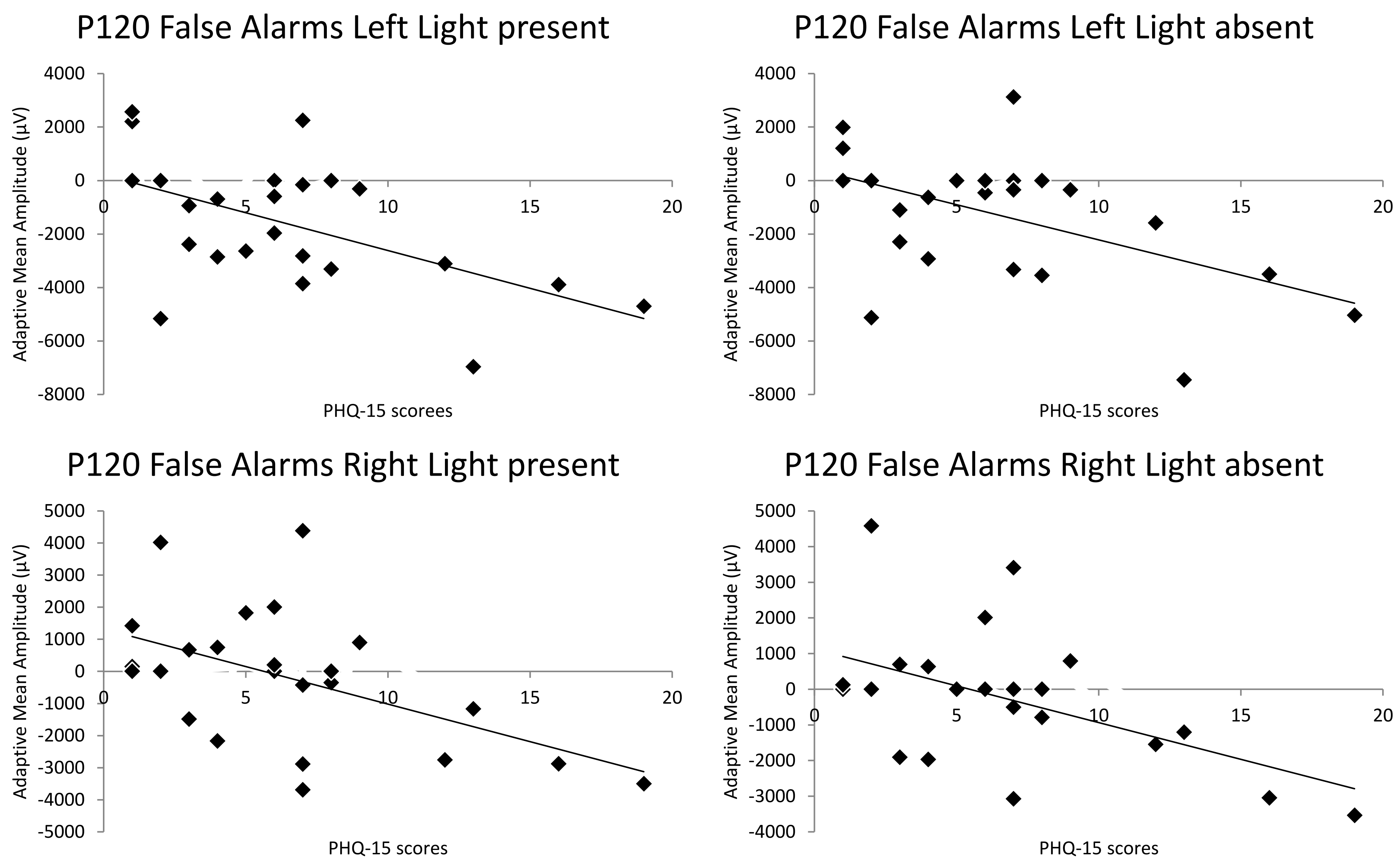


Figure.B.8. Showing the relationship between the AMA of False Alarms for P120 during Light present and absent trials with PHQ-15 scores over Left and Right frontal regions (with trend line of best fit). There is a negative relationship between PHQ-15 and the AMA of False Alarms during both Light conditions and over the left and right electrodes; those with more positive False Alarm AMAs scored lower on the PHQ-15.

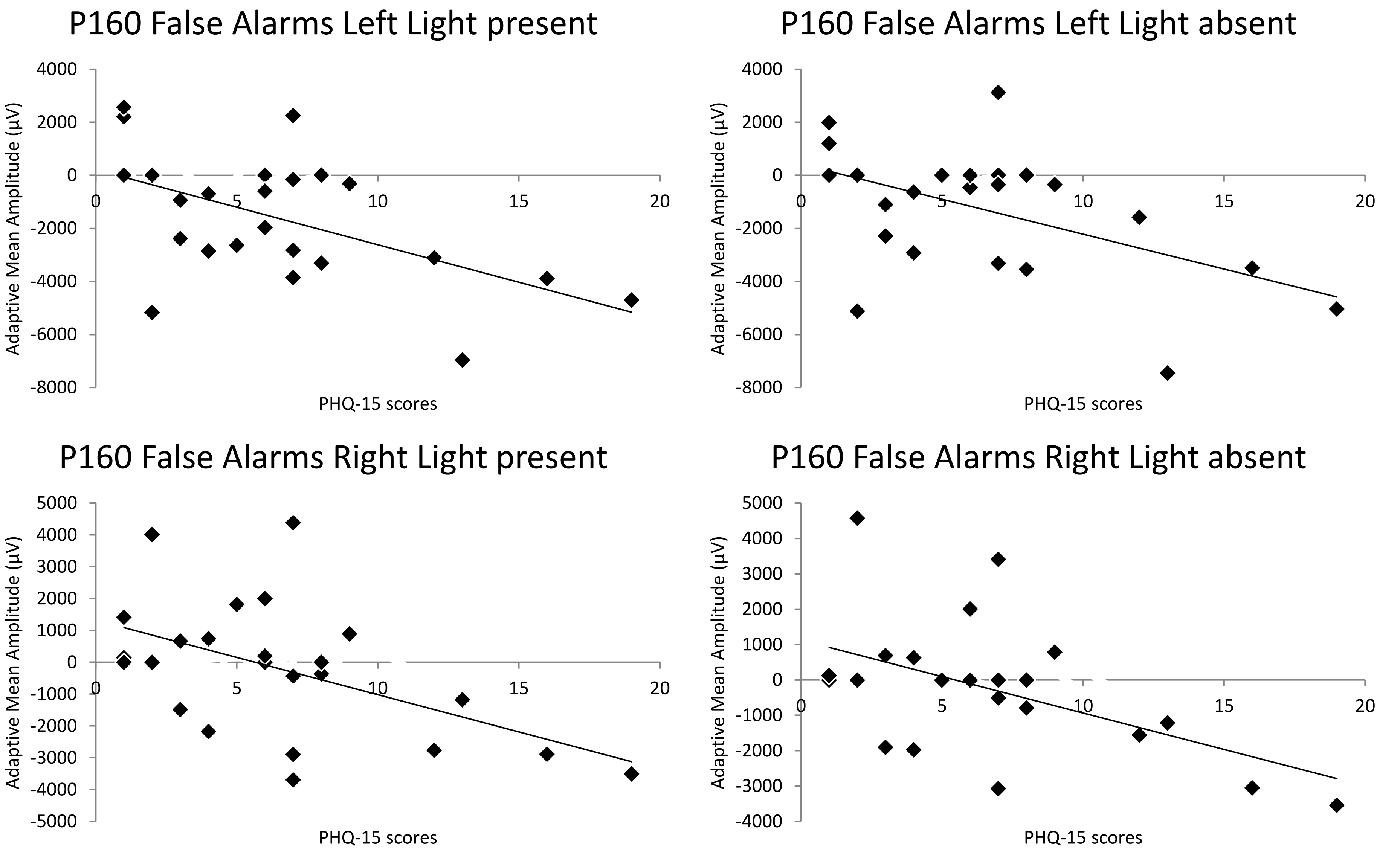
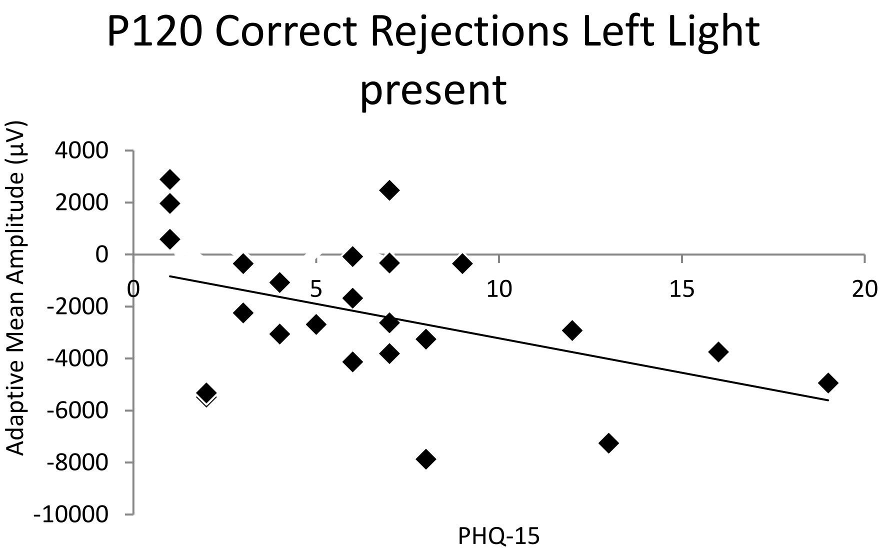


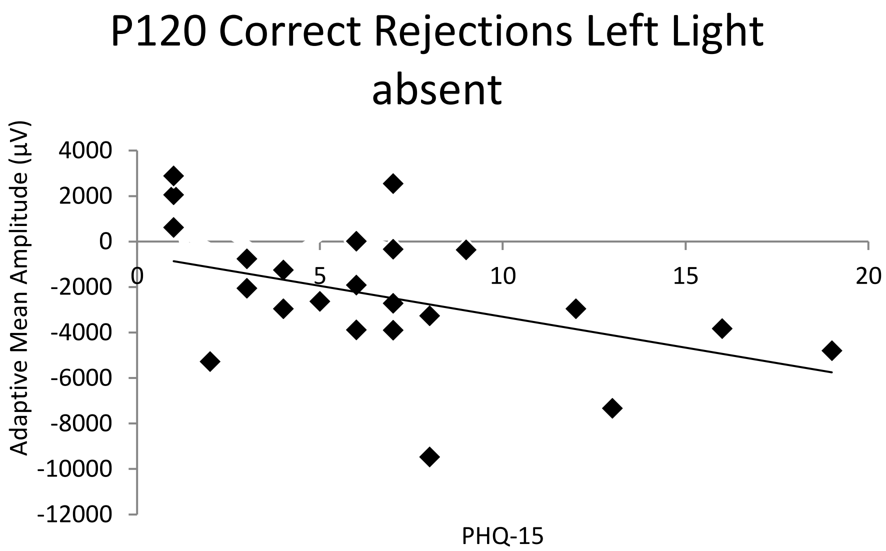
Figure.B.9. Showing the relationship between the AMA of False Alarms for P160 during Light present and absent trials with PHQ-15 scores over Left and Right frontal regions (with trend line of best fit). There is a negative relationship between PHQ-15 and the AMA of False Alarms during both Light conditions and over the left and right electrodes; those with more positive False Alarm AMAs scored lower on the PHQ-15.

Correct Rejections

Table.B.5. Frontal region ANCOVA - Univariate and Pearson's correlation results across all components for Correct Rejections with PHQ-15 (*denotes significance).

			Univariate Analysis of Variance		Pearson's Correlation	
Component	**Region**	**Light**	F	p	r	p
P120	Left	Present	5.14	.03*	-0.44	.03*
		Absent	4.87	.04*	-0.43	.04*
	Right	Present	4.73	.04*	-0.42	.04*
		Absent	4.14	.054		
P160	Left	Present	5.14	.03*	-0.44	.03*
		Absent	4.87	.04*	-0.43	.04*
	Right	Present	4.73	.04*	-0.42	.04*
		Absent	4.14	.054		
P360	Left	Present	5.14	.03*	-0.44	.03*
		Absent	4.87	.04*	-0.43	.04*
	Right	Present	4.73	.04*	-0.42	.04*
		Absent	4.14	.054		
P400	Left	Present	5.14	.03*	-0.44	.03*
		Absent	4.87	.04*	-0.43	.04*
	Right	Present	4.73	.04*	-0.42	.04*
		Absent	4.14	.054		





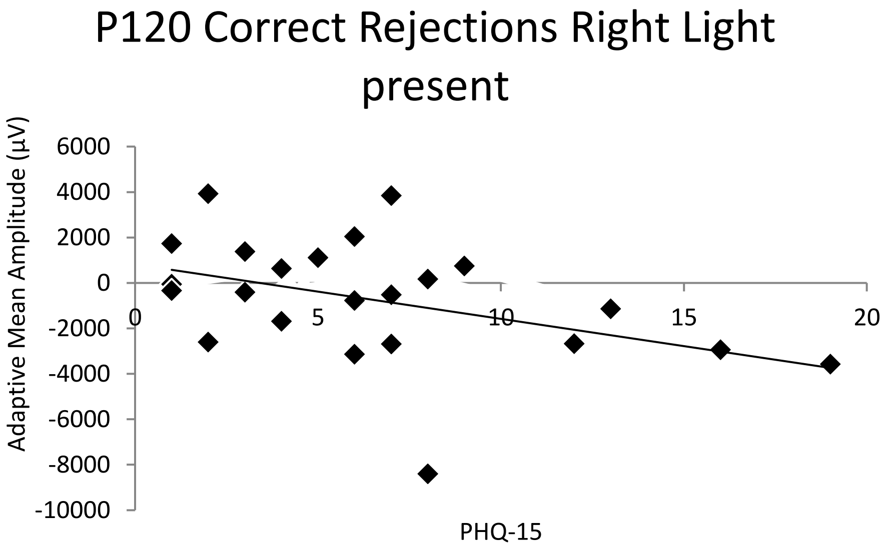


Figure.B.12. Showing the relationship between the AMA of Correct Rejections for P120 over Left frontal region during Light present and absent trials and Right frontal region during Light present trials with PHQ-15 scores (with trend line of best fit). There is a negative relationship between PHQ-15 and the AMA of Correct Rejections; those with more positive Correct Rejection P120 AMA scored lower on the PHQ-15.

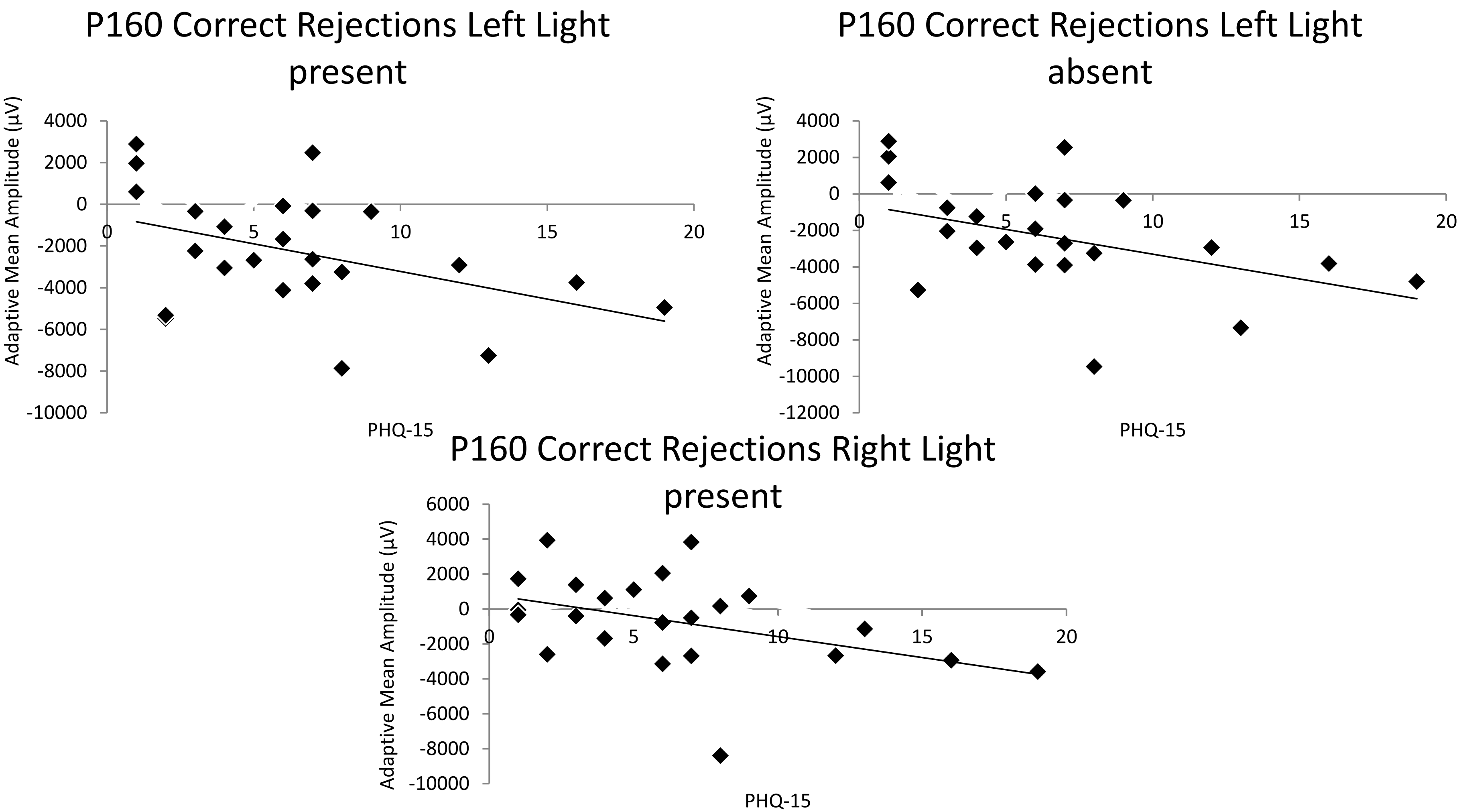


Figure.B.13. Showing the relationship between the AMA of Correct Rejections for P160 over Left frontal region during Light present and absent trials and Right frontal region during Light present trials with PHQ-15 scores (with trend line of best fit). There is a negative relationship between PHQ-15 and the AMA of Correct Rejections; those with more positive Correct Rejection P160 AMA scored lower on the PHQ-15.

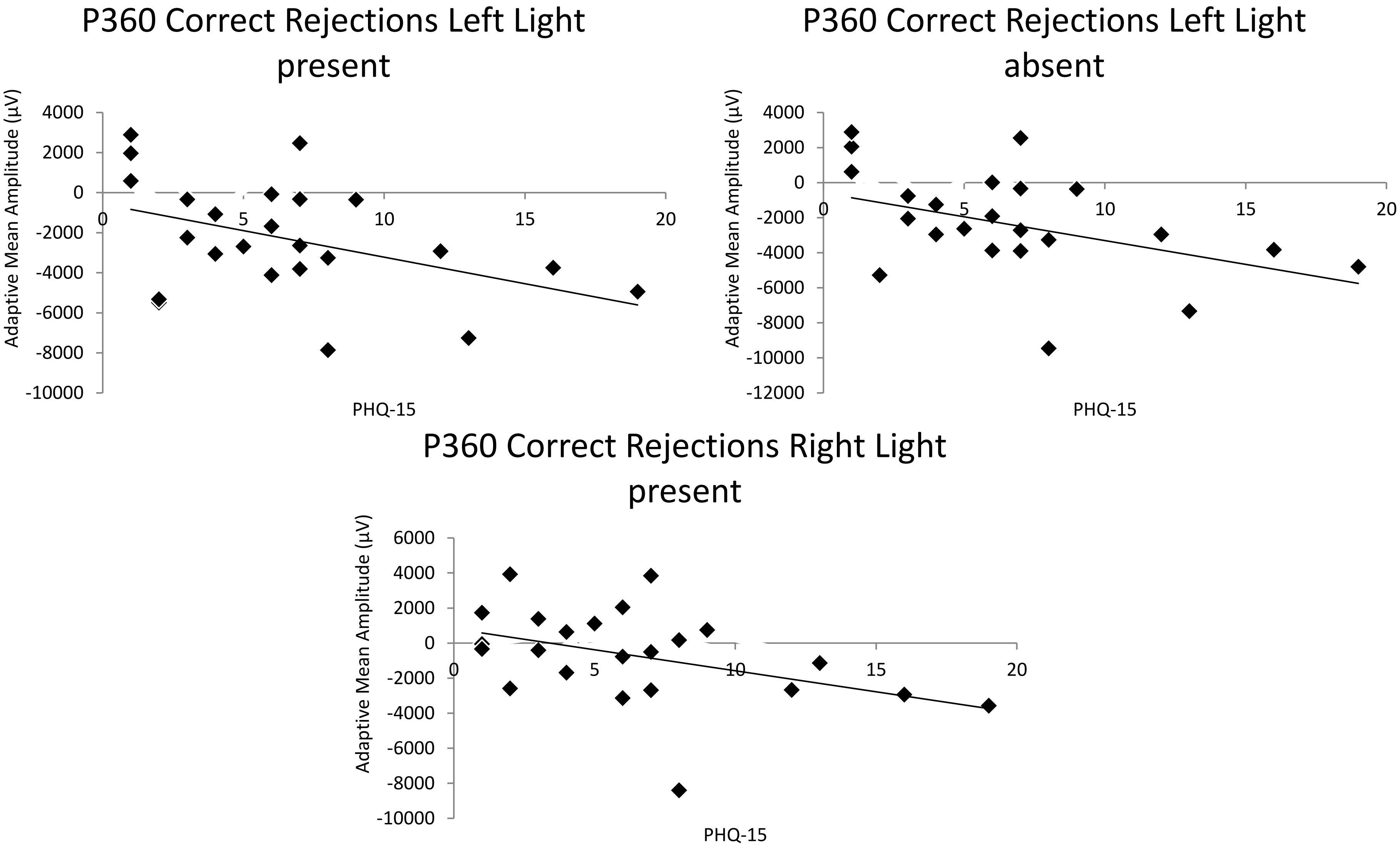
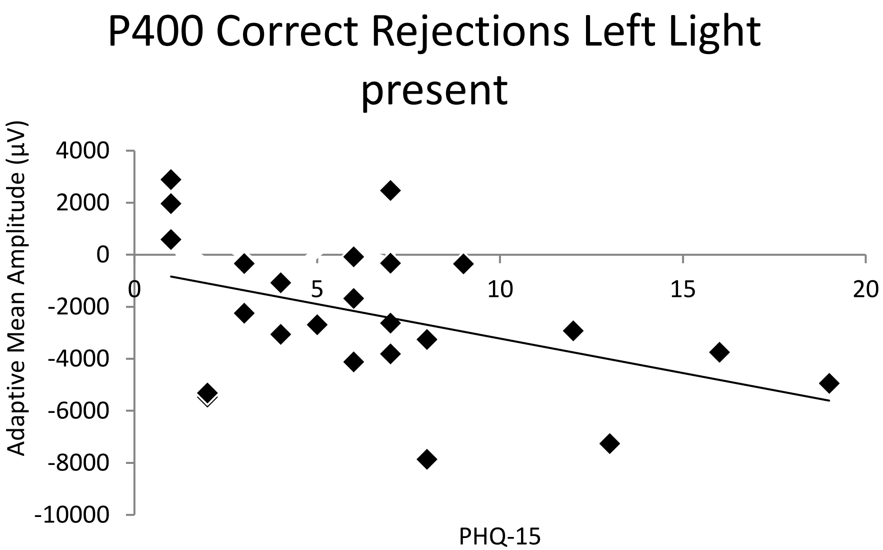
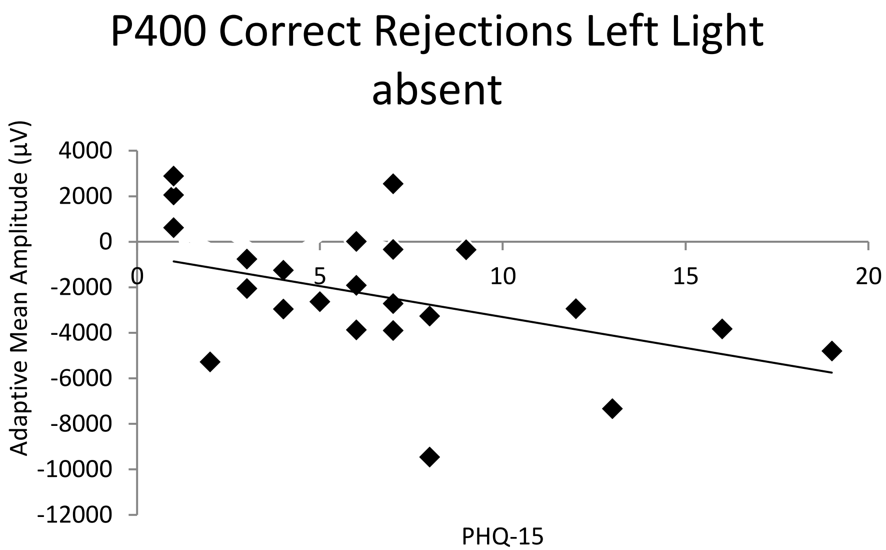


Figure.B.14. Showing the relationship between the AMA of Correct Rejections for P360 over Left frontal region during Light present and absent trials and Right frontal region during Light present trials with PHQ-15 scores (with trend line of best fit). There is a negative relationship between PHQ-15 and the AMA of Correct Rejections; those with more positive Correct Rejection P360 AMA scored lower on the PHQ-15.





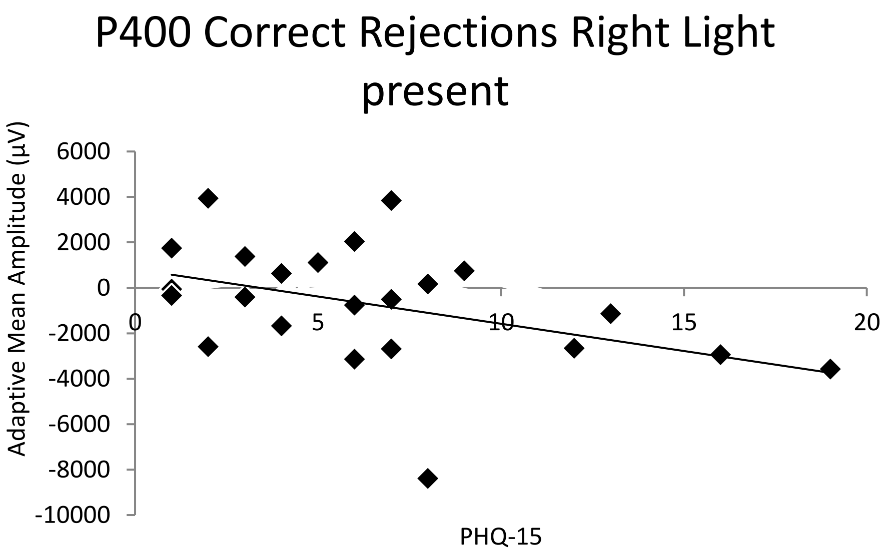
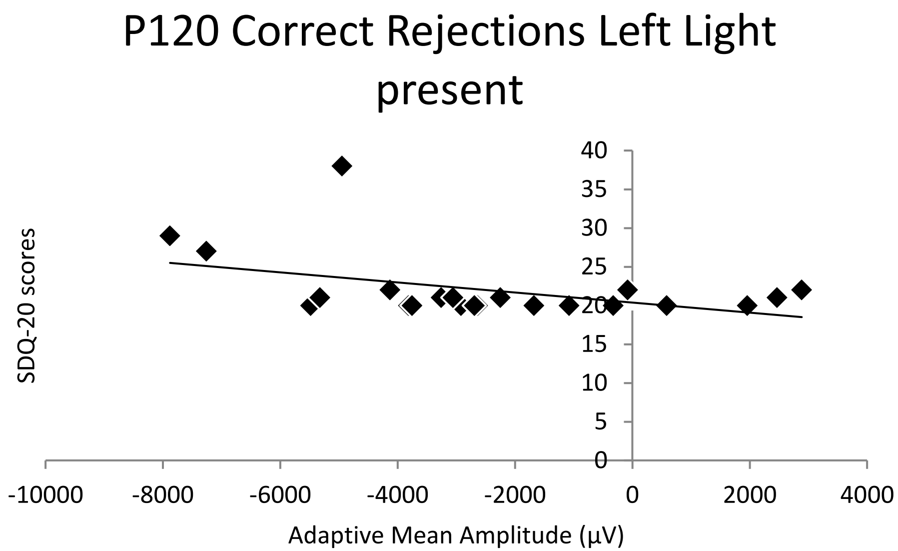
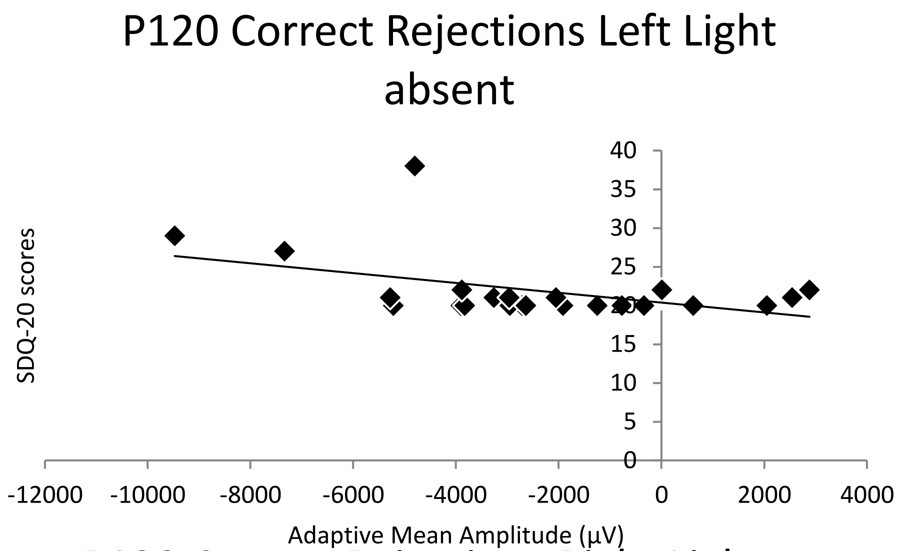


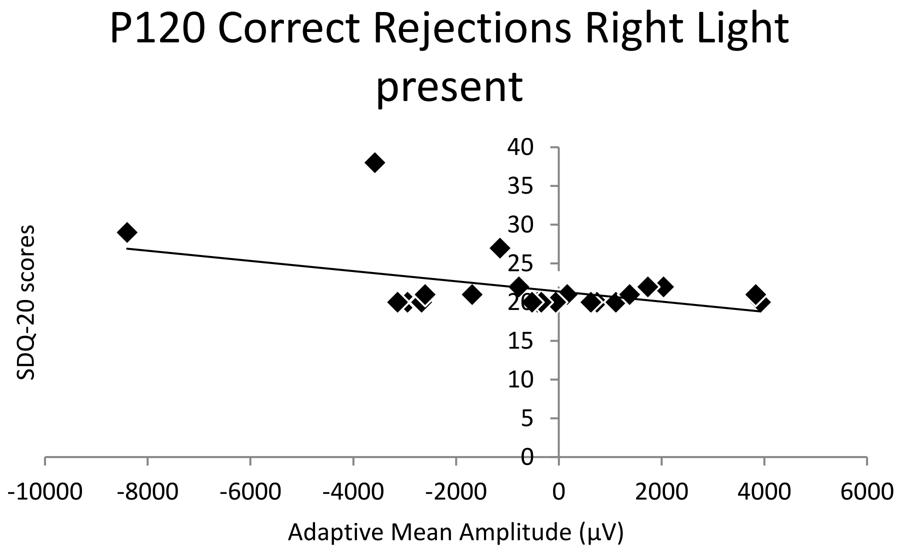
Figure.B.15. Showing the relationship between the AMA of Correct Rejections for P400 over Left frontal region during Light present and absent trials and Right frontal region during Light present trials with PHQ-15 scores (with trend line of best fit). There is a negative relationship between PHQ-15 and the AMA of Correct Rejections; those with more positive Correct Rejection P400 AMA scored lower on the PHQ-15.

Table.B.6. Frontal region ANCOVA - Univariate and Pearson's correlation results across all components for Correct Rejections with SDQ-20 (*denotes significance).

			Univariate Analysis of Variance		Pearson's Correlation	
Component	**Region**	**Light**	F	p	r	p
P120	Left	Present	5.62	.03*	-0.45	.03*
		Absent	5.94	.02*	-0.46	.02*
	Right	Present	4.90	.04*	-0.43	.04*
		Absent	5.28	.03*	-0.44	.03*
P160	Left	Present	5.62	.03*	-0.45	.03*
		Absent	5.94	.02*	-0.46	.02*
	Right	Present	4.90	.04*	-0.43	.04*
		Absent	5.28	.03*	-0.44	.03*
P360	Left	Present	5.62	.03*	-0.45	.03*
		Absent	5.93	.02*	-0.46	.02*
	Right	Present	4.90	.04*	-0.43	.04*
		Absent	5.27	.03*	-0.44	.03*
P400	Left	Present	5.62	.03*	-0.45	.03*
		Absent	5.93	.02*	-0.46	.02*
	Right	Present	4.90	.04*	-0.43	.04*
		Absent	5.28	.03*	-0.44	.03*







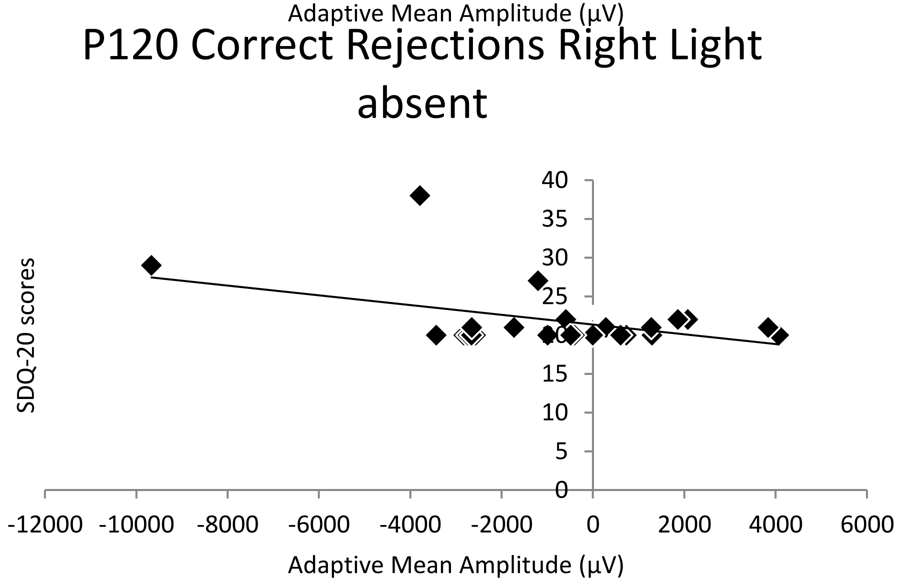


Figure.B.16. Showing the relationship between the AMA of Correct Rejections for P120 over Left and Right frontal regions during Light present and absent trials with SDQ-20 scores (with trend line of best fit). There is a negative relationship between SDQ-20 and the AMA of Correct Rejections; those with more positive Correct Rejection P120 AMA scored lower on the SDQ-20.

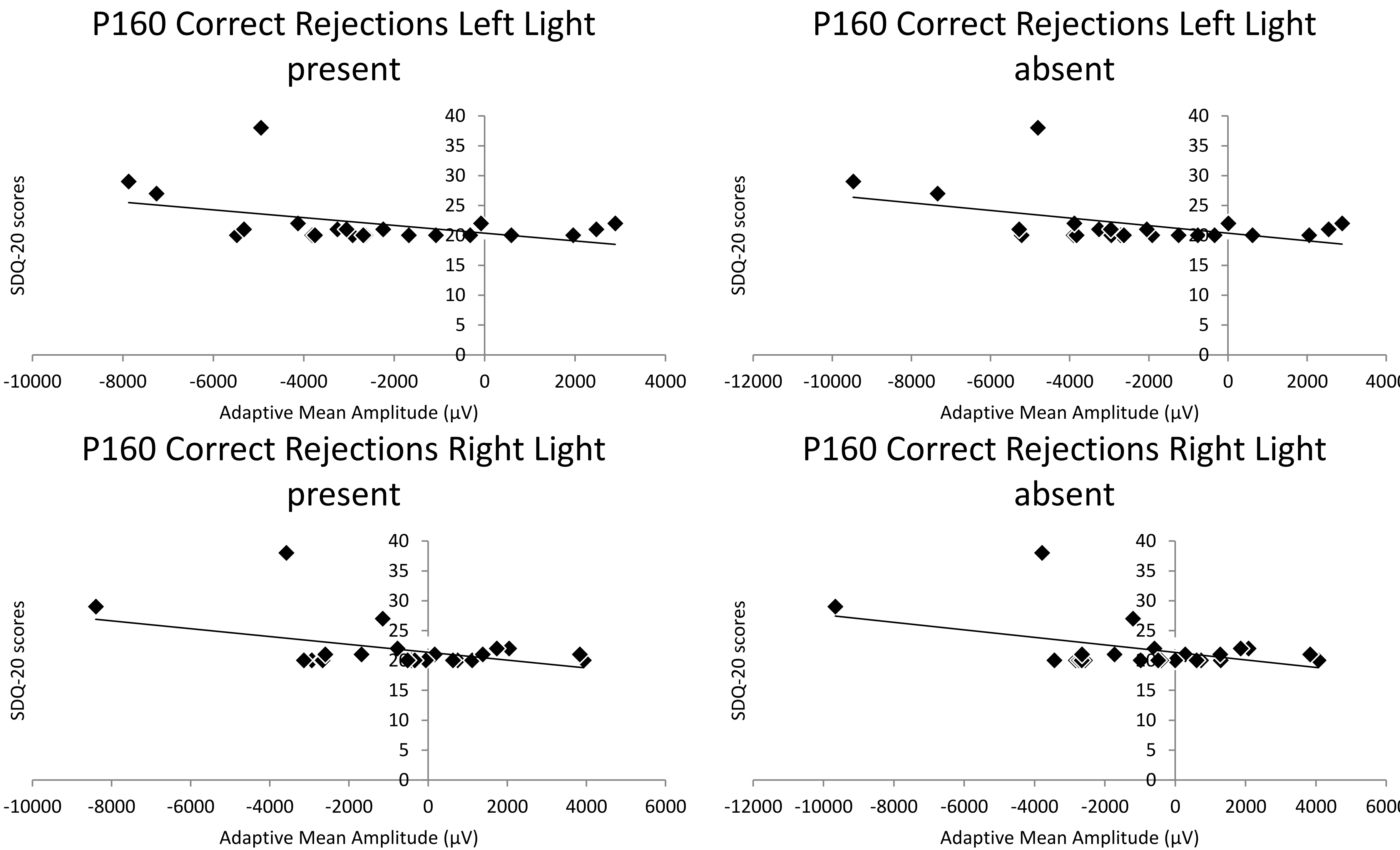


Figure.B.17. Showing the relationship between the AMA of Correct Rejections for P160 over Left and Right frontal regions during Light present and absent trials with SDQ-20 scores (with trend line of best fit). There is a negative relationship between SDQ-20 and the AMA of Correct Rejections; those with more positive Correct Rejection P160 AMA scored lower on the SDQ-20.

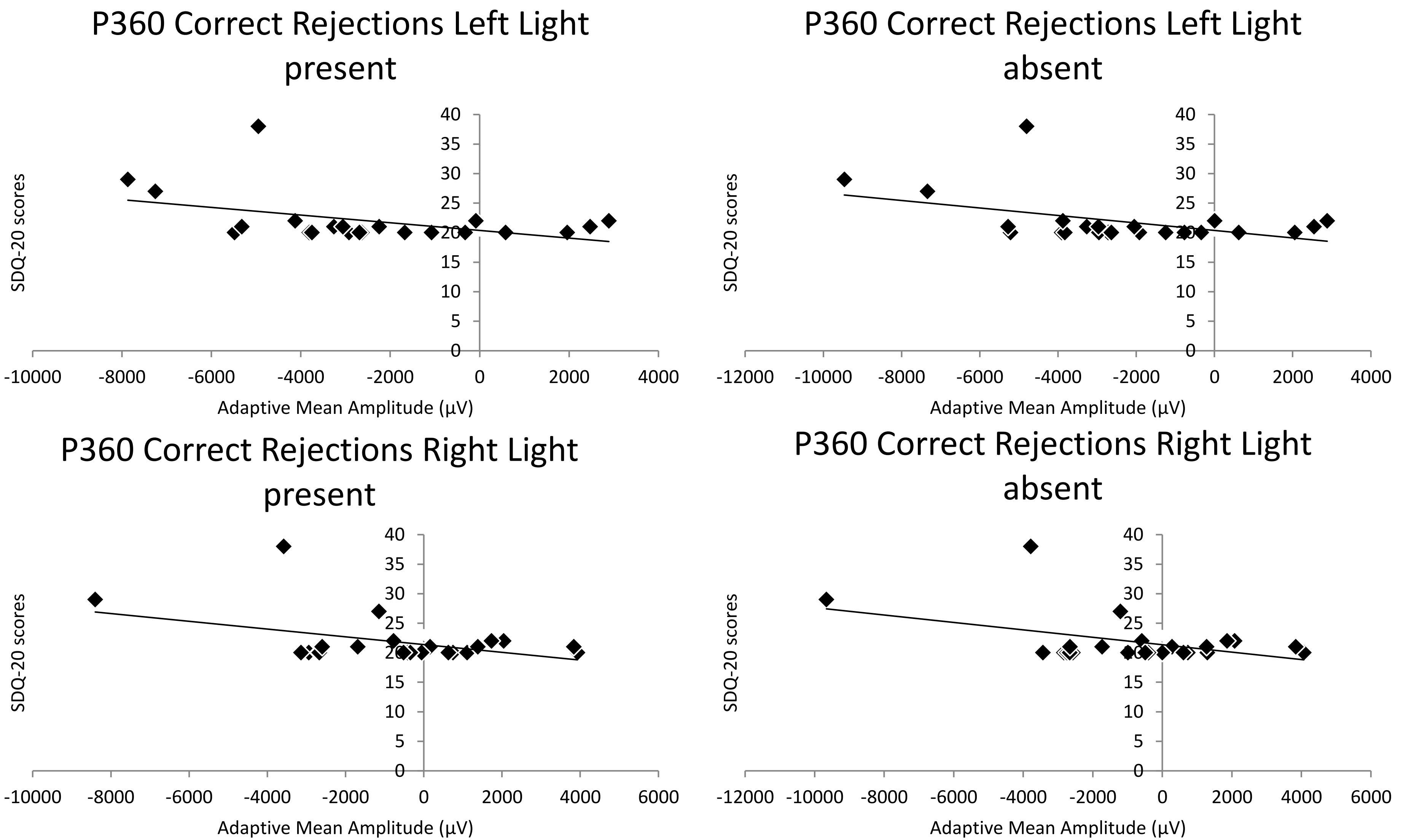


Figure.B.18. Showing the relationship between the AMA of Correct Rejections for P360 over Left and Right frontal regions during Light present and absent trials with SDQ-20 scores (with trend line of best fit). There is a negative relationship between SDQ-20 and the AMA of Correct Rejections; those with more positive Correct Rejection P360 AMA scored lower on the SDQ-20.

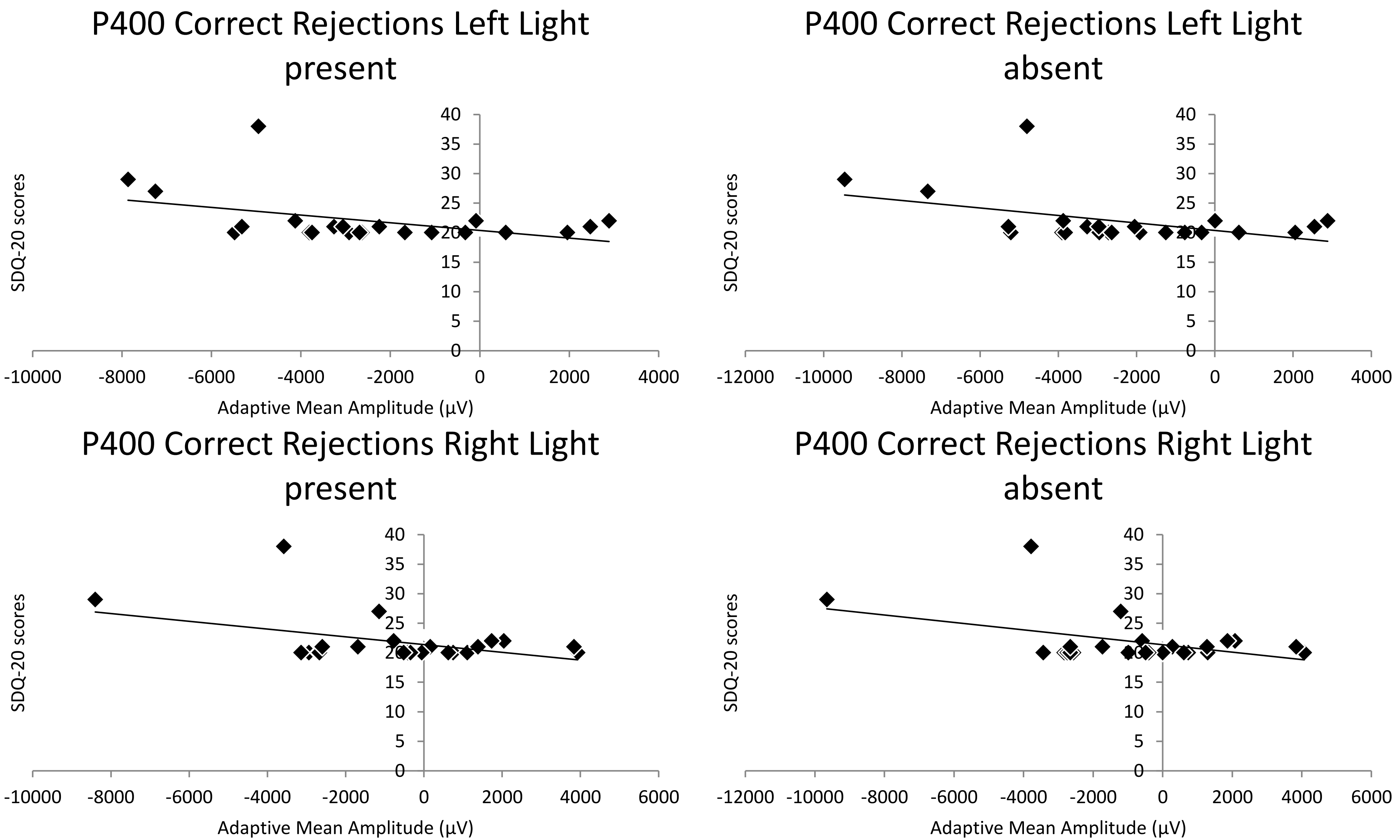
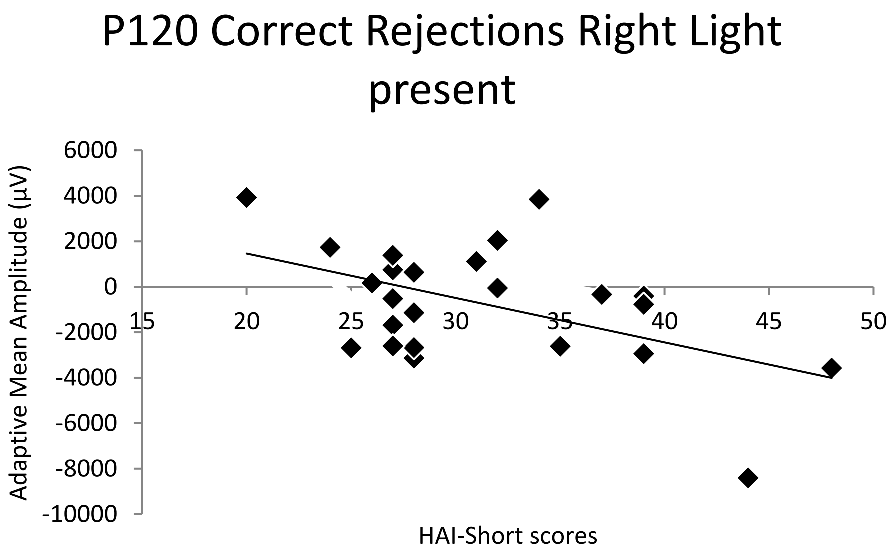
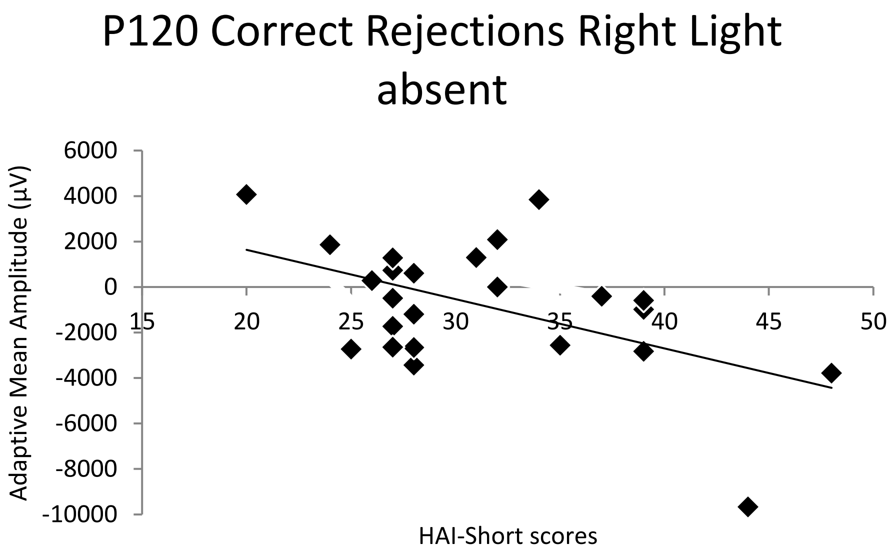


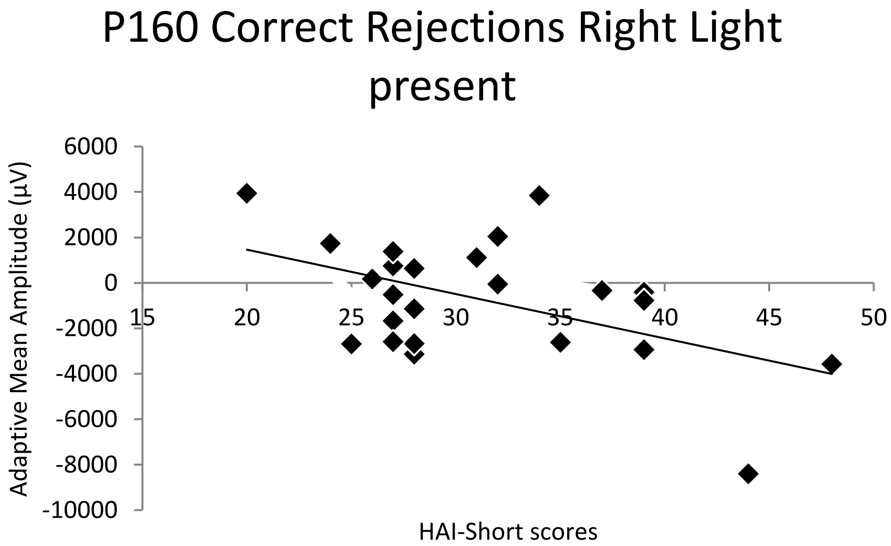
Figure.B.19. Showing the relationship between the AMA of Correct Rejections for P400 over Left and Right frontal regions during Light present and absent trials with SDQ-20 scores (with trend line of best fit). There is a negative relationship between SDQ-20 and the AMA of Correct Rejections; those with more positive Correct Rejection P400 AMA scored lower on the SDQ-20.

Table.B.7. Frontal region ANCOVA - Univariate and Pearson's correlation results across all components for Correct Rejections with HAI-Short (*denotes significance).

			Univariate Analysis of Variance		Pearson's Correlation	
Component	**Region**	**Light**	F	p	r	p
P120	Left	Present	0.74	.40		
		Absent	1.11	.30		
	Right	Present	7.22	.01*	-0.50	.01*
		Absent	7.83	.01*	-0.51	.01*
P160	Left	Present	0.74	.40		
		Absent	1.11	.30		
	Right	Present	7.22	.01*	-0.50	.01*
		Absent	7.83	.01*	-0.51	.01*
P360	Left	Present	0.74	.40		
		Absent	1.11	.30		
	Right	Present	7.22	.01*	-0.50	.01*
		Absent	7.83	.01*	-0.51	.01*
P400	Left	Present	0.74	.40		
		Absent	1.11	.31		
	Right	Present	7.22	.01*	-0.50	.01*
		Absent	7.83	.01*	-0.51	.01*







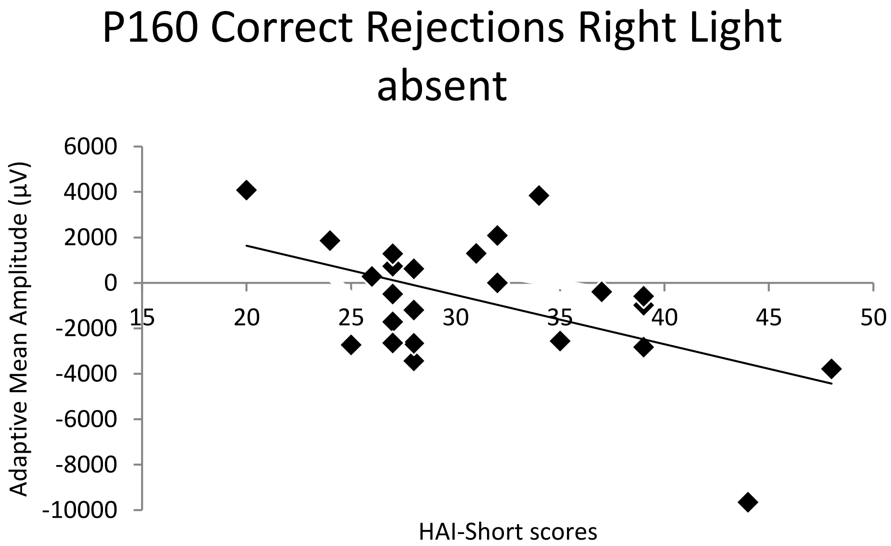


Figure.B.20. Showing the relationship between the AMA of Correct Rejections for P120 and P160 over Frontal Right region during Light present and absent trials with HAI-Short scores (with trend line of best fit). There is a negative relationship between HAI-Short and the AMA of Correct Rejections; those with more positive Correct Rejection P120 and P160 AMA scored lower on the HAI-Short.

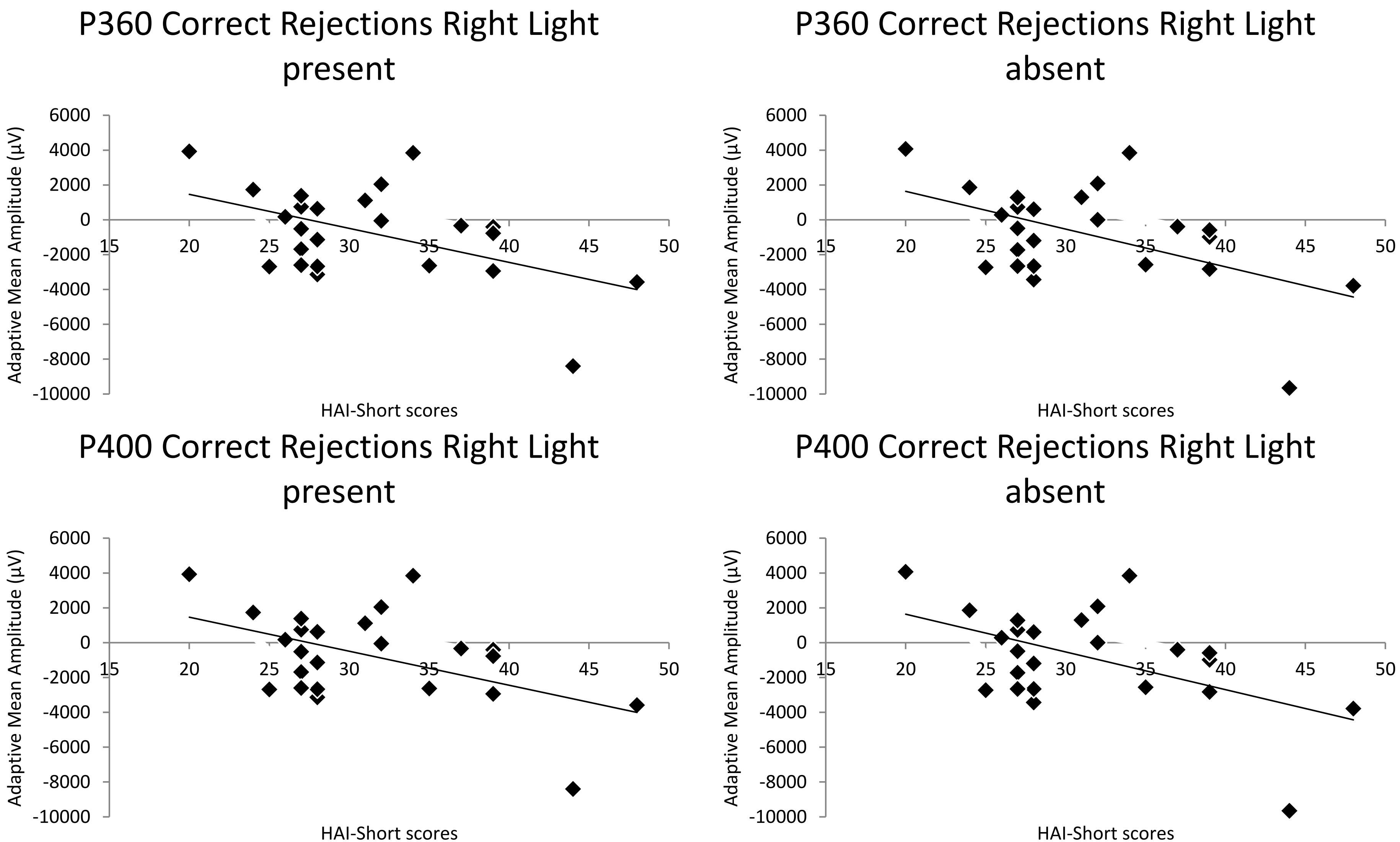


Figure.B.21. Showing the relationship between the AMA of Correct Rejections for P360 and P400 over Frontal Right frontal region during Light present and absent trials with HAI-Short scores (with trend line of best fit). There is a negative relationship between HAI-Short and the AMA of Correct Rejections; those with more positive Correct Rejection P360 and P400 AMA scored lower on the HAI-Short.

Table.B.8. Frontal region ANCOVA - Univariate and Pearson's correlation results across all components for Correct Rejections with STAI-State (*denotes significance).

			Univariate Analysis of Variance		Pearson's Correlation	
Component	**Region**	**Light**	F	p	r	p
P120	Left	Present	8.84	.007*	-0.54	.007*
		Absent	9.69	.005*	-0.55	.005*
	Right	Present	9.55	.005*	-0.55	.005*
		Absent	9.49	.005*	-0.55	.005*
P160	Left	Present	8.84	.007*	-0.54	.007*
		Absent	9.69	.005*	-0.55	.005*
	Right	Present	9.55	.005*	-0.55	.005*
		Absent	9.49	.005*	-0.55	.005*
P360	Left	Present	8.83	.007*	-0.54	.007*
		Absent	9.68	.005*	-0.55	.005*
	Right	Present	9.54	.005*	-0.55	.005*
		Absent	9.48	.005*	-0.55	.005*
P400	Left	Present	8.83	.007*	-0.54	.007*
		Absent	9.67	.005*	-0.55	.005*
	Right	Present	9.55	.005*	-0.55	.005*
		Absent	9.48	.005*	-0.55	.005*

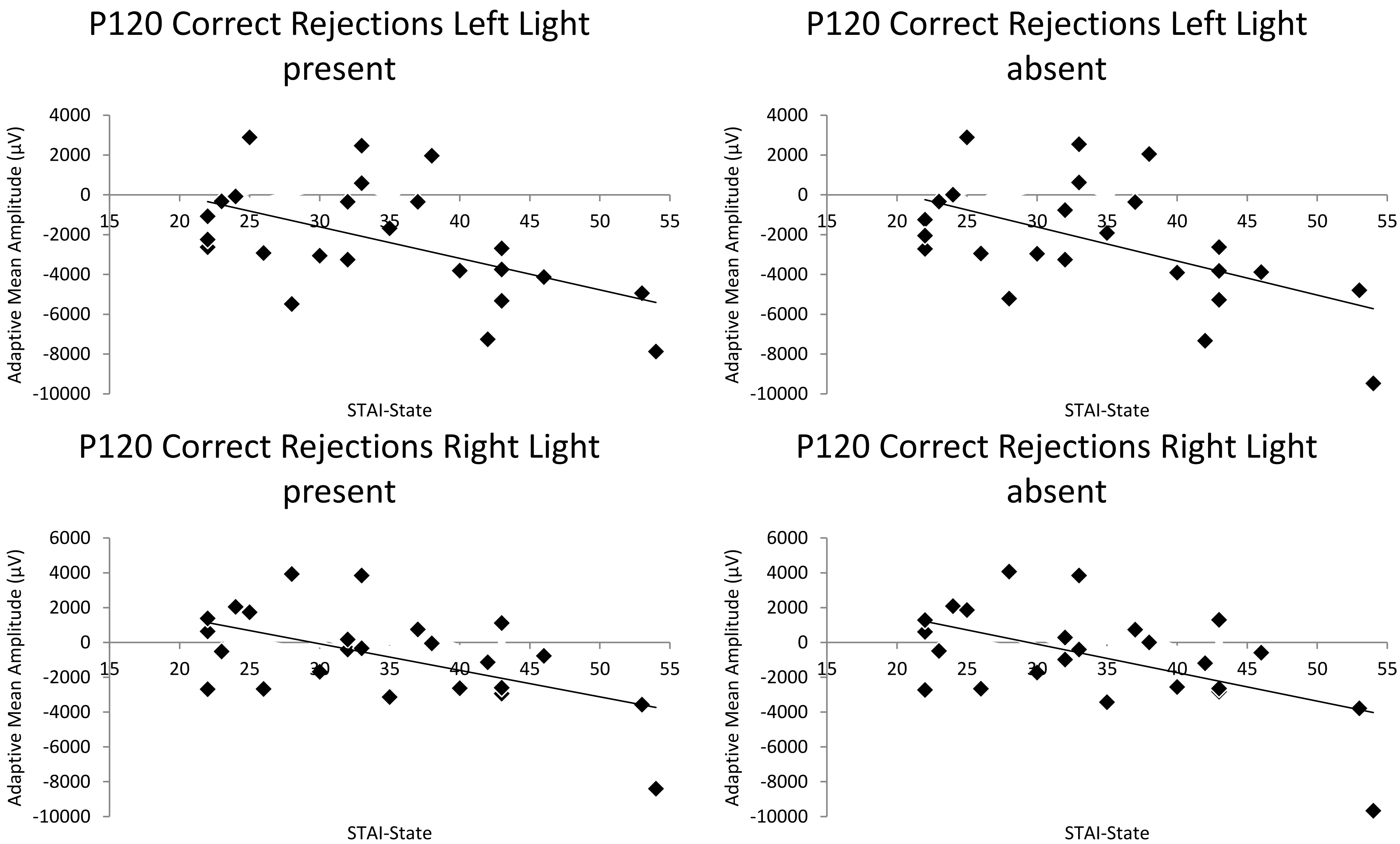


Figure.B.22. Showing the relationship between the AMA of Correct Rejections for P120 over Frontal Left and Right regions during Light present and absent trials with STAI-State scores (with trend line of best fit). There is a negative relationship between STAIT-Short and the AMA of Correct Rejections; those with more positive Correct Rejection P120 AMA scored lower on the STAI-State.

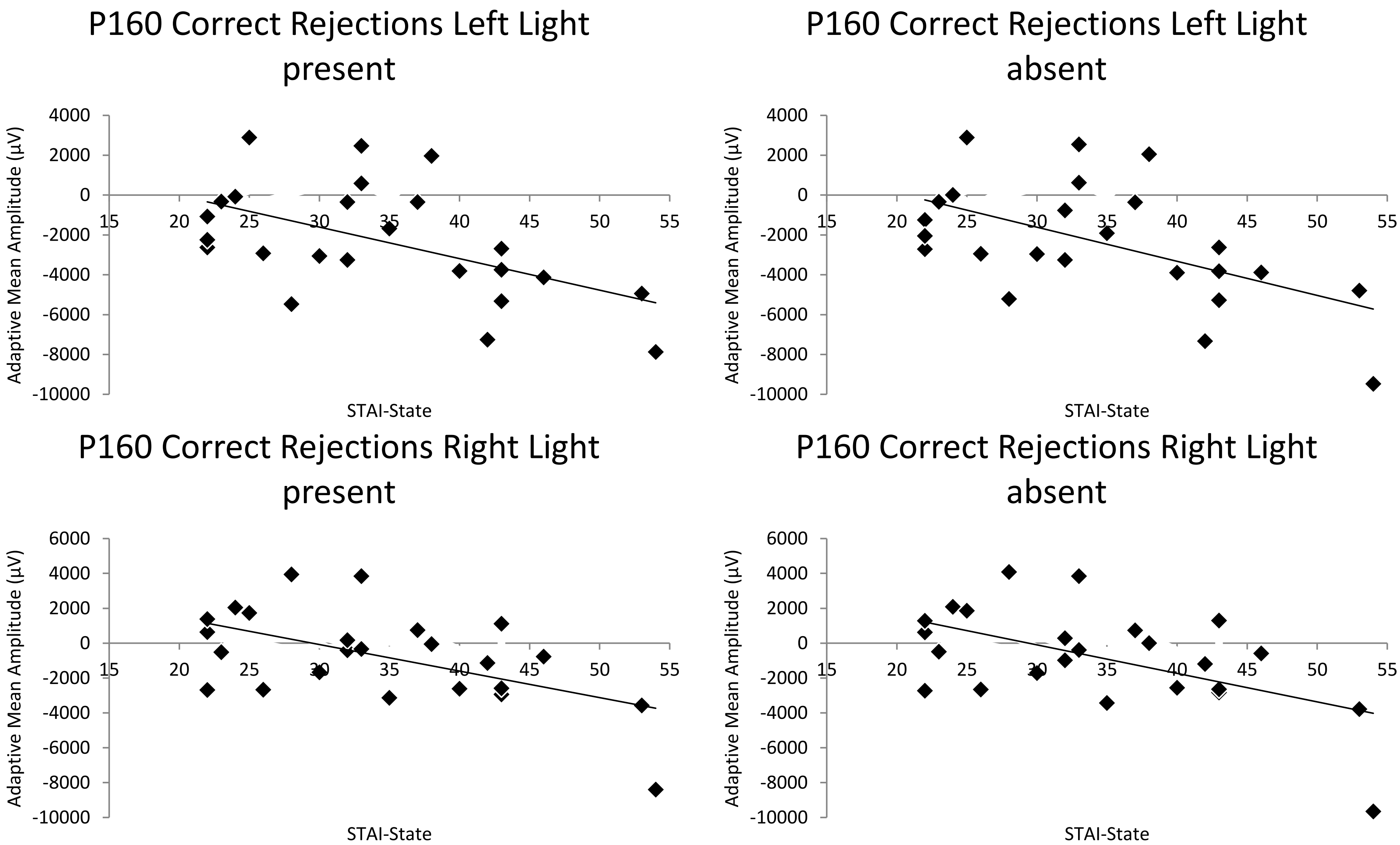


Figure.B.23. Showing the relationship between the AMA of Correct Rejections for P160 over Frontal Left and Right regions during Light present and absent trials with STAI-State scores (with trend line of best fit). There is a negative relationship between STAIT-Short and the AMA of Correct Rejections; those with more positive Correct Rejection P160 AMA scored lower on the STAI-State.

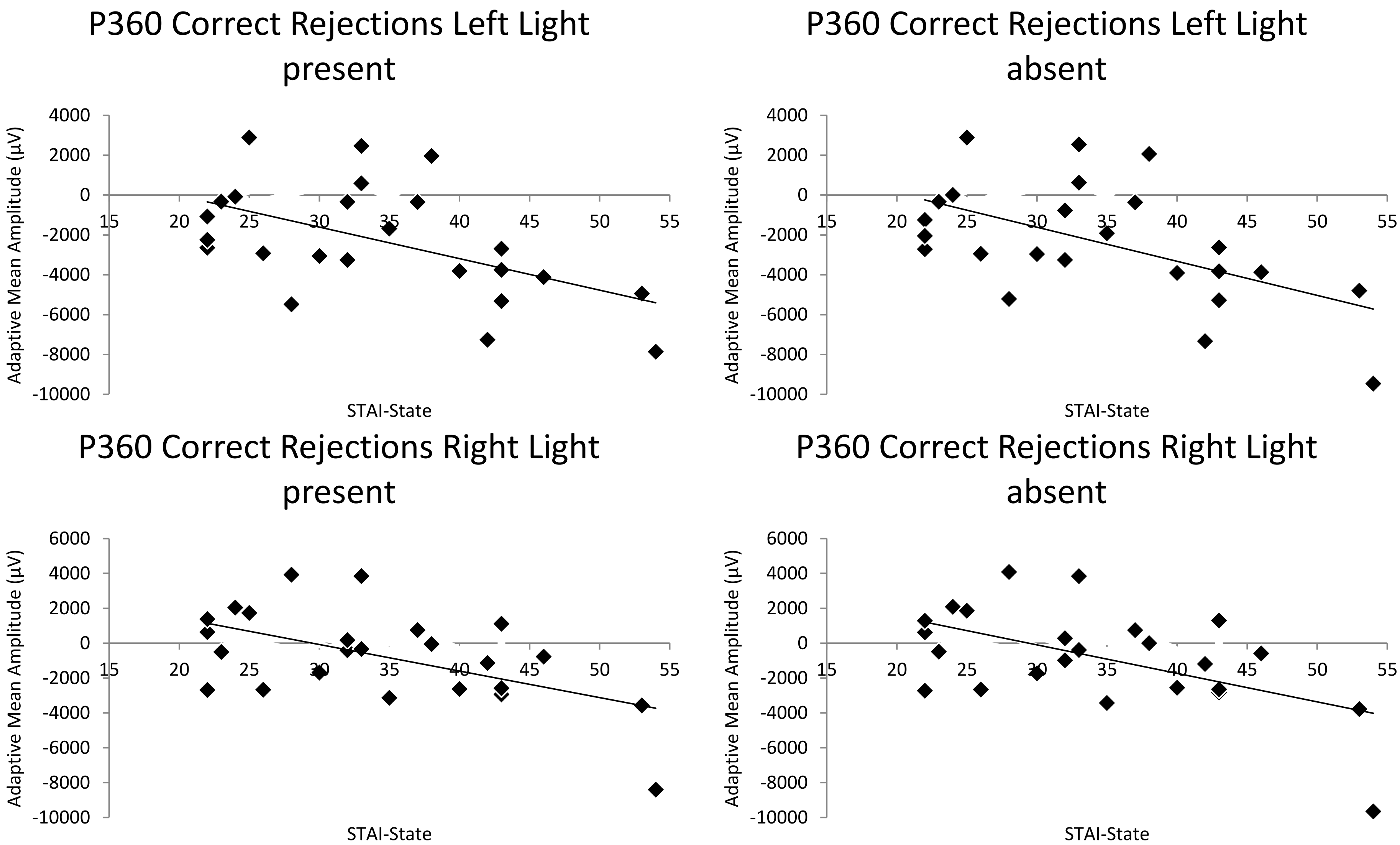


Figure.B.24. Showing the relationship between the AMA of Correct Rejections for P360 over Frontal Left and Right regions during Light present and absent trials with STAI-State scores (with trend line of best fit). There is a negative relationship between STAIT-Short and the AMA of Correct Rejections; those with more positive Correct Rejection P360 AMA scored lower on the STAI-State.

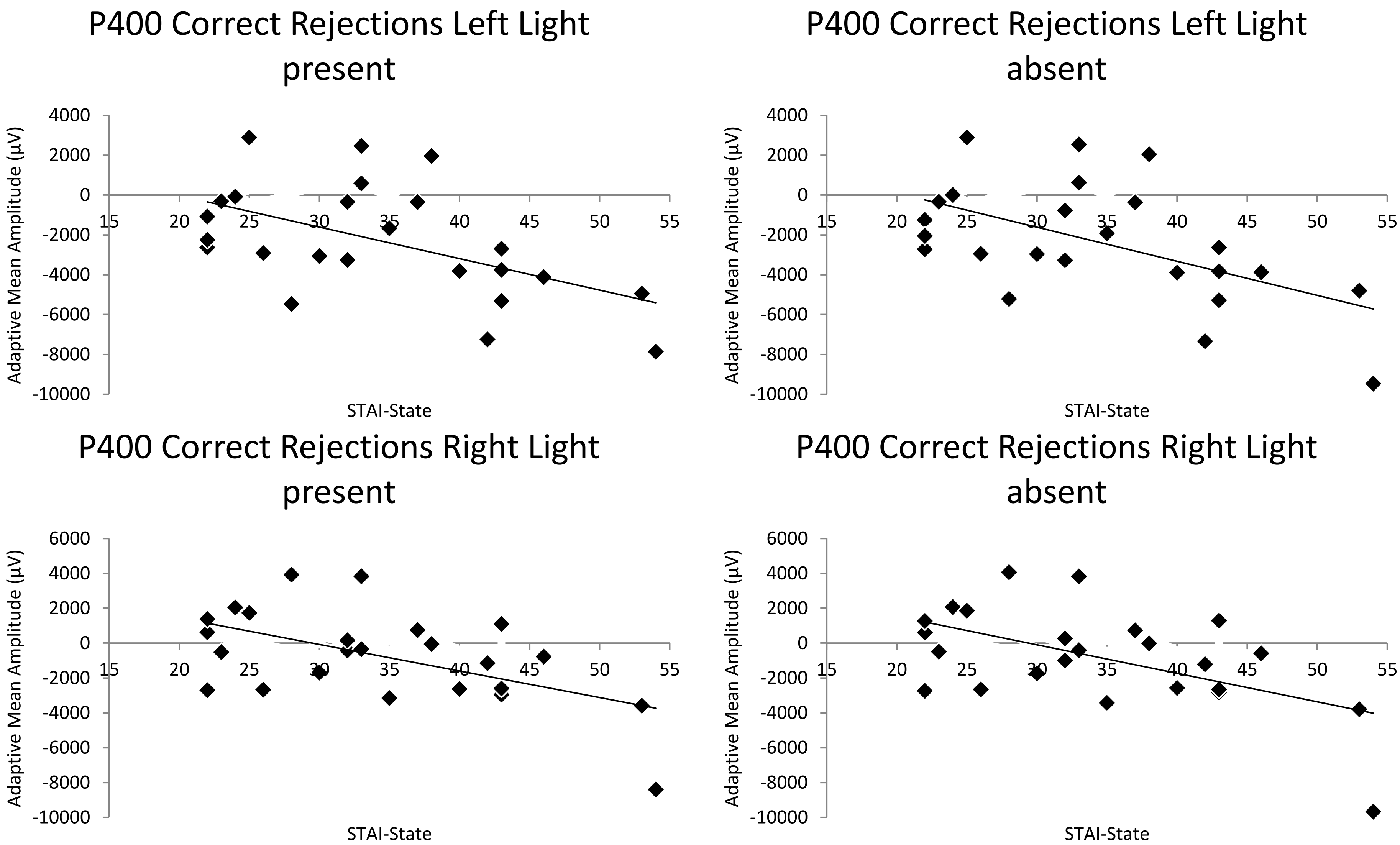


Figure.B.25. Showing the relationship between the AMA of Correct Rejections for P400 over Frontal Left and Right regions during Light present and absent trials with STAI-State scores (with trend line of best fit). There is a negative relationship between STAIT-State and the AMA of Correct Rejections; those with more positive Correct Rejection P400 AMA scored lower on the STAI-State.

Table.B.9. Frontal region ANCOVA - Univariate and Pearson's correlation results across all components for Correct Rejections with STAI-Trait (*denotes significance).

			Univariate Analysis of Variance		Pearson's Correlation	
Component	**Region**	**Light**	F	p	r	p
P120	Left	Present	0.13	.72		
		Absent	0.27	.61		
	Right	Present	4.44	.047*	-0.41	.047*
		Absent	4.58	.044*	-0.42	.044*
P160	Left	Present	0.13	.72		
		Absent	0.27	.61		
	Right	Present	4.44	0.47*	-0.41	.047*
		Absent	4.58	.044*	-0.42	.044*
P360	Left	Present	0.13	.72		
		Absent	0.27	.61		
	Right	Present	4.44	0.47*	-0.41	.047*
		Absent	4.57	.044*	-0.42	.044*
P400	Left	Present	0.13	.72		
		Absent	0.27	.61		
	Right	Present	4.44	0.47*	-0.41	.047*
		Absent	4.57	.044*	-0.42	.044*

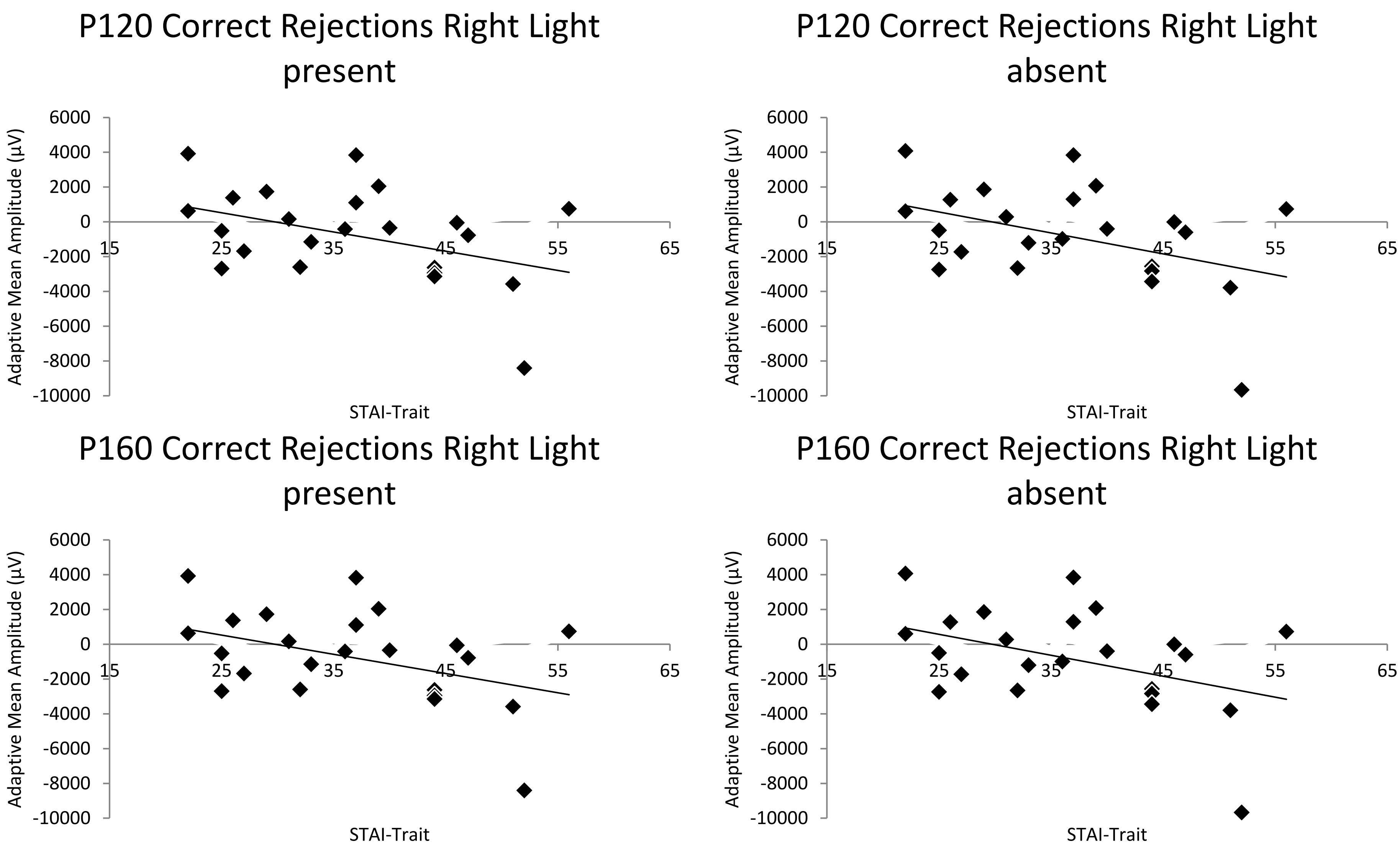


Figure.B.26. Showing the relationship between the AMA of Correct Rejections for P120 and P160 over Frontal Left and Right regions during Light present and absent trials with STAI-Trait scores (with trend line of best fit). There is a negative relationship between STAIT-Trait and the AMA of Correct Rejections; those with more positive Correct Rejection P120 and P160 AMA scored lower on the STAI-Trait.

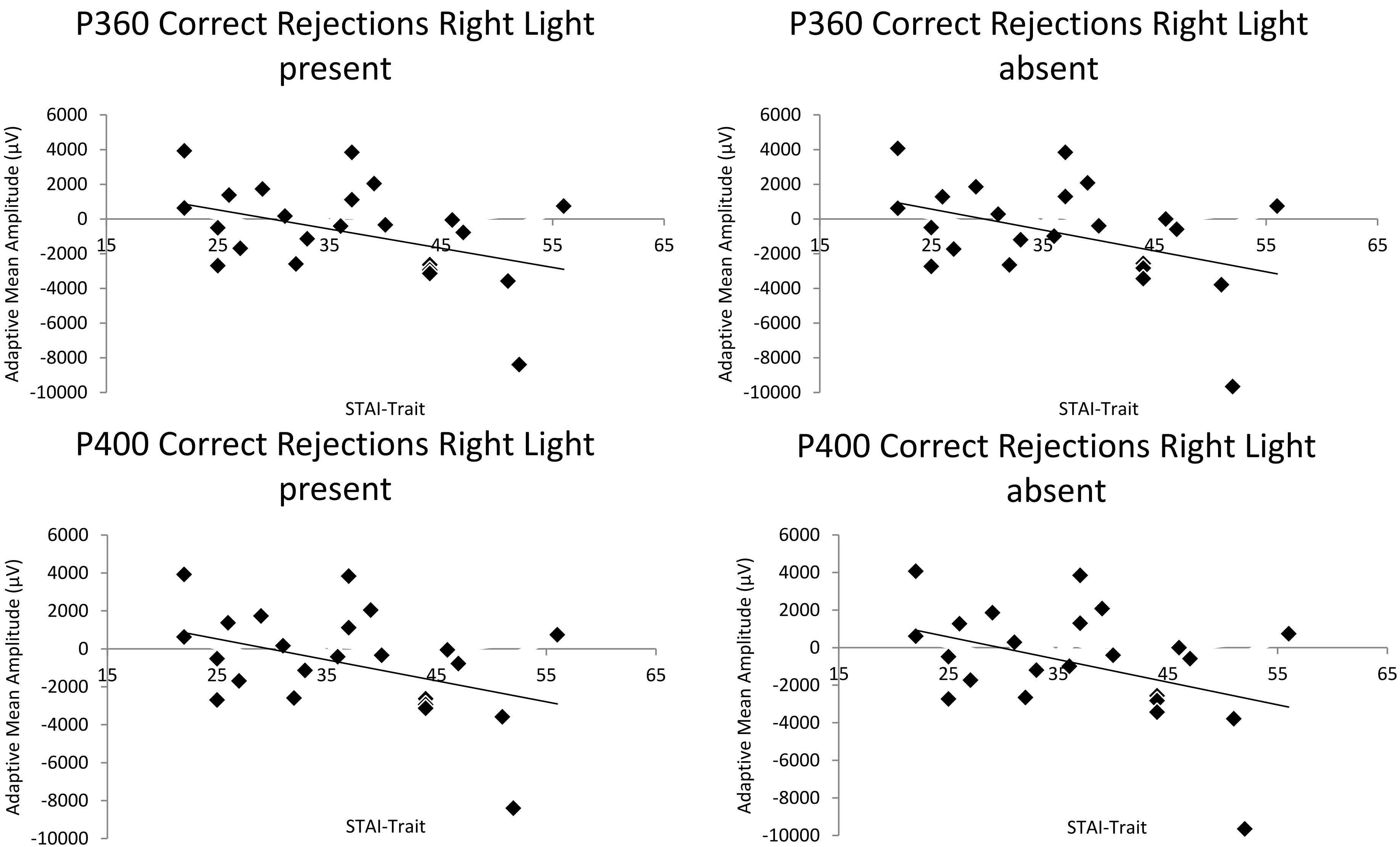


Figure.B.27. Showing the relationship between the AMA of Correct Rejections for P360 and P400 over Frontal Left and Right regions during Light present and absent trials with STAI-Trait scores (with trend line of best fit). There is a negative relationship between STAIT-Trait and the AMA of Correct Rejections; those with more positive Correct Rejection P360 and P400 AMA scored lower on the STAI-Trait.