University of Portsmouth

‘Is this your card?’ Behavioural Inhibition System (BIS) influence on EEG Theta during Guilty Knowledge Task

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ABSTRACT

The act of lying is suggested to be cognitively demanding, since it requires inhibition of the truth, and generation of a new response. Increased cognitive load influences brain activity; therefore the distinction between lies and truths should be able to be differentiated by electroencephalography (EEG). Increased EEG theta activation at frontal brain regions and decreased EEG alpha activation are proposed to be a result of increased task demands. Additionally, activation of the Behavioural Inhibition System is suggested to increase theta rhythm. The assumption was made that the BIS would be activated when an individual was put in a state of conflict induced by deception, thus differentiating between low and high sampled participants by increased EEG theta activity. Furthermore, explorative research was conducted into changes in EEG activity during initial reaction to guilty knowledge stimuli. An increase in alpha waveband activity was hypothesised based on the findings of novel research concerning Guilty Knowledge Task and EEG recordings.

For the task 132 participants were pre-screened on the Carver and White (1994) BIS/BAS questionnaire to measure trait levels of BIS activation. The 19 lowest scoring participants were assigned to the low BIS category, whilst the top 20 were assigned to the high BIS category. EEG was recorded (14 electrodes) whilst participants underwent the modified Guilty Knowledge Task, denying the identity of a concealed card, whilst also being shown control and irrelevant cards.

A frequency analysis was conducted with EEG data considered from 4-28 Hz. This study found that extreme sampled BIS activation did not appear to differentiate between participants using EEG theta. However a decrease in theta activity was found during participants’ initial reaction to guilty stimuli and in anticipation of telling a lie. No effects of EEG alpha were found. The finding that EEG recordings can differentiate the guilty from the innocent using their guilty knowledge could lead to formulation of new EEG deception detection techniques in the future.

KEY WORDS:	EEG	GUILTY KNOWLEDGE	BEHAVIOURAL INHIBITION SYSTEM	EEG THETA	COGNITIVE LOAD

Table of Contents

1 Introduction

1.1 Previous Research

The current study builds on theoretical research that indicates the act of lying is cognitively demanding and thus changes one's brain activity. As a consequence, the distinction between lies and truths should be able to be differentiated by analysis of brain activity. Previous research in regards to deception, deception detection, cognitive complexity and consequently, changed brain activity will all be discussed. Literature regarding Gray's theory of personality will then be addressed concerning the Behavioural Inhibition System (BIS) and personality research into brain activity.

Deception. Lies are prevalent in contemporary society; those with an interest in self-preservation (Paulhus, 1986), those told to avoid embarrassment (Vrij, 2008) and the 'little white lies' that are deemed socially acceptable (Ben-Shakhar & Elaad, 2003). Whilst in everyday life these types of lies can be tolerable, when it comes to the justice system, failure to detect deceit can prove harmful and produce serious consequences (Gamer, Rill, Vossel & Godert, 2006). Although the definition of deception has been depicted in multiple ways, this definition as defined by Vrij (2008, p15) "*a successful or unsuccessful attempt, without forewarning, to create in another a belief which the communicator considers to be untrue*" explicitly concerns intentional deception, rather than accidental misinformation or sympathetic white lies. This is of special interest and will be justified in due course.

Detection techniques. Considerable research has attempted to reliably differentiate between truthful and deceptive statements, and over time methods for deception detection have gained and declined in popularity, one such method being the use of non-verbal cues (Inbau, Reid, Buckley & Jayne, 2001; Zulawski & Wicklander, 1993). Although research has found that belief about the ability of non-verbal cues is still prominent with practitioners, who rely heavily on their own 'expertise' (Vrij, Granhag & Porter, 2010), literature indicates that these observations have only distinguished between truths and lies on a basis only slightly better than chance (Akehurst, Kohnken, Vrij & Bull, 1996; Sporer & Schwandt, 2007).

However two areas of research have fared more successfully when not presenting the idea of unequivocal behavioural or verbal cues that lead to reliable identification of a person's credibility (Gamer et al*.,* 2006). Results from novel studies made possible by technology such as functional magnetic resonance imagining (fMRI) and Electroencephalography (EEG) revealed differentiating factors concerning telling a lie compared to the truth in cognitive activity. On the other hand, a larger amount of in-depth research has been conducted into the physiological changes when telling a lie, showing an increase in respiration, heart rate, blood pressure and galvanic skin response (DePaulo et al., 2003). The measurement of said physiological responses is today's most commonly used method of deception detection, for example the Polygraph (Vrij, Mann, Fisher, Milne & Bull, 2007). However the use of such measures rely heavily on the assumption that there is a characteristic pattern of physiological responses for lying and that this response is different to the response that accompanies the truth (Lykken, 1959). Despite this, research has indicated that a distinct pattern of physiological activity directly related to lying does not exist (Saxe, 1994). Rather, physiological arousals are not linked to lying, but instead increased emotional arousal (Knyazev, Slobodskaya & Wilson, 2002). Therefore the use of measures such as the Polygraph are open to error and thus are highly disputed; an innocent nervous individual could easily be categorised as deceitful if purely measured on their physiological arousal (Gombos, 2010).

Cognitive complexity. Early research by Miller (1955) and later Sweller (1988, 1989), led to the development of the now influential theory of Cognitive Load. This led to conclusions being drawn that the cognitive capacity of working memory is limited (Sweller, Ayres & Kalyuga, 2011; Jong, 2010).

Considerable research has focused on the increased mental load of deception in regard to expression and control of behavioural cues (Kim, Jung & Lee, 2012), with significant results. Lying has been found more cognitively demanding than telling the truth as a consequence of increased cognitive load (Jensen & Tesche, 2002; Meltzer, Negishi, Mayes & Constable, 2007). Vrij's (2008) definition of deception becomes pertinent at this point, as individuals need to intend to lie and therefore inhibit the truth (Proverbio, Vanutelli & Adorni, 2013), as well as produce believable alternatives (Sporer & Schwandt, 2007; Gombos, 2010). Vrij and Heaven (1999) found that deception increases the occurrence of speech disturbances, whilst Zuckerman, DePaulo and Rosenthal (1981) found that lying prompted unnatural control of movements, longer response latencies and speech hesitations. These results have all been linked to increased cognitive load, therefore limiting resources available for verbal and behavioural control (Gombos, 2010).

Although behavioural cues to deception are important, researchers are now conceding that cognitive processes must be behind the behaviours that coincide with telling a lie (Vrij, Fisher, Mann & Leal, 2006). Recent research has consequently delved deeper into the cognitive process involved with deception, finding that deceptive behaviour is associated with a variety of cognitive activations (Kim et al*.,* 2012). As a consequence of such research, it has been conclusively demonstrated that lying requires greater mental effort than telling the truth (Gombos, 2010).

Brain activity and cognitive complexity. Several areas of the brain have been implicated during deception: activity is increased most prominently in the ventroletral (VLPFC) and dorsolateral prefrontal cortex (DLPFC), and the anterior cingulate cortex (ACC) (Bles & Haynes, 2008; Langleben et al., 2005). Research suggests a link between cognitive control and the prefrontal cortex, with increased activation of the VLPFC linked to inhibiting the truth, and increased activation of the DLPFC to generating a new false response (Spence et al., 2004; Phan et al., 2005). Proverbio et al. (2013) suggest that lairs must exert greater cognitive control due to the complexity of lying behaviour and the need to suppress the truth, whilst Klimesch (1999) affirms that EEG reflects the cognitive difficulty of a task, and therefore is related to cognitive complexity/load. As made clear by Vrij's (2008) definition of deception, cognitive control indicates the intention to lie as opposed to mistakenly misinform. The findings of aforementioned neuroimaging studies indicate that deceptive behaviour increases neural activity and consequently the assumption is made that EEG studies are able to examine the changes in brain activity as a result of deceptive, therefore demanding, tasks.

EEG studies regarding deception have highlighted alpha and theta sensitivity to increased cognitive complexity (Gevins, Zeitlin, Doyle, Schaffer, & Callaway, 1979). Alpha band activity (8-12 Hz) has been found to decrease as task demand and subsequently cognitive complexity increases (Klimesch, 1999). Kim et al. (2012) found that increasing task demands led to a reduction in alpha power suggesting that cortical resources are allocated to the task, whilst research by Gevins, Smith, McEvoy, and Yu (1997) showed that further skill development increased alpha activity. This allows the assumption that deception would reduce activity in the alpha frequency band, therefore enabling discrimination from truths.

Furthermore, Gevins et al. (1997) found that localised frontal midline theta increased as participant's working load increased, suggesting that as cognitive load increases, as does theta activity. Whilst research evidences that firstly, prefrontal activation increases in tasks that involve heightened cognitive load, and secondly, deception is cognitively complex, this could lead one to assume that telling lies compared to truths will involve increased activity at frontal brain regions.

Deception detection assessments. As briefly mentioned above, conventional methods of lie detection focused on behavioural cues with the belief that credibility can be established by a lack of nervous behaviour (DePaulo, 1992). However changes to observable behaviour are now considered signs of physiological arousal, which can also be caused by anxiety - a phenomenon innocent people also suffer from (Vrij et al., 2007). Lie detection methods now focus on the more direct approach, using technology to assess whether a person is telling the truth, although directly measured rather than observed, physiological arousal is still the key component. As aforementioned the use of the Polygraph independently to measure whether a person is credible is highly criticised, however research suggests a more favourable attitude towards such measures when used in conjunction with other dependent measures such as the Control Question Technique (CQT), the Statement Validity Assessment (SVA) and the Guilty Knowledge Task (GKT) (Gombos, 2010). As relevant to the current study, the Guilty Knowledge Task will be discussed.

The Guilty Knowledge Task (GKT) was developed by Lykken (1959) based on the assumption that familiar items will evoke different responses when presented within a large number of unfamiliar items (Abootalebi, Moradi, & Khalilzadeh, 2009). In the limited amount of research for the Guilty Knowledge Task and respective brain activity recording, three types of stimuli have been typically presented to participants. The first are target stimuli; items related to concealed information and only a person with guilty knowledge would be expected to know. The second are irrelevant stimuli; items unrelated and thus, unrecognised by all participants, guilty or innocent. The third are control stimuli; items known by both innocent and guilty.

Research regarding the GKT and brain activity recording, although limited, has revealed the advantages of neurological over physiological measures, with some literature regarding this as less vulnerable to manipulation (Bles & Haynes, 2008). New research by Matsuda, Nittono and Allen (2013) found that participants who had concealed stolen items and then underwent the GKT elicited greater left frontal EEG alpha activity, suggestive of right frontal cortical activity upon recognising the concealed item in comparison to other items. They suggested that recognition of said item might have induced withdrawal motivation.

Personality traits and deception. Individual differences can be assessed to see how people differ in how they react to cues of threat (withdrawal motivation), and cues of reward (approach motivation) (Gray, 2001). Based on Gray's Model of Personality (1970, 1982), two separate systems were hypothesised for controlling behavioural activity, the Behavioural Inhibition System (BIS), and the Behavioural Activation System (BAS). This was later encompassed into Reinforcement Sensitivity Theory (Gray and McNaughton, 2000) with the additional distinguishing feature of fear and anxiety, proposing a Fight/Flight system. The BAS system modulates reactions to appetitive stimuli, and the BIS, associated greatly with anxiety, works as a conflict and resolution system (Colder et al., 2011). The later revised addition of Fight/Flight is said to be responsible for mediating reactions to aversive stimuli (Anderson, Moore, Venables & Corr, 2009). Personality measures such as Carver and White's (1994) BIS/BAS questionnaire have been developed to assess individual differences of trait sensitivity to cues of threat (BIS) and cues of reward (BAS).

In terms of neurological factors, according to Gray and McNaughton (2000), BIS activation generates a distinct neurophysiological rhythm in the septo-hippocampal system. Studies since have specifically shown EEG theta to be linked to the Behavioural Inhibition System (Moore, Mills, Marshman & Corr, 2012), with Razoumnikova (2003) also reporting the connection between BIS and theta activity. Furthermore, Moore, Gale, Morris and Forester (2006) reported increased EEG theta during increased goal conflict, indicating that those with high levels of BIS will have increased levels of EEG theta compared to others, as the BIS system is known to work as conflict and resolution system. Regarding deception, Giesen and Rollison (1980) found that whilst using the GKT, participants with high levels of self-reported BIS responded more in the guilty condition than that of the innocent. Considering these findings increased theta should, theoretically, be more evident in those with high levels of BIS compared to those with low levels of BIS.

A recent deception study in the field of neurological research is that of Moore, Spanhel, Marshman and Corr (in prep). This study found that telling story-like lies in contrast to telling the truth revealed an increase of frontal theta activation. However the task used was not well established, and this current research aims to remedy this limitation by using a modified version of Lykken's (1959) Guilty Knowledge Task (similar to that used by Merzagora, Bunce, Izzetoglu & Onaral, 2006) due to convincing empirical evidence for its statistical reliability (Ben-Shakhar, Bar-Hillel, & Kremnitzer, 2002). Furthermore this research takes investigation a step further by exploring how EEG activity changes upon seeing guilty knowledge, and cognitive changes that occur in the moments leading up to deception, rather than just the deceptive act.

1.2 The Current Study

The aim of the current study was to first analyse the changes that occur in EEG activity in a person's initial reaction to guilty stimuli, and secondly the changes that occur in EEG activity in the moments before a lie is executed. The modified Guilty Knowledge Task was implemented in the current study (full description of this task can be found in the task sub-section). The use of such task (Merzagora et al., 2006) has been shown to differentiate between when a participant was lying and telling the truth. Matsuda et al. (2013) found participants elicited greater frontal EEG alpha activity upon recognition of guilty knowledge stimuli. This task has also been utilised in studies using neuroimaging techniques such as fMRI (Phan et al., 2005), which found increased activity in the VLPFC, DLPFC and the ACC.

However most research using the modified Guilty Knowledge Task have either analysed event-related potentials (ERPs) when looking at EEG data, which have been reported to not be sufficiently reliable for detection of deception (Rosenfeld, Soskins, Bosh & Ryan, 2004), or focused solely on neuroimaging techniques, which are said to have poor spatial resolution (Bosch, Mecklinger & Friederici, 2001). Therefore, in the current study a novel approach was adopted whereby continuous EEG recordings were made of participants' instant reactions to truthful and deceptive stimuli from 14 electrode sites. Based on the results of Matsuda et al. (2013), it was assumed that the initial reaction to guilty stimuli would produce an increase in alpha activity compared to irrelevant or control stimuli (Hypothesis 1).

This study was also based on the assumed connection between telling lies and increased cognitive load. Thus it was assumed that, similar to neuroimaging studies and analysis of ERPs, cognitive control induced by increased task demands will subsequently increase cognitive load, which will in turn lead to increased theta activity at frontal brain regions. This indicates that in the seconds before telling a lie, a person would need to inhibit the automatic truthful response, requiring increased cognitive control and in turn, increasing task demands. Therefore the anticipation of telling a lie compared to telling the truth will reflect an increase in EEG theta activity at frontal brain regions (Hypothesis 2).

Research has also shown decreased alpha activity during increased cognitive load. As previously indicated, prior to telling a lie a person must first inhibit the truth, a cognitively demanding task that requires increased cortical resources. Thus, a reduction in alpha wave activation during the anticipation of lying was hypothesised (Hypothesis 3).

Furthermore, research into personality measures has suggested the Behavioural Inhibition System works as a conflict and resolution system, and thus, upon activation generates increased theta activity. Concerning deception: when an individual with highly active BIS system is faced with a cognitively complex task, they experience a greater degree of arousal. As this is rarely subject to control, heightened activation of BIS may therefore provide relatively consistent cues to deception (Giesen & Rollison, 1980). Therefore it is assumed that heightened EEG theta will be more apparent in participants with high sampled BIS (Hypothesis 4).

2 Method

2.1 Participants

One hundred and thirty-two undergraduates (40 males), aged 18 to 39 (M: 19.33, SD: 2.72) were recruited at stage 1 of the study and pre-screened on the Carver and White (1994) BIS/BAS questionnaire. The criterion for participation was that participants were familiar with the suits in a pack of playing cards, and were thus informed prior to the study that they would need to be able to recognise each suit.

Participants were mainly first-year psychology students who were able to collect course credits for participating.

Thirty-nine participants (13 males) aged 18 to 39 (M: 19.89, SD: 3.69) were recruited to the second stage of the study. The 19 lowest scoring participants on the pre-screening questionnaire (11 male) were assigned to the low BIS category (M: 15.36, SD: 3.25) and the top 20 scoring participants (2 male) to the high BIS category (M: 26.1, SD: 1.12). Due to technical issues with the EEG recording, 6 participants were removed from the sample prior to submitting EEG data for analysis.

2.2 Materials and Apparatus

The Carver and White (1994) BIS/BAS questionnaire was utilised in this study. It consists of 24 items and is completed using a 4-point Likert scale (from 1, *very true for me* to 4, *false for me*). The BIS scale consists of 7 of these items, for example "*Criticism or scolding hurts me quite a bit",* and *"If I think something unpleasant is going to happen I usually get pretty 'worked up'"*. The BIS items are said to be responsible for negative emotions such as fear, anxiety and frustration (Carver & White, 1994), measuring a person's anticipation and response to potentially distressing events.

The rest of the questionnaire is separated into three components related to the participant's BAS score; BAS Drive (4 items), BAS Reward Responsiveness (5 items), BAS Fun-Seeking (4 items). The Drive component assesses behavioural responding, the Reward Responsiveness assesses affective responding, and the Fun-Seeking component assesses both affective and behavioural responding. The total of these components is equal to a person's overall BAS level, with 4 filler items included to disguise the intent of the questionnaire.

The Carver and White BIS/BAS questionnaire is widely used in research, demonstrating relationships to measures of personality, information processing and cerebral activity, with empirically sound convergent and discriminant validity (Campbell-Sills, Liverant & Brown, 2004). In the present study, the Cronbach's alpha value for BIS anxiety was .84, suggesting the items had a high level of internal consistency with the sampled population.

The program used in this study for the participant's task was created on ePrime 2 (Psychology Software Tools, Inc). The custom software was displayed on a computer monitor. Continuous EEG was recorded with BrainVision 72 Channel QuickAmp, and an EasyCap was used for electrode placement and recording.

2.3 The Task

The current study used a modified Guilty Knowledge Task similar to that originally developed by Merzagora et al. (2006). The task involved participants being given five cards, four of which were laid face up on the table directly in front of the participant, and one which was drawn from a deck of cards and kept in the participant's hand (see example in Figure 1). They were informed through standardised instructions read out by the researcher that the identities of the cards laid on the table were known to both researcher and participant, therefore any deception about said cards would be needless. However, the fifth card held by the participant was their ‘hidden’ card, the identity of which was to be kept secret. Participants would then start the computer program by pressing the space bar. The participant would then be presented with a card on the computer screen with the following question of “Do you have this card?”. If the card on the screen matched any of the control cards on the table, the “correct” response to the question was “yes”, if the card on screen was not any of the five cards, the “correct” response to the question was “no”. However if the card on the screen matched the single ‘hidden’ target card in the participant’s hand, the “correct” response to the question was “no”.

Instructions read prior to the study made it explicit that by pressing “no” to their ‘hidden’ card, the participant was making a dishonest response. Participants were prompted to give their answer by a on-screen written statement “Please get ready to answer now”, and then the option to respond with “Yes” and “No” appeared on the screen and participants could click on the chosen icon using a mouse (see example of task sequence in Figure 2). This procedure was repeated 60 times. Participants were asked to discard the card in their hand after each trial, and received a new one whilst the researcher replaced the four cards on the table. Over the course of the 60 trials, all participants would subsequently tell the truth 30 times (15 “yes” control stimuli: card on table, 15 “no” irrelevant stimuli: card not included), and tell a lie 30 times (30 “no” target stimuli: protecting identity of hidden card). Incorrect answers for individual trials were removed and not included in the averages

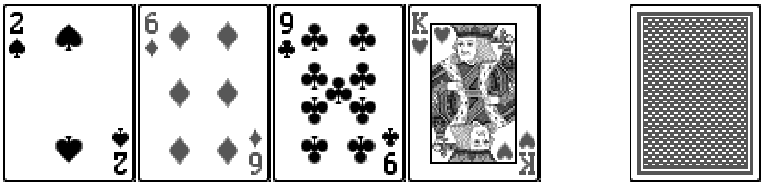

Figure 1: Example of four control cards laid face up on table, and ‘hidden’ (target) card, held in hand of participant.

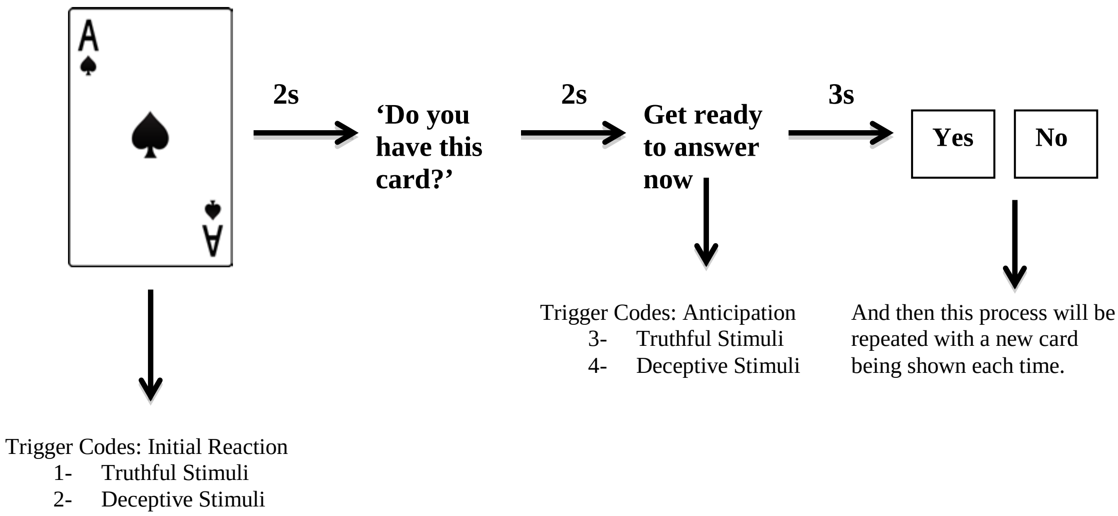

Figure 2: Example of the order in which a card and subsequent question would be displayed to a participant for one individual trial, including the length of time each item was on screen and when trigger codes were allocated.

2.4 Procedure

Stage 1. Individuals from the University of Portsmouth, Department of Psychology Participant Pool website were invited to participate in the study. The Participant Pool is a specially developed website for researchers to gather participants by uploading an online version of a questionnaire that participants can complete by logging on to the website. Participants provided consent for the study, followed by demographic information including age and sex. Participants then completed Carver and White's (1994) BIS/BAS questionnaire.

Stage 2. Participants eligible for stage 2 were invited via email to the laboratory. Participants were seated directly in front of a computer monitor and given further information about general procedures regarding EEG studies before signing the informed consent form. The participants were then attached to the EEG and after the preparation procedures for the EEG had been conducted, recording was then started (see EEG Data Recording and Data Reduction sub-section). The study was initiated with the researcher explaining the task ahead. The instructions emphasised the participant's right to withdraw at any point, and explained how the task was going to proceed. For the purpose of counterbalancing, participants were randomly assigned to one of ten conditions, equally split between the low and high BIS groups (4 participants in each condition, except condition 8 which had 3). In each condition participants would all tell the truth 30 times, and lie 30 times, but the order in which they did this differed over the conditions. After the program finished the participants were disconnected from the EEG, debriefed on the study and allowed to ask any questions.

2.5 EEG Data Recording and Data Reduction

Continuous EEG was recorded with Vision Recorder (version 1.03), from 14 electrode sites (Fp1, Fp2, F3, F4, F7, F8, C3, C4, T3, T4, P3, P4, O1, O2) based on a standard 10/20 electrode placement configuration. The right and left mastoids were used for reference and two additional bipolar electrodes were used to measure vertical and horizontal electrooculogram (EOG) activity, placed in the medial supraorbital Vs outer canthus configuration. Participant EEG and EOG recording was continuous throughout the task. Electrode impedances were kept below 10 kΩ throughout the duration of EEG recording, though in most cases the impedances were as low as 4-6 kΩ.

Raw data was stored and analysed offline with Vision Analyser (version 2.0). All EEG data was treated with an eye movement reduction algorithm based on Gratton, Coles, & Donchin (1983). Offline, a filter was set up with the low pass filter at 2 Hz, and the high pass at 30 Hz high cut off. A notch filter was also included at 50 Hz. Eye movement artefacts were treated with an offline ocular artefact procedure (Gratton et al., 1983). The program applied trigger codes in the EEG data for future analysis (See Figure 1) at two separate points in the process of the participant working through the questions. The data were segmented with the use of these trigger codes:

Initial Reaction. When the card first appeared on the screen, if the participant would later be telling the truth a trigger code of 1 would be applied, and if the participant would subsequently be lying, the trigger code would be 2. The full two seconds that the card first appeared on screen was split into truth and lie two second segments. There was therefore one segment depicting an average for initial EEG response to a lie stimulus over the two seconds and one depicting an average for initial EEG response to a truth stimulus.

Anticipation. When the participant was prepared to answer following the statement “Get ready to answer now”, the same logic applied as previously, with a trigger code of 3 being applied for truth trial, and a 4 for a following lie. The three seconds that the participant waited to answer the question “Do you have this card?”, prompted by “Get ready to answer now” was split into three second by second segments for truth and lie, and one full three second average for both truth and lie. Thus there were four segments depicting an EEG response in anticipation to a lie stimulus, and four depicting EEG response in anticipation to a truth stimulus.

Following this, all EEG segments described above were screened for artefacts. Segments including data with an amplitude of more than ‘+ 75μV’ or less than ‘−75μV’ were rejected; participants with a rejection rate greater than 25% were excluded from further analysis. A fast Fourier transform (FFT) was applied to all the segments described above, yielding a unique power spectrum for each segment. Power spectra were averaged across each category of 30 epochs yielding a single average power spectrum representing a participant’s initial reaction for both truth and lie stimuli and the anticipation of having to either lie or tell the truth. Next, for each participant, eight average power values were exported for these task stages. EEG power values were extracted for: 4-6 Hz (low theta), 6-8 Hz (high theta), 8-10 Hz (low alpha), 10-12 Hz (high alpha), 12-19 Hz (low beta) and 19-28 Hz (high beta).

2.6 Statistical Analysis

The EEG analysis began with a mixed omnibus ANOVA for both data sets following the method described by Moore et al. (2006). The within subjects variables were Waveband (6 levels; 4-6, 4-8, 8-10, 10-12, 12-19, 19-28), Electrodes (14 levels; Fp1, Fp2, F3, F4, F7, F8, C3, C4, T3, T4, P3, P4, O1, O2), Condition (2 levels; truth versus lie) and for the Initial Reaction data set, Time (2 levels, as previously defined in 2.5.1), and the Anticipation data set, Time (4 levels, as previously defined in 2.5.2). The between subjects factor was BIS (2 levels; high and low).

Follow up investigative analysis was conducted for certain interactions. For instance, only interactions including waveband and condition were investigated in the initial repeated measures ANOVA due to the hypothesised changes in EEG activity in specific wavebands, and between conditions (truth versus lie). The significance criterion at the omnibus stage of the analysis was relaxed to avoid making a Type II error in later stages of the analyses due to the multi-dimensional nature of the data. Additionally, to prevent from making Type I errors, the significance criterion reverted back to 0.05 in follow up analyses and, additionally, all *p* values were subject to a highly conservative Bonferroni correction (Rosenthal, Rosnow & Rubin, 2000). As is typical with physiological research, the Greenhouse Geisser adjustment was used at each stage of the analysis. The omnibus ANOVA was also conducted with log-transformed data to eliminate participant differences.

3 Results

3.1 EEG Theta

3.1.1 EEG theta power decreased during the initial reaction to guilty stimuli.

Hypothesis 1 stated that there would be an increased activation in the alpha waveband during stimuli relating to guilty knowledge compared to irrelevant or control stimuli. The initial step of analysis was the omnibus ANOVA, including the factors described above (see Statistical Analysis sub-section). In order to test this hypothesis, the within subjects factor of truth versus lie was relevant. Initial analysis revealed a Waveband×Condition×Electrode ($F(65, 2405) = 1.55$, $p < 0.1$, EPS: 0.192) interaction, although above .05, the significance criterion at the omnibus stage of the analysis was relaxed (see Statistical Analysis sub-section). This first prompted further analysis into individual wavebands, revealing a significant interaction of Condition×Electrode in high theta (6-8 Hz) waveband ($F(13,481) = 3.91$, $p < 0.05$, EPS: 0.3), indicating changes within theta activity, during stimuli relating to guilty knowledge. A significant interaction of Condition×Electrode was also found in the 10-12 Hz (low alpha) waveband ($F(13,481) = 3.38$, $p < 0.5$, EPS: 0.436). However further analysis conducted to extract individual electrode significance revealed no notable results following Bonferroni correction.

Additional follow up analyses were conducted into high theta (6-8 Hz) waveband to extract individual electrode power means for both conditions, as illustrated in Figure 3. This revealed that high theta (6-8 Hz) differentiates between a person's reaction to guilty stimuli compared to control or irrelevant stimuli. The involvement of specific electrodes were then examined, indicating decreased activation during guilty stimuli at each electrode except C4 (shown in Table 1).

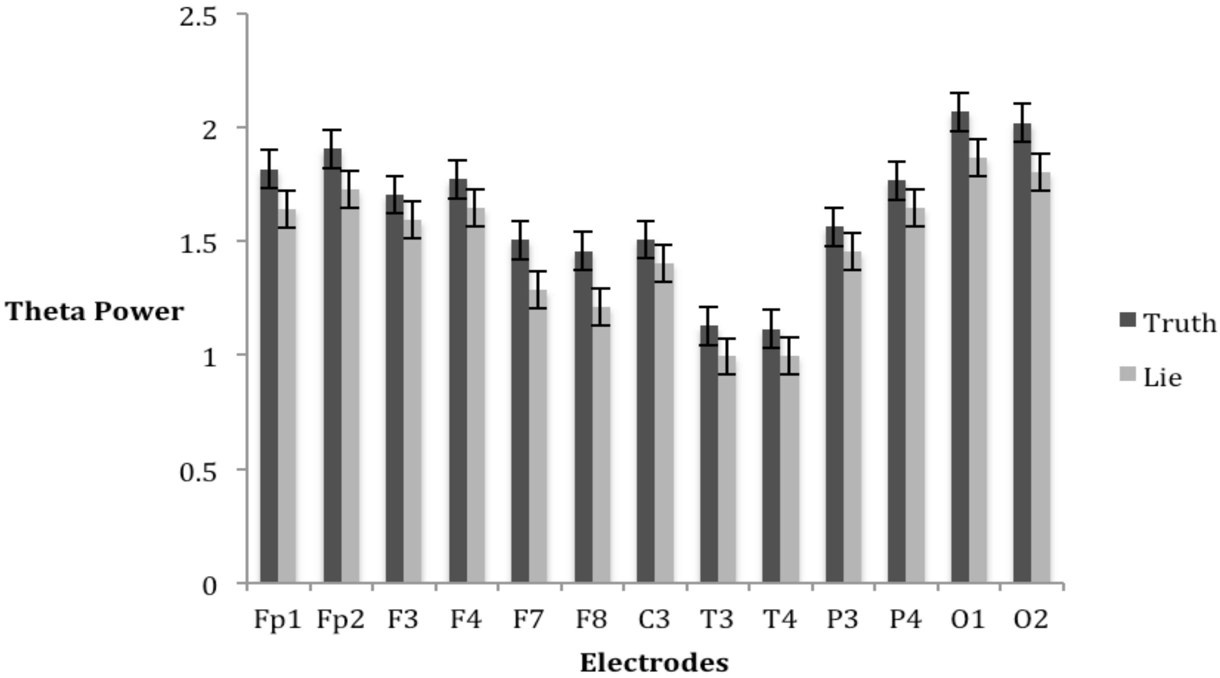

Figure 3: Differences in theta activity (6-8 Hz waveband) between guilty stimuli and control/irrelevant stimuli for each electrode, error bars illustrate ± standard errors. A decrease in theta activation is shown for guilty stimuli. (*N*=39)

Table 1
Condition×Electrode Interaction: Specific Electrode Involvement in Decreased 6-8 Hz Activation During Guilty Stimuli.

Electrode	Main effect of Condition (Truth versus Lying)
Fp1	$F(1,38) = 35.63$, $p<.01$
Fp2	$F(1,38) = 24.38$, $p<.01$
F3	$F(1,38) = 15.12$, $p<.01$
F4	$F(1,38) = 18.22$, $p<.01$
F7	$F(1,38) = 13.76$, $p<.01$
F8	$F(1,38) = 20.63$, $p<.01$
C3	$F(1,38) = 14.04$, $p<.01$
C4	$F(1,38) = 7.87$, $p>.1$
T3	$F(1,38) = 15.38$, $p<.01$
T4	$F(1,38) = 10.52$, $p<.05$
P3	$F(1,38) = 11.57$, $p<.05$
P4	$F(1,38) = 20.50$, $p<.01$
O1	$F(1,38) = 42.88$, $p<.01$
O2	$F(1,38) = 60.55$, $p<.01$

All epsilon values were 1.00 as there was only one factor with two levels.

3.1.2 There is a significant reduction in EEG theta when a person is anticipating lying.

In order to test the hypothesis ‘Anticipation of telling a lie compared to telling the truth will reflect an increase in EEG theta activity at frontal brain regions’, the within subjects factor of condition (truth versus lie) was of specific interest. When making selections for follow up analyses, interactions uncovered at this stage were not considered to be meaningful if they did not collectively involve both the factors ‘waveband’ and ‘condition’. The former confirmed that the interaction was waveband specific and the latter that it was significant between conditions of truth versus lie. The omnibus ANOVA revealed the significant interaction of Waveband×Condition ($F(5,185) = 5.85$, $p < 0.05$, EPS: 0.495), enabling follow-up analysis. Consequently, an ANOVA for each of the 6 wavebands was conducted with the entire 3-second averages of anticipation to immediate deception to examine whether any specific waveband revealed a significant change during anticipation of telling truths and lies. The 4-6 Hz (low theta) waveband showed a significant main effect of condition (truth versus lie) $F(1,38) = 28.46$, $p < 0.05$, EPS: 1.00). At the same time, the 6-8 Hz (high theta) waveband also revealed a significant main effect of condition ($F(1,38) = 10.01$, $p < 0.05$, EPS: 1.00). This indicates changes in brain activity whilst anticipating lying, revealed only in theta activation, suggesting theta activity can differentiate between individuals anticipating lying compared to telling the truth. Truth and Lie means for the lower (4-6 Hz; see Figure 4) and upper (6-8 Hz; see Figure 5) theta wavebands were extracted to reveal the significant condition effect for these wavebands. This revealed that EEG theta activity is decreased, not increased, during lying.

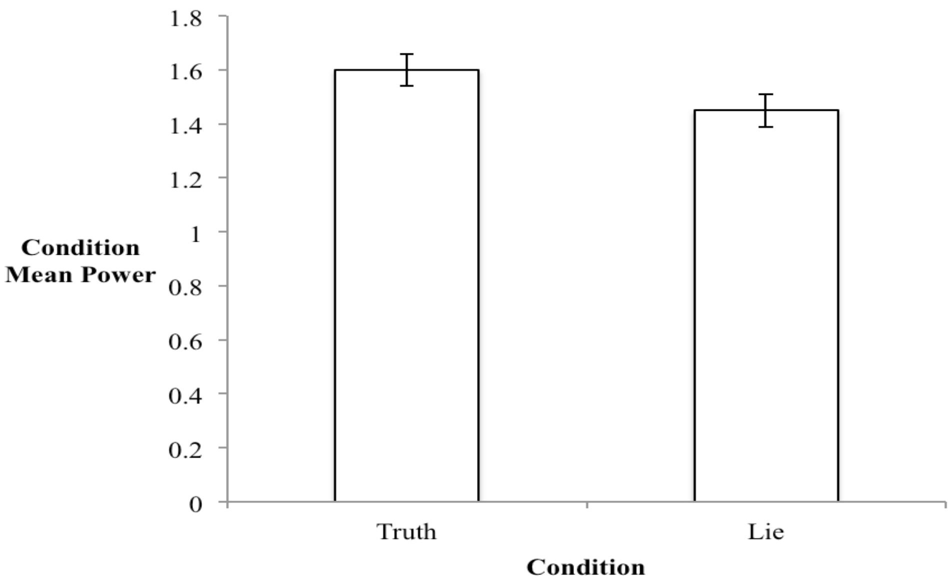

Figure 4: Mean (scalp-wide) 4-6 Hz power levels μV (± standard errors) for truth and lying conditions (*N*=39).

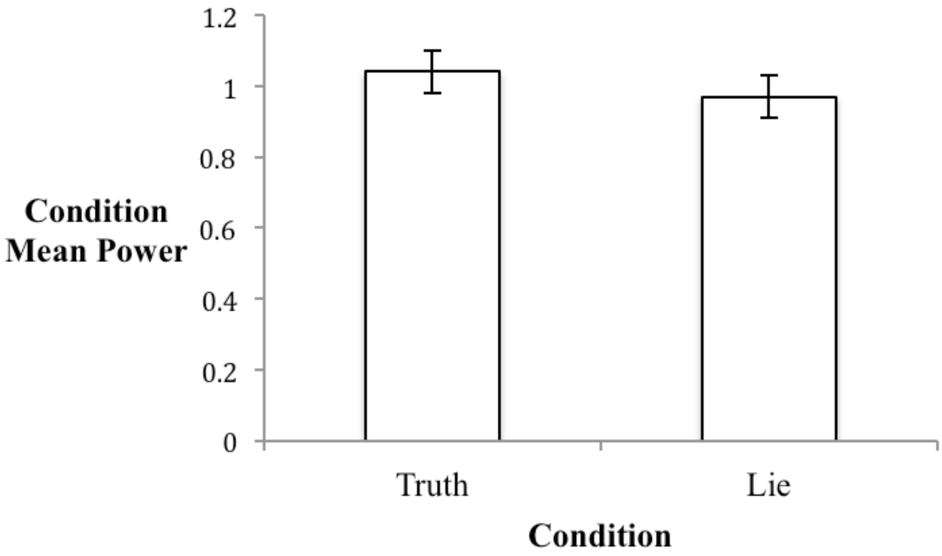

Figure 5: Mean (Scalp wide) 6-8 Hz power levels μV (± standard errors) for truth and lying conditions (N=39).

3.2 EEG alpha

3.2.1 EEG alpha is not affected when anticipating lying compared to anticipating telling the truth.

During the initial omnibus ANOVA and follow-up analysis in the hierarchical ANOVA (as described above, see section 3.1.2), changes in alpha activation were also analysed. Due to the significant interaction of Waveband×Condition, follow-up analyses of each individual waveband were carried out alongside 8-10 Hz (low alpha) and 10-12 Hz (high alpha). However no effects of condition on alpha activity were revealed. The significant main effect of Condition (truth versus lie) on alpha activity is neither significant for low (8-10 Hz) alpha ($F(1,38) = .194$, $p>0.1$, EPS: 1.00), nor for high (10-12 Hz) alpha ($F(1,38) = .262$, $p>0.1$, EPS: 1.00). This indicates that lying compared to telling the truth does not influence alpha activity, and thus, the hypothesised effect was not found.

3.3 BIS

3.3.1 Low/High BIS differentiation in EEG power

No significant interactions that involved the between groups BIS factor were found, indicating that extreme sampled levels of BIS did not interact with any specific waveband ($F(5,185) = .885$, $p>0.1$, EPS: 0.482) nor differentiate between lying and truthful conditions ($F(1,37) = 2.34$, $p>0.1$, EPS: 1.00) during the initial reaction to truth or lie stimuli. Furthermore no significant interactions involving the between groups BIS factor were found for anticipating truthful or deceptive responses for specific wavebands ($F(5,185) = .817$, $p>0.1$, EPS: 0.529) nor for truthful or lying conditions ($F(1,37) = 1.84$, $p>0.1$, EPS: 1.00). Since there were no interactions which involved the BIS factor, it can be concluded that individuals sampled with extreme levels of high and low BIS could not be differentiated when looking at the initial reaction to guilty stimuli, nor when anticipating telling a lie compared to telling the truth. The reasons for this are discussed in section 4.3.1.

4 Discussion

The results from the current study will be discussed in relation to previous literature, with three main findings illustrated and examined throughout this discussion. The changes in EEG theta (finding 1) revealed though a) deceased theta power during the initial reaction to guilty knowledge stimuli in the high theta waveband (6-8 Hz), and b) decreased theta power during anticipation of immediate lying with both low (4-6 Hz) and high (6-8 Hz) theta waveband, will be discussed. The absence of significantly decreased alpha power during deceptive behaviour (finding 2) and the non-significant between subjects effect of BIS (finding 3) will also be explored. Further research and future investigations will be examined, as well as limitations for the current study.

4.1 EEG Theta

4.1.1 Initial reaction to guilty stimuli produced decrease in high EEG theta waveband activity

EEG theta power was shown to reduce when participants viewed stimuli concerning guilty knowledge compared to control or irrelevant stimuli. This opposed the hypothesised results, as effects were demonstrated for high theta (6-8 Hz), but not high alpha (10-12 Hz), nor low alpha (8-10 Hz) following Bonferroni Correction.

When exploring the reasons behind this significant finding, the basic assumption of the task implemented in this study will be explained. The belief of the GKT is that an individual will unconsciously evoke a physiological reaction to the guilty knowledge item presented (Ben-Shakhar & Elaad, 2003). This is based on research in to the Orienting Response (OR) (Sokolov, 1963), and the connection that significant stimuli will evoke enhanced ORs. However OR releasing stimuli have been shown to lose their significance over repeated trials as a result of habituation (Zimmer, 2005).

Furthermore it has been proposed that the OR can also be induced by novel stimuli (Barry, 1997). Thus in the current study, the significant findings of increased EEG theta in the initial reaction to truth stimuli could be a result of dishabituation and heightened attention to novel information. During the task participants were presented with 60 cards, 30 of these were truth stimuli and 30 were lie stimuli. As is convention in the modified Guilty Knowledge Task and EEG activity (see Deception Detection Assessments sub-section), participants were presented with three types of cards; Target, Control, and Irrelevant. Hence the only unfamiliar information presented to participants which may have inadvertently induced an OR were irrelevant stimuli; as for all of the lie trials the participant held the target card in hand, and for half of the truth trials the control card could be found face-up on the table. In light of this, the increased theta activity observed in the truth condition may be attributed to the irrelevant stimuli influencing the participant’s averaged power spectra across all of the 30 truth trials; control and irrelevant. In addition, the significant result in high theta (6-8 Hz) as opposed to alpha waveband could be explained by Dietl, Dirlich, Vogl, Lechner and Strian (1999), who found theta activation to be associated with the encoding of new information. One could assume the increased theta activity in the truth condition could be a result of novel irrelevant stimuli triggering a response in brain activity due to the need to encode the unfamiliar information.

4.1.2 Decreased theta activity when anticipating telling a lie

Contrary to previous research, and subsequently the second hypothesis, EEG theta was not found to increase at the frontal brain regions when anticipating telling a lie. Moreover, both low (4-6 Hz) and high (6-8 Hz) theta activity have been demonstrated to reduce during the anticipation of telling an immediate lie compared to the truth (Figure 4 and Figure 5). This decrease of theta power contradicts all previous literature including Moore, Spanhell, Marshman and Corr (in prep) and will subsequently be discussed in light of this.

The basic premise that increased cognitive complexity is linked to increased theta activity has been demonstrated in numerous studies (Gevins et al., 1997; Bles & Haynes, 2008), which when related to the current study indicates that the truth condition required increased cognitive resources compared to the lying condition. This leads to the assumption that participants found the truth condition more cognitively demanding, evidenced by the increased theta activity.

For a better understanding of this finding it might be helpful to analyse what participants were doing in each of the conditions. For a dishonest trial, the participant always had their ‘hidden’ card shown on screen, therefore would always press “no” to ‘Do you have this card?’. However for a truth trial, the card shown on screen could be either a control or an irrelevant stimulus, resulting in a “yes” to control stimuli, or “no” to irrelevant stimuli. Thus participant’s attention would first be drawn to their ‘hidden’ card for that individual trial, to ascertain if they held the card shown on the screen. Participants would then refer to the four control cards laid on the table in order to answer truthfully, whether it be a “yes” or a “no”. In comparison to the ease of which participants could lie based solely on whether the card on screen matched the card in their hand, participants were instead forced to attend to all four control cards, which may or may not have contained the card shown. As a consequence, the increased theta activity shown in the anticipation of telling the truth could be a result of increased cognitive load when determining the correct response, as opposed to the assumed objective of the task in measuring cognitive load as an outcome of deception.

4.2 EEG Alpha

4.2.1 Alpha activity not influenced by anticipating a lie

Based on the premise that alpha waveband activity desynchronises during cognitively complex tasks (Klimesch, 1999), and that lying is more cognitively demanding than telling the truth (Jensen & Tesche, 2002), it was hypothesised that a reduction in alpha activity would be prominent in the lying condition. This, however, was not established in the current study. In neither low (8-10 Hz) nor high (10-12 Hz) alpha activity were significant differences established as a result of condition (truth versus lie). Consequently, the results indicate that EEG alpha is not linked with cognitive processes associated with lying, also found by Moore, Spanhell, Marshman and Corr (in prep). However Kim et al*.* (2012) found that a decrease in alpha frequency only occurred with spontaneous deception, rather than instructed deception. Participants in both the current study and in Moore et al. (in prep) were instructed about where during the task to lie. Therefore it could be reasoned that spontaneous lying may require increased cognitive resources, whilst instructed lying may have reduced the implications of cognitive load.

However data reduction procedures implemented for analysing truth compared to lie trials may have influenced the non-significant findings. Gevins et al. (1997) found decreased alpha activity during cognitively demanding tasks, but after rehearsal of said task, alpha activity was shown to increase again. This suggests that with practice, less attention and cortical resources are needed to attend to the task, and subsequently the task demands are less cognitively strenuous. As following regular convention with EEG data (Moore et al., 2012) during the current study, participant's power spectra were averaged across all of the 30 trials that would prompt a truthful answer, and all of the 30 trials that would induce a deceptive answer. If task practice does in fact influence cognitive load, one could argue that after repeated trials participants became accustomed to the task and therefore the cognitive demands were decreased and alpha activity increased. Thus, averaging a single power spectrum for each condition may have concealed any effects that may have been found at the initial stage of the task.

4.3 BIS

4.3.1 All findings not significantly more apparent in high BIS

Increased theta activity was hypothesised to be more apparent in individuals with high levels of measured BIS. However analysis revealed no interactions relating to waveband or condition. Conclusions could be drawn suggesting the possibility that EEG theta does not differentiate according to BIS level when anticipating telling a lie compared to the truth.

Research has found that upon activation, the BIS increases arousal, heightens attention and increases anxiety (Corr, 2002), generating increased theta activity (Razoumnikova, 2003). Research by Anderson et al. (2009) explored the links between EEG theta and BIS as a conflict and resolution system, suggesting EEG theta was enhanced during anxiety provoking conflicts. Therefore the EEG response of participants in the current study with heightened BIS activation should have shown increased theta rhythm during anticipation of lying, due to cognitive conflict when suppressing truthful responses. However as no differentiation was found between the samples, one could argue the task may not have evoked substantial cognitive conflict to have activated the Behavioural Inhibition System. Thus, the task in the current study may not have invoked conflict anxiety within the participant whilst lying, only the need to suppress the truth as opposed to generating an alternative, leading to no significant differentiation in EEG theta between participants.

However, the findings of the current study could be argued not to indicate an absence of high/low BIS differentiation regarding EEG theta, but instead the influence of the highly conservative statistical analysis implemented. The non-significant finding is consistent with other studies such as Moore et al., (2012) who were not successful in finding differentiation in low/high BIS groups using the conventional ANOVA. When analysing data using ANOVA analysis as used in the current study, compared to a discriminate analysis, their results indicated a discrepancy. Although extreme sampled BIS appeared to be distinguished in the discriminate analysis, when using the omnibus ANOVA all interactions modulated by BIS level were not significant (Moore et al., 2012). The discrepancy between results was explained by the conservative approach of the hierarchical ANOVA, with Bonferroni correction being applied at every level. In comparison, the discriminate analysis filters the data, reducing sources of error, therefore significant effects are more prominent and less likely to be washed away by the correction. It could be that the analysis in the current study may have been affected by these problems.

4.4 Critique of current study, and suggestions for further and future research

The results of the current study offered differences in EEG activity, although findings opposed previous literature, for example Moore et al. (in prep). Results suggest that EEG theta can discern between individuals with guilty knowledge and those without, and differentiate between truths and lies. However, individuals compared by extreme samples in high and low BIS could not be differentiated by theta power.

Obstacles within the current study will now be examined, beginning with the task. The modified Guilty Knowledge Task is predominantly used in electroencephalography lie detection research, as lies told cannot differ in quality among participants. Moore et al. (in prep) instructed participants to tell a truthful or deceptive story, but did not account for the length and quality of lie told by an individual, hence the implementation of the well-established task in the current study as a control measure. However the simplicity of lying behaviour in the current study may have reduced the influence of cognitive load instigated by deception. Hence, it is not clear whether the cognitive complexity associated with deception is similarly present when participants press “Yes” or “No”. Additionally, increased cognitive load may have been found in truth trials as a result of the participant needing to determine the correct response, as opposed to the ease of always saying “No” when lying. This may have unintentionally caused increased cognitive load, and thus impeded analysis into lying behaviour.

Furthermore the real world application of the GKT is usually administered in situations in which the person would be highly motivated to deceive. Research utilising the modified GKT employed the tactic of leading participants to believe their brain activity and responses would be monitored by an external observer who would attempt to identify deceptive responses (Phan et al., 2005), likening the task to real life situations where a person needs to convince the interviewers of their credibility, and therefore ‘innocence’ (Vrij & Mann, 2001). The motivational factors employed may have increased an individual’s desire to remain undetected, contrasting the current study where producing a ‘successful’ lie would not prove advantageous to a participant.

As findings conflict with previous research, further data analysis could be conducted to explore the reasons as to why. An important analysis would be to compare truthful and lying conditions on a trial-by-trial basis for participants.

This would explore whether results found in the initial reaction to guilty stimuli that oppose the findings of Matsuda et al. (2013) are able to be replicated, or are a result of habituation, and thus a reduction in OR as a consequence of repeated trials.

Furthermore, similar analysis would need to be conducted into the decreased EEG theta upon anticipation of telling a lie. This would evidence whether task practice and therefore reduction in cognitive complexity played a part in the current findings, and also whether the anticipation of telling a lie initially led to a decrease in alpha activity. In order to explore these, power spectra could be averaged across 0-10, 10-20, and 20-30 trials for each condition as this would explain whether results found were a product of data reduction methods implemented, a result of various factors affecting detectability, or whether deception itself heeded less cognitive resources than previously believed.

In regard to the BIS differentiation, no significant interactions were found differentiating extreme sampled high/low BIS individuals. Although research into personality, brain activity and deception is relatively novel, results from numerous studies demonstrate the association between BIS activation and theta activity (e.g. Razoumnikova, 2003; Anderson et al., 2009). Therefore it may be pertinent to explore whether using a task that forced participants to not only suppress the truth, but generate a plausible lie would lead to activation of the BIS as a conflict and resolution system, as suggested by Anderson et al. (2009).

Furthermore, drawing inspiration from Moore et al. (2012), the current data could be analysed by applying a stepwise discriminate analysis (SDA) rather than the conventional ANOVA to see whether low/high BIS could be discriminated concerning the theta waveband when using a less conservative measure.

Research interested in the networks involved in cortical activation is slowly becoming more prominent. The current study only measured region specific activity, thus interesting future research could be conducted into EEG coherence to assess what networks are activated in studies such as this one.

4.5 Conclusion

The aim of the current study was to distinguish between a person’s instant reaction to guilty knowledge, and subsequently, their anticipation of telling a lie compared to the truth. Furthermore, whether the BIS would be activated when an individual was put in a state of conflict induced by deception, thus differentiating between low and high sampled participants.

On the whole, the conclusion can be drawn that guilty knowledge stimuli can distinguish the innocent from the guilty in agreement with the new research of Matsuda et al. (2013). However the findings were revealed in different frequencies, with the current study finding a decrease in theta, opposed to an increase in alpha as found by Matsuda et al. (2013). The current study also found that there was a conclusive neurological difference between the moments of anticipation prior to revealing a truth, compared to a lie. However the findings were in direct opposition to those of Moore et al. (in prep), prompting suggestion that further research is needed to explore the link between EEG theta and type of deceptive behaviour. However, the conclusion drawn that BIS does not appear to have an influence on theta activity during the GKT certainly warrants future investigation, due to limited research into personality measures with regards to deception and the potential for interesting results.

Research into the GKT and brain activity is still in its inception, however the potential for exploration of the subject matter could conceivably indicate a new, innovative and, most importantly, reliable method in the field of deception detection.

5 References

Abootalebi, V., Moradi, M. H., & Khalilzadeh, M. A. (2009). A new approach for EEG feature extraction in P300-based lie detection. *Computer Methods and Programs in Biomedicine,* 94, 48-57.

Akehurst, L., Kohnken, G., Vrij, A., & Bull, R. (1996). Lay persons' and police officers' beliefs regarding deceptive behaviour. *Applied Cognitive Psychology,* 10*,* 461-471.

Anderson, S. B., Moore, R. A., Venables, L., & Corr, P. J. (2009). Electrophysiological correlates of anxious rumination. *International Journal of Psychophysiology,* 71, 156-169.

Barry, R. J. (1997). The effect of significance upon indices of Sokolov's orienting response: A new conceptualization to replace the OR. *Physiological Psychology,* 5(2), 209-214.

Ben-Shakhar, G., Bar-Hillel, M., & Kremnitzer, M. (2002). Trial by polygraph: Reconsidering the use of the Guilty Knowledge technique in court: *Law and Human Behavior,* 26*,* 527-541.

Ben-Shakhar, G., & Elaad, E. (2003). The validity of psychophysiological detection of information with the Guilty Knowledge Test: A meta-analytic review. *Journal of Applied Psychology,* 88*,* 131-151.

Bles, M., & Haynes, J. D. (2008). Detecting concealed information using brain-imaging technology. *Neurocase: The Neural Basis of Cognition,* 14(1), 82-92.

Bosch, V., Mecklinger, A., & Friederici, A. D. (2001). Slow cortical potentials during retention of object, spatial and verbal information. *Cognitive Brain Research,* 10, 219-237.

Campbell-Sills, L., Liverant, G. I., & Brown, T. A. (2004). Psychometric evaluation of the Behavioural Inhibition/Behavioural Activation Scales in a large sample of outpatients with anxiety and mood disorders. *Psychological Assessment,* 16(3), 244-254.

Carver, C. S., & White, T. L. (1994). Behavioural inhibition, behavioural activation, and affective responses to impending reward and punishment: the BIS/BAS Scales. *Journal of Personality and Social Psychology,* 67(2), 319-333.

Colder, C. R., Trucco, E. M., Lopez, H. I., Hawk Jr, L. W., Read, J. P., Lengua, L. J., Weiczorek, W. F., & Eiden, R. G. (2011). Revised reinforcement sensitivity theory and laboratory assessment of BIS and BAS in children. *Journal of Research in Personality,* 45*,* 198-207.

Corr, P. J. (2002). J. A. Gray's reinforcement sensitivity theory: tests of the joint subsystems hypothesis of anxiety and impulsivity. *Personality and Individual Differences,* 33, 511-532.

DePaulo, B. M. (1992). Nonverbal behavior and self-presentation. *Psychological Bulletin,* 111(2), 203-243.

DePaulo, B. M., Lindsay, J. J., Malone, B. E., Muhlenbruck, L., Charlton, K., & Cooper, H. (2003). Cues to deception. *Psychological Bulletin,* 129(1), 74-118.

Dietl, T., Dirlich, G., Vogl, L., Lechner, C., & Strian, F. (1999). Orienting response and frontal midline theta activity: a somatosensory spectral perturbation study. *Clinical Neurophysiology,* 110(7), 1204-1209.

Gamer, M., Rill, H. G., Vossel, G., & Godert, H. W. (2006). Psychophysiological and vocal measures in the detection of guilty knowledge. *International Journal of Psychophysiology,* 60(1)*,* 76-87.

Gevins, A., Smith, M. E., McEvoy, L., & Yu, D. (1997). High-resolution EEG mapping of cortical activation related to working memory: Effects of task difficulty, type of processing, and practice. *Cerebral Cortex,* 7(4), 374-385. doi: 10.1093/cercor/7.4.374

Gevins, A. S., Zeitlin, G. M., Doyle, J. C., Schaffer, R. E., & Callaway, E. (1979). EEG patterns during "cognitive" tasks. Analysis of controlled tasks. *Electroencephalography and clinical neurophysiology,* 47(1), 704-710.

Giesen, M., & Rollison, M. A. (1980). Guilty Knowledge versus innocent associations: Effects of trait anxiety and stimulus context on skin conductance. *Journal of Research in Personality,* 14(1), 1-11.

Gombos, V. A. (2010). The cognition of deception: The role of executive processes in producing lies. *Genetic, Social, and General Psychology Monographs,* 132(3), 197-214.

Gratton, G., Coles, M. G., & Donchin, E. (1983). A new method for off-line removal of ocular artifact. *Electroencephalography and Clinical Neurophysiology,* 55(4), 468-484.

Gray, J. R. (1970). The psychophysiological basis of introversion-extraversion. *Behavioural Research and Therapy,* 8, 249-266.

Gray, J. R. (1982). *The neuropsychology of anxiety: An enquiry into the functions of the septo-hippocampal system.* Oxford, England: Oxford University Press.

Gray, J. R. (2001). Emotional modulation of cognitive control: Approach-withdrawal states double-dissociate spatial from verbal two-back task performance. *Journal of Experimental Psychology,* 130(3), 436-452.

Gray, J. R., & McNaughton, N. (2000). *The Neuropsychology of Anxiety: An Enquiry into the Functions of the Septo-Hippocampal System (2nd ed.).* Oxford: Oxford University Press.

Inbau, F. E., Reid, J. E., Buckley, J. P., & Jayne, B. P. (2001). *Criminal interrogations and confessions*. Gaithersburg, MD: Aspen.

Jensen, O., & Tesche, C. D. (2002). Frontal theta activity in humans increases with memory load in a working memory task. *European Journal of Neuroscience,* 15(8), 1395-1399.

de Jong, T. (2010). Cognitive load theory, educational research and instructional design: some food for thought. *International Journal of Learning Sciences,* 38, 105-135. doi: 10.1007/s11251-009-9110-0

Kim, S., Jung, K. H., & Lee, J-H. (2012). Characteristics of alpha power event-related desynchronization in the discrimination of spontaneous deceptive responses. *International Journal of Psychophysiology,* 85, 230-235.

Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. *Brain research reviews,* 29(2-3), 169-195.

Knyazev, G. G., Slobodskaya, H. R., & Wilson, G. D. (2002). Psychophysiological correlates of behavioural inhibition and activation. *Personality and Individual Differences,* 33(4), 647-660

Langleben, D. D., Loughead, J. W., Bilker, W. B., Ruparel, K., Childress, A. R., Busch, S. I., & Gur, R. C. (2005). Telling truth from lie in individual subjects with fast event-related fMRI. *Human Brain Mapping,* 26(4), 262-272.

Lykken, D. T. (1959). The GSR in the detection of guilt. *Journal of Applied Psychology,* 43, 385-388.

Matsuda, I., Nittono, H., & Allen, J. J. (2013). Detection of concealed information by P3 and frontal EEG asymmetry. *Neuroscience Letters,* 537*,* 55-59.

Meltzer, J. A., Negishi, M., Mayes, L. C., & Constable, R. T. (2007). Individual differences in EEG theta and alpha dynamics during working memory correlate with fMRI responses across subjects. *Clinical Neurophysiology,* 118(11), 2419-2436.

Merzagora, A. C., Bunce, S., Izzetoglu, M., and Onaral B. (2006). Wavelet analysis for EEG feature extraction in deception detection*. Engineering in Medicine and Biology Society,* 1*,* 2434-2437.

Miller, G. A. (1955). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *American Psychological Association Psychological Review* 101(2), 343-352.

Moore, R. A., Gale, A., Morris, P. H., & Forrester, D. (2006). Theta phase locking across the neocortex reflects cortico-hippocampal recursive communication during goal conflict resolution. *Journal of the International Organization of Psychophysiology,* 60(3), 260–73.

Moore, R. A., Mills, M., Marshman, P., & Corr, P. J. (2012). Behavioural Inhibition System (BIS) sensitivity differentiates EEG theta responses during goal conflict in a continuous monitoring task. *International Journal of Psychophysiology.* 85, 134-144.

Moore, R. A., Spanhel, K., Marshman, P., & Corr, P. J. (in prep). The effects of telling lies on brain activity: An investigation with the EEG.

Paulhus, D. L. (1986). Self-deception and impression management in test responses. In A. Angleitner, & J. S. Wiggins (Eds.), *Personality Assessment via Questionnaires* (pp. 143-165). Berlin: Springer Berlin Heidelberg.

Phan, K. L., Magalhaes, A., Ziemlewicz, T. J., Fitzgerald, D. A., Green, C., & Smith, W. (2005). Neural correlates of telling lies: A functional magnetic resonance imaging study at 4 Tesla. *Academic Radiology,* 12(2), 164-172.

Proverbio, A. M., Vanutelli, M. E., & Adorni, R. (2013). Can you catch a liar? How negative emotions affect brain responses when lying or telling the truth. *PLoS ONE*, 8(3), 1-12, doi:10.1371/journal.pone.0059383.

Razoumnikova, O. (2003). Interaction of personality and intelligence factors in cortex activity modulation. *Personality Individual Differences,* 35, 135-162.

Rosenfeld, J. P., Soskins, M., Bosh, G., & Ryan, A. (2004). Simple, effective countermeasures to P300-based tests of detection of concealed information. *Psychophysiological Research,* 41(2), 205-219.

Rosenthal, R., Rosnow, R. L., & Rubin, D. B. (2000). *Contrasts and effect sizes in behavioural research: A correlational approach*. Cambridge: Cambridge University Press.

Saxe, L. (1994). Detection of deception: Polygraph and integrity tests. *Current Directions in Psychological Science,* 3, 69-73.

Sokolov, E. H. (1963). *Perception and the conditioned reflex*. New York: Macmillan.

Spence, S. A., Hunter, M. D., Farrow, T. F., Green, R. D., Leung, D. H., & Hughes, C. J. (2004). A cognitive neurobiological account of deception: Evidence from functional neuroimaging. *Biological Sciences,* 359, 1755-1762.

Sporer, S. L., & Schwandt, B. (2007). Moderators of nonverbal indicators of deception: A Meta-Analytic Synthesis. *Psychology, Public Policy, and Law,* 13(1), 1-34.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science,* 12, 257-285.

Sweller, J. (1989). Cognitive technology: Some procedures for facilitating learning and problem solving in mathematics and science. *Journal of Educational Psychology,* 81, 457-466.

Sweller, J., Ayres, P., & Kalyuga, S. (2011). *Cognitive Load Theory.* New York: Springer.

Vrij, A. (2008). *Detecting lies and deceit: Pitfalls and opportunities.* (2nd ed.). Chichester, England: John Wiley & Sons Ltd.

Vrij, A., Fisher, R., Mann, S., & Leal, S. (2006). Detecting deception by manipulating cognitive load. *Trends in Cognitive Science,* 10, 141-142.

Vrij, A., Granhag, P. A., & Porter, S. (2010). Pitfalls and opportunities in nonverbal and verbal lie detection. *Psychological Science in the Public Interest.* 11(3), 89-121.

Vrij, A., & Heaven, S. (1999). Vocal and verbal indicators of deception as a function of lie complexity. *Psychology, Crime and Law,* 5*,* 203-215.

Vrij, A., & Mann, S. (2001). Telling and detecting lies in a high-stake situation: The case of a convicted murderer. *Applied Cognitive Psychology,* 15, 187-203.

Vrij, A., Mann, S., Fisher, R., Milne, B., & Bull, R. (2007). Interviewing to Detect Deception: Full Research Report. ESRC End of Award Report, RES-000-23-0292. Swindon: ESRC

Zimmer, H. (2005). Habituation of the orienting response as reflected by the skin conductance response and by endogenous event-related brain potentials. *International Journal of Psychophysiology,* 60, 44-58.

Zuckerman, M., DePaulo, B. M., & Rosenthal, R. (1981). Verbal and nonverbal communication of deception. In L. Berkowitz (Ed.), *Advances in experimental social psychology* (Vol. 12, pp. 1-59). New York: Academic Press.

Zulawski, D.E. & Wicklander, D.E. (1993). *Practical aspects of interview and interrogation.* New York: Elsevier.