Suppressing Unwanted Memories and Thoughts: Psychological Traits and Forensic Brainwave Investigations

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Abstract

Scientists have rigorously examined general patterns surrounding memory suppression and hundreds of articles address corresponding cognitive and neuroscientific mechanisms. Although humans differ generally, and more so due to the effects of psychological conditions, little attention has been paid to the differences in memory suppression abilities among humans. The current studies address this gap in the literature by investigating potential individual differences in a memory suppression technique, the Think/No-Think paradigm, with respect to psychological traits of obsessive-compulsive disorder and post-traumatic stress disorder.

Individual differences in the accuracy of an event-related potential (ERP)-based knowledge detection system, Brain Fingerprinting, in the general population versus those with criminal histories are also reported. Brain Fingerprinting is used to detect the presence or absence of concealed knowledge related to a specific incident in a subject's memory. The examination of two countermeasures in Brain Fingerprinting, direct-suppression and thought-substitution, are reported as well.

These studies were motivated by the fact that no empirical studies have reported individual differences in memory suppression due to psychological traits and no studies have tested the resistance of Brain Fingerprinting to memory suppression manipulations. To investigate these issues, four studies were designed that involved cognitive psychology, forensic neuroscience, and integrating cognitive psychology with forensic neuroscience. Study-1 and Study-2 addressed the Think/No-Think paradigm in relation to purported traits, Study-3 investigated Brain Fingerprinting, and Study-4 examined cognitive countermeasures to Brain Fingerprinting.

The Think/No-Think task is used to examine suppression of recently learned memories

and its effect on subsequent recall. The paradigm consists of intentional retrieval suppression of one member of recently learned word pairs which are examined in a final recall test. In Study-1, an extension of the Think/No-Think paradigm was conducted with $n = 24$ university students using word pairs with a smaller frequency (12 repetitions) of suppression (No-Think) and facilitation (Think) trials than the standard Think/No-Think experiment (that used 16 repetitions). This study showed no significant temporary impairment in recollection of the suppressed members of word pairs when only 12 No-Think trials were used.

Study-2 investigated whether or not the capacity to suppress one member of the recently learned word pairs is impaired in people with higher Yale-Brown Obsessive Compulsive Scale (YBOCS) scores and in people with higher PTSD CheckList - Civilian Version (PCLC) scores, compared to those with lower scores. A large number of university students ($n = 367$) were screened to identify high and low scorers. $N = 25$ high YBOCS scorers, $n = 27$ high PCLC scorers, $n = 28$ low YBOCS scorers, and $n = 29$ low PCLC scorers participated in this study. To examine the differences, those with higher scores were examined to test if they had more difficulty suppressing memories using No-Think suppression than subjects with lower scores on YBOCS (Experiment-1), and on PCLC (Experiment-2), with the same frequency of Think and No-Think trials as Study-1 (i.e., 12). Each of these experiments (Experiment-1 and Experiment-2) showed a suppression effect due to the No-Think manipulation when the data of high and low scorers in either YBOCS or PCLC were combined. However, neither in YBOCS (comparing high scorers with low) nor in PCLC (comparing high scorers with low) was the capacity to suppress memories using No-Think significantly different between high and low scorers. Therefore, Study-2 did not confirm that the high scorers had more difficulty suppressing memories than the low scorers.

The effect of Think manipulation resulted in mixed outcomes: an overall increased recall due to Think manipulation was not observed in either Study-1 or Study-2. However, this effect interacted with different types of testing the recall, with a facilitation effect when recall was tested with the original cue but no facilitation effect when tested with an independent cue.

Study-3 is the first known study to examine the accuracy of Brain Fingerprinting in parolees ($n = 17$ subjects from a half-way house facility). Contrary to published Brain Fingerprinting studies dealing with the general population, Brain Fingerprinting was found to be less than 100% accurate in determining the guilt or innocence of parolees. In addition, this study also provided evidence that Brain Fingerprinting cannot be used with everyone, as several subjects could not complete the test for various reasons.

Study-4 investigated two cognitive techniques as potential countermeasures in Brain Fingerprinting ($n = 36$ university students). A modification of No-Think, direct-suppression, as well as another method known as thought-substitution were used as countermeasures. In Study-4 Experiment-1, Brain Fingerprinting was used to confirm that information related to specific life incidents was present in participants' memories. Subsequently, in Experiment-2, both countermeasures were tested on the subjects of Experiment-1 in an attempt to render Brain Fingerprinting ineffective. Neither technique was found to be an effective countermeasures in Brain Fingerprinting.

Together, these results suggest that No-think suppression remains marginally effective with a smaller frequency of No-Think. However, there was no significant difference between the suppression capacity of high versus low scorers on psychological traits. In addition, these results have revealed limitations in the capacity of the current Brain Fingerprinting technique when applied to detection of information in persons with criminal histories. Notwithstanding, the results have also demonstrated the resistance of Brain Fingerprinting to direct-suppression and thought-substitution countermeasures.

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Contents

Glossary of Abbreviations

ADHD attention-deficit hyperactivity disorder 130

BFP Brain Fingerprinting 131

DLPFC dorsolateral prefrontral cortex 11

ERP event-related potential 121

fMRI functional magnetic resonance imaging 118

IA Information Absent 122

IP Information Present 122

OCD obsessive-compulsive disorder 127

PCLC PTSD CheckList - Civilian Version 127

PTSD post-traumatic stress disorder 127

T/NT Think/No-Think 111

YBOCS Yale-Brown Obsessive Compulsive Scale 127

Preface

This dissertation is submitted for the degree of Doctor of Philosophy in Psychology at the University of Canterbury. The research was carried out between January 2019 and January 2022. Conducting research on studies 1, 2, and 4 was supported by a University of Canterbury Doctoral Scholarship and Study 3 was completed with support from New Zealand Law Foundation. Studies 1 and 2 are extensions of the Think/No-Think paradigm that has been adopted from the MRC Cognition and Brain Sciences Unit of the University of Cambridge. Studies 3 and 4 were replications and countermeasures of the ERP-based Brain Fingerprinting technology. I was supervised by Associate Professor Ewald Neumann (University of Canterbury) and Professor Richard Jones (University of Canterbury, University of Otago, New Zealand Brain Research Institute). Two studies from this thesis have been submitted for publication, and the manuscript for publication of the remaining two studies is in preparation (as below).

Publications

Research Articles related to PhD

1. **Afzali, M. U.**, Seren-Grace, A. P., Palmer, R. W., Neumann, E., Makarious, S., Wilson, D., and Jones, R. D. (2022). Detection of concealed knowledge via the ERP-based technique *Brain Fingerprinting*: Real-life and real-crime incidents. *Psychophysiology,* 00:e14110, 1-21. https://doi.org/10.1111/psyp.14110

2. **Afzali, M. U.**, Jones, R. D., Seren-Grace, A. P., Palmer, R. W., Makarious, D., Rodrigues, M. N. B., and Neumann, E. Robustness of ERP-based Brain Fingerprinting to direct-suppression and thought-substitution countermeasures. Under review at *Applied*

Cognitive Psychology.

3. **Afzali, M. U.**, Jones, R. D., Lynskey, J., Newlands, J., and Neumann, E. Behavioural evidence of suppression-induced forgetting and its interaction with psychological traits. Manuscript in Preparation for *Journal of Applied Research in Memory and Cognition.*

PhD Research Presentation

1. Behavioural evidence of suppression-induced forgetting and its interaction with psychological traits. School of Psychology, Speech and Hearing, University of Canterbury. Jun 2022.

2. University of Canterbury Brain Fingerprinting Studies. School of Psychology, Speech and Hearing, University of Canterbury. Dec 2021.

3. Brain Fingerprinting: Replication and Countermeasures. New Zealand Psychological Society Annual Conference. Sep 2021.

4. Detection of concealed knowledge via the ERP-based technique Brain Fingerprinting: Real-crime scenarios. Australasian Experimental Psychology Society Annual Conference. Apr 2021.

Extracurricular Research Articles

1. Byrne, K., Dorahy, M., Gale, J., **Afzali, M. U.**, Bulbulia, J. A., Sibley, C. G., and Yogeeswaran, K. Are they us? Psychological impact of far-right terrorism against Muslim minorities on national distress, community, and well-being. Accepted for publication in *Scientific Reports.*

2. Shanaah, S., Yogeeswaran, K., Greaves, L., Bulbulia, J. A., Osborne, D., **Afzali, M. U.**, & Sibley, C. G. (2021). Hate begets warmth? The impact of an anti-Muslim terrorist attack on public attitudes toward Muslims. *Terrorism and Political Violence.* https://doi.org/10.1080/09546553.2021.1877673

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7. Yogeeswaran, K., **Afzali, M. U.**, Andrews, N. P., Chivers, E. A., Wang, M.-J., Devos, T., & Sibley, C. G. (2019). Exploring New Zealand National Identity and Its Importance for Attitudes toward Muslims and Support for Diversity. *New Zealand Journal of Psychology, 48*(1), 29–35.

Chapter 1

Introduction

Research on memory suppression has some remarkable implications. While it is true that revisiting an item usually facilitates its later recall, it has also been found that actively stopping a behavioural response to an unwanted item by control mechanisms can result in its temporary amnesia in a subsequent recall test even if recollection is desired (Anderson & Green, 2001; Levy & Anderson, 2008). The technique used in this endeavour is known as the Think/No-Think (T/NT) paradigm. T/NT is commonly employed to investigate whether people can suppress unwanted memories and the degree to which such suppression can affect subsequent recall.

The standard T/NT task has three phases. In Phase 1, a subject memorises a certain number of *cue-response* word pairs (e.g., ORPHAN – LAMB). The subject is then prompted with individual cues in order to recall the responses from memory and is provided with either one or two instances of feedback so they can recall 50% of the right-hand members of the pairs (response) correctly when they are presented with left-hand members of each pair (cue) individually (Anderson & Green, 2001). If they cannot recall 50% within two feedback instances, they are excused. In Phase 2, a third of the cues are individually presented and subjects are instructed not to allow the corresponding response to enter awareness when they are paying attention to the cue. These are called *No-Think suppression* trials. For another one third of cue-response pairs, subjects have to retrieve the response when they are presented with the cue. These are called *Think facilitation* trials. The Think and No-Think trials are presented in an intermixed order. The remaining one third of trials provide baseline response items that were initially memorised in Phase 1, but are neither suppressed nor retrieved during Phase 2. In a seminal experiment, the Think and No-Think trials occurred either once, eight times, or 16 times for different cue-response word pairs (Anderson & Green, 2001). In Phase 3, the subject's memory is tested for all cue-response pairs memorised in Phase 1 when they are presented with each cue individually (e.g., ORPHAN for ORPHAN – LAMB) and are required to recall the response aloud. This type of recall testing is known as the same-cue test. Another type of recall testing typically used with T/NT paradigm is known as the independent-cue test (Anderson & Green, 2001; Anderson & Spellman, 1995). In the independent-cue test, a subject is presented with an alternate category name that represents the response along with a hint to the response word (e.g., ANIMAL – L for ORPHAN – LAMB), and the subject is required to recall the response aloud. The recall of Think and No-Think responses is compared with the recall of baseline responses. If there is a significant decrease in the recall of No-Think responses, this would suggest the presence of a suppression effect due to the No-Think manipulation in Phase 2 that temporarily limits access to the unwanted memory.

One of the main aims of this study was to examine potential differences in suppressing unwanted memories between individuals who scored on the extreme ends of particular psychological scales. Before examining individual differences, the current study initially attempted to conduct an extension of the standard T/NT paradigm (Study-1) to find out if a smaller frequency of suppression trials (12 in Study-1 instead of 16 in the standard T/NT task) could nevertheless result in the intended temporary amnesia in order to investigate the feasibility of a more efficient T/NT approach, since a reduced frequency of trials takes less time (further details in Sections 2.4, 2.5, and 2.6).

The majority of T/NT researchers have not screened their research subjects for psychological traits (e.g., Abramowitz et al., 2014; Streb et al., 2016). However, the general population can be placed on the spectrum of several psychological scales. An individual's higher score on a particular scale is often indicative of possessing varying levels of a cognitive trait compared to those who score lower on the same scale. For instance, a subject's higher score on an obsessive-compulsive disorder (OCD) measure could indicate that they might be impaired in areas involving executive functioning (Ouimet et al., 2019) and response inhibition (Bannon et al., 2008). This, in turn, may impact the subject's performance on the T/NT task since T/NT also employs executive function systems required to inhibit No-Think suppression responses (Anderson, 2003; Anderson & Green, 2001). Similarly, a subject's higher score on a post-traumatic stress disorder (PTSD) measure could be indicative of impaired memory suppression ability (Catarino et al., 2015). These two instances warranted examining No-Think suppression in subjects who scored high on OCD and PTSD measures, because of potential differences in the ability to suppress unwanted memories. Yale-Brown Obsessive Compulsive Scale (YBOCS) (Goodman et al., 1989) and PTSD CheckList - Civilian Version (PCLC) (Weathers et al., 1993) were used to measure scores of OCD and PTSD, respectively. Their performances on the T/NT task was compared with those who scored low on the mentioned scales. Study-2 Experiment-1, attempted to find out if individuals with higher YBOCS scores had more difficulty suppressing memories using No-Think suppression than those with lower YBOCS scores. Study-2 Experiment-2, investigated whether individuals with higher PCLC scores had more difficulty suppressing memories using No-Think suppression than those with lower PCLC scores.

The second main aim of this project was to examine potential differences in employing Brain Fingerprinting (BFP) (Farwell & Donchin, 1991) as a *concealed knowledge* detection tool in parolees versus the general population. Although the primary use of BFP is for detecting crime-related information, most of the published empirical BFP studies have reported findings on general population only (e.g., Farwell et al., 2013; Farwell & Smith, 2001; Farwell & Donchin, 1991). In addition, published BFP articles to date have not been independent of Dr Larry Farwell, the generator and main stakeholder of BFP. This motivated Study-3 wherein BFP was tested on parolees who had previously committed various crimes and were processed within the criminal justice system of New Zealand.

Study-4 Experiment-1, examined the accuracy of BFP in testing real-life incidents in university students. This, together with Study-3, highlighted limitations in BFP as an information detection tool. In Study-4 Experiment-2, a variant of No-Think, direct-suppression, and another potential countermeasure, thought-substitution, were used against BFP to test whether or not BFP was resistant to these countermeasures. This comprised the third main aim of the current project. Previously, the No-Think component of T/NT has been examined as a countermeasure in other forensic brainwave analysis techniques (e.g., Bergström et al., 2013; Funicelli et al., 2021; Hu et al., 2015; klein Selle et al., 2021; Rosenfeld et al., 2004). These researchers reported No-Think suppression as a potential countermeasure that could limit the utility of event-related potential (ERP)-based forensic brainwave analysis techniques as an information detection tool. On the other hand, Farwell et al. (2013) contended that No-Think suppression would not limit the utility of BFP. Study-4, Experiment-2 was warranted to further investigate these contradictory claims (detailed in Section 3.2). As will be detailed in Section 3.2, the design of BFP makes it impossible to employ the regular No-Think suppression manipulation, so it was modified in a way that fit with the requirements of BFP. In addition, another memory impairing method known as thought-substitution (Hertel & Calcaterra, 2005) was also examined as a potential countermeasure in BFP.

Details relevant to the standard T/NT paradigm used to investigate memory suppression are discussed first, followed by its potential applicability to examining the effect of certain traits on ability to forget unwanted memories via suppression. This will provide fundamental underpinnings for the other major components of the project involving BFP.

Chapter 2

Literature Review: The Think/No-Think Paradigm

2.1 Theoretical Basis

In the past, considerable research has taken place on passive mechanisms of forgetting such as decay over time and changed associations between memory traces in the brain (R. Allen & Baddeley, 2009; Anderson & Hanslmayr, 2014). Another passive mechanism of forgetting pertains to interference from cluttering of many similar events in memory (Anderson, 2003) resulting in limited access to a certain memory overtime. These mechanisms, however, neglected motivated and deliberate attempts of memory suppression employed to push unwanted troubling memories from consciousness when reminded (Anderson & Hanslmayr, 2014). People often engage in active and motivated forgetting when reminded of troubling experiences rather than waiting for passive forgetting to take place (Anderson, 2003; Anderson & Hanslmayr, 2014; Benoit & Anderson, 2012). These active and deliberate attempts could be employed during memory encoding or memory retrieval. If attempted during memory encoding, it would prevent memory consolidation and memory formation. If motivated forgetting is attempted during retrieval of unwanted memories, it would stop the automatic association between memory reminders and the resultant unwanted memories, known as *retrieval suppression* (Anderson & Hanslmayr, 2014). Research has shown that attempting deliberate retrieval suppression when someone is being reminded of unwanted memories led to difficulty accessing these memories in the future (Anderson, 2003; Anderson & Green, 2001; Benoit & Anderson, 2012; Levy & Anderson, 2008). These deliberate attempts form the basis of the Think/No-Think (T/NT) paradigm.

According to Anderson and Green (2001), inherent to the nature of the T/NT task is the Freudian defence mechanism of repression (Freud, 1966), proposing that unwanted memories could be forgotten if pushed out of awareness. Since such memories could be related to trauma, the ethical and practical considerations hindered studying these mechanisms in controlled experiments for decades (Anderson & Green, 2001). In the latest few decades, however, emerging behavioural and neuroscientific research determined humans' capacity to reduce perceptual distraction (Chao & Knight, 1995; Dagenbach & Carr, 1994; Neumann & DeSchepper, 1991), reducing interference during memory tasks (Anderson & Spellman, 1995; Dagenbach & Carr, 1994; Smith & Jonides, 1999), and stopping habitual responses to stimuli (Carter et al., 1999; Knight et al., 1999; Logan & Cowan, 1984) with the use of executive control processes in the brain — that are not specifically linked to trauma (Anderson & Green, 2001). Hence, T/NT was conceptualised as a means to employ these mechanisms to stop certain declarative memories from entering awareness that would eventually lead to lasting consequences for the stopped memories (Anderson & Green, 2001). During Phase 2 of the T/NT task in which a subject is prompted with cues but are instructed to stop the declarative response (i.e., saying aloud the *response* word), it becomes difficult for them to access the *response* word during Phase 3 of T/NT. Furthermore, this inaccessibility (forgetting) increases as a factor of number of times (frequency) of active suppression efforts (Anderson & Green, 2001; Anderson & Hanslmayr, 2014). Therefore, T/NT can theoretically be considered a voluntary form of Freudian repression (Anderson, 2003; Anderson & Green, 2001).

T/NT has been characterized as analogous to the go/no-go task in that a response is required to one stimulus, combined with withholding response to another one (Anderson & Green, 2001). Furthermore, research shows that participating in T/NT simultaneously with the go/no-go task could also result in a suppression effect (Herbert & Sütterlin, 2012).

In the T/NT study by Anderson and Green (2001) wherein the frequency of stopping the declarative memory of a response word (i.e., No-Think suppression) was 1, 8, or 16, the impaired recall was found to be proportionate with this frequency. Hence, exerting executive control to stop a response from entering consciousness impaired its recall such that the highest frequency of implementing No-Think suppression resulted in the worst recall compared to the baseline condition with the same-cue test. More specifically, the recall of baseline words was >80% while the recall of 16 times suppress trial words decreased to around 70%. Further meta-analytic studies showed that the difference between baseline and No-Think trials (the percentage of recalled baseline items minus the percentage of recalled No-Think items) was generally about 6% based on Levy and Anderson (2008) and about 8% based on Stramaccia et al. (2021).

Anderson and Green (2001) further tested recall using the independent-cue testing type and the outcome was similar to the same-cue test. In other words, the recall of words in the No-Think suppression condition was impaired regardless of being tested with the cue it was learned with (i.e., the same-cue test) or with an independent cue, and this was beyond simple forgetting over time. Anderson and Green (2001), therefore, concluded that the impaired recall was not due to unlearning or associative interference (Anderson, 2003; Anderson & Green, 2001; Anderson et al., 2004; Bergström et al., 2009; Lambert et al., 2010) — both could have been true if the impairment did not take place with the independent-cue test — but rather it was due to reduced access to the conceptual representation of the word itself via employing the executive control processes during No-Think suppression. From this, Anderson and Green (2001) concluded that the impairment in recall was localised to the inhibited response word itself. Facilitated trials (i.e., the Think manipulation), as expected, resulted in a proportionately increased recollection of responses during the recall test (Anderson & Green, 2001). Hence, when employing the T/NT procedure, one should be able to regulate the degree of future recall by enhancing or suppressing a target stimulus, resulting in an increase or decrease in recall, respectively.

2.2 An active process that employs executive control systems

Since the No-Think task needs continuous regulation of awareness and overcoming interference of competing depictions, Anderson and Green (2001) speculated that the No-Think task may very likely be using executive control centres in the brain. Executive function is a sum of brain processes used in planning, attention, following instructions, and multitasking (Center on the Developing Child, 2022). Executive control, by contrast, is a more complicated set of processes needed for thought-regulation and action-regulation to facilitate adaptive, planned and goal-driven behaviour. It involves working memory, attentional control, planning, concept development and etc. (Jurado & Rosselli, 2007; Karbach & Unger, 2014). Attentional control, that is fundamental to the T/NT task, involves focusing and staying focused on one stimulus, while not paying attention to anything else (Sippl, 2022). Animal and human studies indicate that lesions in the brain areas related to the executive control system impair attentional control (Rossi et al., 2009; Szczepanski & Knight, 2014).

Anderson et al. (2004) showed that the brain areas involved in stopping habitual motor responses and exerting control over cognitive tasks were active during No-Think trials. This suggested that such suppression was an active process which employed executive control centres in the brain to stop unwanted memories from entering consciousness (Anderson & Hulbert, 2021; Anderson et al., 2004; Levy & Anderson, 2008). In addition, hippocampal activation was reduced during No-Think trials, but increased during Think trials; indicating that the recollection of unwanted memories appeared to be linked with a reduction in hippocampal activity (Anderson et al., 2004; Levy & Anderson, 2008). Hence, it was suggested that unwanted memories were suppressed by recruiting executive control centres, further assisted by hippocampal deactivation (Anderson et al., 2004).

Depue et al. (2007) conducted a variant of the T/NT experiment wherein they used images of faces as cues and images from emotional memories (e.g., car accidents) as responses. The task consisted of three phases similar to the standard T/NT paradigm. The No-Think and the Think conditions had 16 face-picture trials each, with 12 repetitions for each trial. The baseline condition consisted of the 8 trials that were not used in the experimental phase (Phase 2 of the T/NT). They divided the repetition of the 12 No-Think trials into four quartiles and plotted the difference of functional magnetic resonance imaging (fMRI) signal changes across these quartiles for each brain area that showed differential activation for No-Think trials compared to Think trials. One of those areas was the hippocampus. They performed a remembered versus forgotten analysis for the fourth quartile of No-Think trials and their effects on the hippocampus — since it showed the largest effects of cognitive control. The results demonstrated a linear decrease in activity of hippocampus from Think trials towards the baseline, with a further decrease in hippocampal activity from the baseline as a function of increasing No-Think trials (Depue et al., 2007). Additional fMRI findings from Hulbert et al. (2016) demonstrated that a cluster of cognitive control regions in the dorsolateral prefrontal cortex (DLPFC) were active during No-Think trials, indicating involvement of an executive control system of the brain in the T/NT task. Considering that DLPFC provides feedback to hippocampus (Depue et al., 2007; Preston & Eichenbaum, 2013), and that increased hippocampus downregulation and stronger DLPFC activation, both, are associated with increasing No-Think trials and more forgetting (Anderson & Hanslmayr, 2014; Anderson et al., 2004; Benoit & Anderson, 2012; Hulbert et al., 2016), it can be concluded that the executive control centres and hippocampus network are involved in the No-Think task.

Levy and Anderson (2008) speculated that individual differences in executive control ability might mediate the ability of controlling unwanted memories, thus, they suggested *executive deficit hypothesis* as a framework for the T/NT task. As mentioned, memory-suppression involves activation of right DLPFC and inhibition of hippocampus (Anderson & Hanslmayr, 2014; Benoit & Anderson, 2012; Levy & Anderson, 2008). Therefore, according to executive deficit hypothesis, subjects with varied executive control abilities might demonstrate relatively varied degrees of suppression capability with No-Think suppression such that those with higher levels of executive deficit would demonstrate lesser suppression ability and vice versa (Küpper et al., 2014; Levy & Anderson, 2008). Individual differences tend to be generalised to other factors that affect executive function such as neurotransmitters and sleep habits, and differences in these would also potentially lead to differences in suppression ability with No-Think suppression (Levy & Anderson, 2008).

An important factor in causing forgetting due to induced suppression is compliance to experimental instructions by subjects. A recent study with a large sample size (>400) by Liu et al. (2021) confirmed that No-Think suppression effect was negatively correlated with the level of subject compliance. Liu et al. (2021) recommended close monitoring of subjects' compliance during the manipulation phase.

2.3 Direct-suppression or thought-substitution?

Two strategies have normally been used for suppression induced forgetting: direct-suppression and thought-substitution. Direct-suppression is the method of exerting cognitive control during No-Think trials using the executive control systems of the brain to stop an unwanted response word from entering awareness (Anderson & Green, 2001; Anderson & Spellman, 1995; Levy & Anderson, 2002, 2008). Direct-suppression involves a top-down process that involves activation of the right DLPFC that, in turn, inhibits hippocampus (that is fundamental to conscious recall) (Anderson & Hanslmayr, 2014; Benoit & Anderson, 2012).

Thought-substitution is the process of generating alternative thoughts to occupy memory during a No-Think trial, so that a subject can stop an unwanted response word from entering consciousness (Benoit & Anderson, 2012; Hertel & Calcaterra, 2005; Levy & Anderson, 2002, 2008). In some studies, thought-substitution could be achieved by asking subjects to retrieve a previously learned alternative memory (Benoit & Anderson, 2012). For instance, if the original pair was (BEACH – AFRICA), subjects learned (BEACH – SNORKEL), and were asked to retrieve (SNORKEL) to substitute (AFRICA) during thought-substitution. In either case, thought-substitution has also led to limited access of the substituted memory (Benoit & Anderson, 2012). Conversely, only those provided with alternative response (e.g., SNORKEL in the previous example) showed suppression effect and those who were asked to generate alternative thoughts, did not (Hertel & Calcaterra, 2005). Mechanistically, thought-substitution assumes that the resultant amnesia is a product of changes in the cue-response relationship (Bergström et al., 2009). Benoit and Anderson (2012) showed that thought-substituion involved activation of the left caudal prefrontal cortex, midventrolateral prefrontal cortex, and a functional connection between these two structures. In contrast with direct-suppression, downregulation of hippocampus was not found in thought-substitution (Anderson & Hanslmayr, 2014; Benoit & Anderson, 2012).

Bergström et al. (2009) reported mechanistic differences between these two approaches during the Phase 2 of T/NT, as well as qualitatively distinct patterns in later forgetting, with the use of behavioural and event-related potential (ERP) measures. Subjects were divided into direct-suppression (instructed to suppress the unwanted response without thinking about an alternative response during No-Think trials) and thought-substitution (instructed to generate alternative associations to cues so as to occupy memory during No-Think trials) groups, and the recall was tested with both same cue and independent cue testing. Only direct-suppression resulted in impaired recall in both same cue and independent cue testing. Supplementary to these behavioural effects, there was a reduced amplitude in the ERP correlate of conscious recollection known as the the parietal episodic memory effect. In addition, the ERP measure for direct-suppression matched with the markers related to stopping prepotent motor responses (Anderson et al., 2004; Levy & Anderson, 2002), namely an enhanced fronto-central negativity at 150-400 ms for motor stopping followed by an enhanced fronto-central positive deflection at 300-500 ms for motor execution (Bergström et al., 2009). Whereas, for the thought-substitution group, the recall of responses in the No-Think condition was only impaired when the same cue testing was used, leading to the conclusion that direct-suppression, solely, led to cue-independent (based off independent cue test) forgetting (Bergström et al., 2009). They explained that the lack of cue-independent forgetting in thought-substitution might have been a result of lesser intrusion from the original responses. For instance, if the word pair was (BEACH – AFRICA), it would have been easier for a subject to generate a stronger substitute for the response, such as (BEACH – SAND). Now that the response SAND is more related to BEACH than AFRICA, it would be easier for a the subject to access SAND with less intrusion from the original response AFRICA subsequently leading to the lack of cue-independent forgetting (Bergström et al., 2009).

In a study by Gagnepain et al. (2014), subjects learned word-photo (cue-object) pairs and were instructed the same way as in the T/NT task – wherein during the No-Think trials, they were not to generate any distracting thoughts, but instead to focus on the cue by the way of suppressing the conscious awareness of the object. The baseline condition of this experiment consisted of cue-object pairs that were studied, but without instructions to Think or No-Think during the manipulation phase. Gagnepain et al. (2014) argued that suppression of unwanted objects during the No-Think trials would trigger inhibitory control mechanisms that target the neocortical traces of memory, eventually impairing repetition priming (facilitated response to a stimulus as a result of previous encounter with the same stimulus) for the No-Think items. In Phase 3, subjects were required to perceptually identify facilitated (Think) or suppressed (No-Think) objects; rather than using the recall phase of the classic T/NT task. They were being scanned with fMRI and time taken to identify these objects was measured. Subjects took longer to recognise No-Think items than the time taken to recognise Think items, leading to the conclusion that the extent of priming was reduced for the No-Think objects, indicating that the repetition priming was impaired. Neurobiological markers showed that perceptual identification was associated with increased activation for No-Think objects compared to Think and baseline objects — mainly since the instructions required participants to focus on the cues, rather than involve thought-substitution. However, the overall neural priming was decreased for No-Think objects in the fusiform cortex — meaning the subjects did not show awareness of No-Think objects, thus exhibiting the after-effects of suppression on neural priming (Gagnepain et al., 2014). In the light of these findings, Gagnepain et al. (2014) suggested that it was only active direct-suppression, and not thought-substitution, that led to impaired memory of unwanted pieces of information.

In a review article, Engen and Anderson (2018) supported the conjecture that direct-suppression and thought-substitution used different pathways to achieve memory suppression. However, they suggested that both these mechanisms could be employed together to achieve a stronger suppression effect. More explicitly, they suggested that one could suppress an unwanted memory (by the means of direct-suppression) and also generate alternative thoughts (by the means of thought-substitution), that would lead to a longer lasting and a more potent suppression effect (Engen & Anderson, 2018). Overall, these findings show that direct-suppression and thought-substitution engage different neural pathways related to the pre-frontal cortex, with some evidence showing that direct-suppression is a stronger strategy than thought-substitution for forgetting. Nonetheless, Benoit and Anderson (2012) showed that a specific type of thought-substitution, retrieving a previously learned alternative memory during thought-substitution, could result in impaired memory too.

2.4 Think/No-Think and memory suppression

The aforementioned literature shows that the No-Think component of the T/NT procedure entails an active process of direct-suppression, and uses executive function centres of the brain, combined with the hippocampus, to produce temporary, cue-independent amnesia of unwanted memories. In addition, this signals existence of a controllable cognitive process that would diminish access to memories by intentional suppression, which could potentially be employed to prevent conscious recollection of unwanted memories (Anderson & Green, 2001; Anderson et al., 2004; Bergström et al., 2009; Depue et al., 2007; Gagnepain et al., 2014; Hulbert et al., 2016).

It is worth noting that although response items might intrude on a participants' awareness, they do not necessarily have any overall negative impacts on the net result of the suppression effect. In an effort to uncover this, Levy and Anderson (2012) tasked their participants to report intrusions of response items to their memories after each trial during Phase 2 of the T/NT task. Their T/NT manipulation consisted of six blocks of 54 trials (a total of 324 trials), wherein each block had two sets of each experimental cue-response pair (12 No-Think and 12 Think cues). Participants had 1.5 s after each trial to report, by pressing the corresponding key, whether they experienced intrusions of response items. For the Think trials, as expected, the response items intruded on awareness in almost all instances. For the No-Think trials, however, the response memories intruded on awareness in only about one third of the trials. These intrusions declined with the increased frequency of suppression attempts. In other words, it appeared that subjects could exert continuous control over intrusive memories with increased frequency of suppression. The overall effect of this T/NT paradigm was consistent with the former literature (Levy & Anderson, 2012), pointing out that although there were some intrusions, the temporary amnesia still took place due to the No-Think manipulation. In Section 2.2, the role the hippocampus downregulation and involvement of DLPFC were mentioned during No-Think suppression trials. Further research showed that more effortful suppression during intrusions led to further hippocampus downregulation, and repeated suppression efforts led to a decline in intrusions (Anderson, 2003; Anderson & Hanslmayr, 2014).

2.5 Think/No-Think and Obsessive-compulsive Disorder

Obsessive-compulsive disorder (OCD) is characterised by a display of continuous, anxiety provoking, unwanted thoughts, known as obsessions; and a series of ritualistic compulsive behaviours in an attempt to overcome these obsessive thoughts (Bernstein et al., 2021). Therefore, on one hand, obsessive-compulsive disorder (OCD) involves unwanted thoughts, and on the other hand, research on OCD in relation to cognitive processes has revealed that individuals with OCD may demonstrate impairment in executive function areas that involve response inhibition and decision making (Bannon et al., 2008; Ouimet et al., 2019), as well as abnormal prefrontal cortex functioning (Menzies et al., 2008; Remijnse et al., 2006). As mentioned earlier (Section 2.2), the T/NT paradigm employs executive function centres (Anderson & Green, 2001; Anderson & Hanslmayr, 2014; Anderson et al., 2004; Benoit & Anderson, 2012; Hulbert et al., 2016; Levy & Anderson, 2008). However, there is no background research addressing T/NT in relation to OCD.

Attempts have been made to examine the utility of other suppression techniques with OCD cases. A non-T/NT suppression technique asking subjects with OCD to suppress particular intrusive thoughts from coming to mind showed that one fourth of these subjects reported more intrusive thoughts after suppression compared to healthy control subjects (Janeck & Calamari, 1999). Moreover, excessive intrusive thoughts were reported by subjects in the OCD suppression group than the control suppression group (Janeck & Calamari, 1999). Another study reported that diagnosed OCD patients were completely unable to overcome ruminative obsessions, possibly due to impaired cognitive inhibitory processes (Tolin et al., 2002). In addition, a study by Ryckman and Lambert (2015) revealed association of neuroticism, intrusive thoughts, and rumination with failure in memory suppression. As it stands, there is convincing evidence that people with OCD and similar traits might experience various degrees of executive dysfunction (Ouimet et al., 2019). Research on OCD has attempted memory suppression with non-T/NT techniques (Janeck & Calamari, 1999), whereas there is no research addressing T/NT in people with OCD. Therefore, it was considered necessary to determine whether or not OCD-proneness (i.e., high Yale-Brown Obsessive Compulsive Scale (YBOCS) scores) indicates an impairment of the No-Think suppression capability, to help fill this gap in the literature.

2.6 Think/No-Think and Post-traumatic Stress Disorder

A number of studies have examined the T/NT procedure in terms of suppressing ruminating thoughts in post-traumatic stress disorder (PTSD), although they did not exactly duplicate the standard T/NT experiment of Anderson and Green (2001). For instance, Depue et al. (2007) argued that emotional memories needed a larger extent of cognitive control than non-emotional memories. In their study, subjects were trained on cue-response pictures, not with word pairs as used by Anderson and Green (2001), and their fMRI of prefrontal regions, emotional control areas, and visual processing areas were recorded while conducting the T/NT task. Results demonstrated that neural activity increased in the mentioned brain centres during the No-Think trials – suggesting that these areas were involved in the control of emotional memories. Moreover, a negative signal change during No-Think trials of emotional memories at otherwise active sensory cortices of the brain was indicative of decreased activity of these areas during suppression. Hence, Depue et al. (2007) discovered that a two-phase process of cognitive control over sensory elements of a memory representation and cognitive control over emotional elements of a memory representation were involved in the suppression of emotional memories. They concluded that such findings might be applied to exerting cognitive control over emotionally distressing memories in conditions such as OCD and PTSD (Depue et al., 2007).

Streb et al. (2016) examined whether a deficiency in retrieval suppression was a potential risk factor for subsequent PTSD. Subjects went through a T/NT procedure, watching either a mild traumatic clip or a neutral one, and were asked to register any ruminating thoughts of the clip over the following days. No significant relationship was found between forgetting via the No-Think manipulation and the frequency of intrusive thoughts due to memories of the traumatic clip. However, a deficit in ability to suppress memories was related to later traumatic experiences. Conversely, subjects with higher suppression abilities reported fewer intrusive real-life distressing memories than subjects with lower suppression abilities (Streb et al., 2016). These correlational findings imply that it is likely that PTSD-prone subjects are less able to suppress intrusive thoughts.

More recent research has shown that trauma-exposed subjects are less able to suppress unwanted memories (Sullivan et al., 2019). Sullivan et al. (2019) recruited subjects who were either clinically diagnosed with PTSD (PTSD group), were exposed to trauma but did not meet the PTSD clinical diagnostic criteria (no-PTSD group), or had no trauma-exposure and no-PTSD (control group) in a T/NT experiment with face pictures. They found that trauma-exposed subjects—with or without PTSD diagnosis—had less odds of being classified as suppressors than the control group. FMRI markers demonstrated higher activation of lateral prefrontal cortex during No-Think retrieval trials in the PTSD and no-PTSD groups than the control group, suggesting that it was more difficult for the trauma-exposed subjects to suppress unwanted memories irrespective of the presence or absence of a PTSD diagnosis. In other words, it was trauma-exposure—and not the PTSD diagnosis—that defined suppression ability. Trauma exposure was also associated with impaired activity of the middle frontal gyrus during suppression attempts, and the same subjects reported more memory suppression efforts in day-to-day life. Therefore, Sullivan et al. (2019) concluded that exposure to trauma, regardless of PTSD, was related to memory suppression impairment based on both behavioural and neural evidence.

Catarino et al. (2015) determined that impairment of neural inhibitory control mechanisms was one of the leading factors in deficient memory suppression in PTSD. They employed the T/NT paradigm in terms of object-scene pairs with currently diagnosed PTSD subjects (PTSD group) and control subjects. The scene images were designed to be emotionally upsetting. They found evidence of No-Think suppression impairment in the PTSD group. The negative relationship between No-Think suppression and PTSD scores indicated that the more severe symptoms of PTSD a subject had, the more impaired was their ability to suppress unwanted images. Conversely, subjects with successful control over their thoughts had greater ability to suppress with the No-Think manipulation. Catarino et al. (2015) argued, based on former evidence (Anderson et al., 2004; Depue et al., 2007; Gagnepain et al., 2014), that impairment of No-Think suppression in the PTSD group could be a reflection of pre-frontal brain disorders such as inhibitory control deficits. This is consistent with the findings from Fani et al. (2012) that indicated abnormalities in the pre-frontal areas of PTSD patients. However, none of these studies speculated as to whether pre-frontal abnormalities preceded PTSD or followed it. Other studies such as Lyoo et al. (2011) showed that survivors who exhibited more DLPFC thickness a year past trauma had a heightened decline in PTSD symptoms. Notably, Streb et al. (2016) showed that a deficiency in retrieval suppression was a potential risk factor for subsequent PTSD. These findings converge to suggest that some neural deficiency could predispose one to PTSD.

Taken together, the mentioned studies have differing conclusions regarding the factors leading to impaired memory suppression ability in PTSD. Some studies (Catarino et al., 2015; Depue et al., 2007; Streb et al., 2016) suggested that PTSD-prone people were impaired in their ability to suppress unwanted memories. On the other hand, Sullivan et al. (2019) demonstrated that trauma exposure, and not PTSD, led to impairment in suppression ability. In any case, all these findings are suggestive of a strong link between memory suppression and affective psychopathologies such as PTSD, as posited by Engen and Anderson (2018). Critically, some researchers showed evidence of memory suppression with emotionally negative stimuli, but not with emotionally positive stimuli (Lambert et al., 2010). Moreover, suppressing fabricated autobiographical negative future scenarios impaired the memory of these scenarios, but the effect did not replicate in fabricated positive future scenarios (Ryckman et al., 2018). Notably, all these studies used emotion-provoking stimuli that are more consistent with real-life memory suppression efforts while dealing with trauma. Additionally, Engen and Anderson (2018) suggested that the No-Think memory suppression could be utilised as an emotion regulation strategy. They further added that direct-suppression can be used alongside thought-substitution to result in a more potent, longer lasting suppression effect. However, the original T/NT study (Anderson & Green, 2001) did not do so. Anderson and Green (2001) demonstrated a suppression effect using neutral word pairs. This being the case, it was deemed appropriate to determine whether No-Think effect can be obtained with neutral stimuli in PTSD-prone subjects too. Simply put, is the No-Think effect robust enough that it can be obtained using neutral stimuli in persons subject to psycho-emotive conditions such as PTSD? Therefore, it was decided to determine whether or not PTSD-proneness (i.e., high PTSD CheckList - Civilian Version (PCLC) scores) indicates an impairment of No-Think suppression ability even with neutral, non-emotionally valenced word pairs. This, in turn, will also inform if it is the PTSD score, rather than trauma exposure, that defines memory suppression ability. If confirmed, this might also imply that the findings of Sullivan et al. (2019) that trauma exposure leads to impairment in suppression ability are different due to their use of non-neutral stimuli.

There appears to be a need to (1) determine if No-Think suppression is as effective in subjects with OCD as it is in a healthy sample, and (2) examine whether or not PTSD is so damaging that it impairs the No-Think suppression ability with neutral stimuli as it does with emotional stimuli. Notably, a meta-analysis reported impairment in suppression capability for subjects with PTSD and other anxiety disorders (Stramaccia et al., 2021). However, the meta-analyses typically report an overall effect, and unless there are focused studies on each trait (e.g., PTSD and OCD), one cannot be sure about the relevance of each psychological condition separately. In this pursuit, it is not uncommon for researchers to use subclinical samples (i.e., individuals with higher scores but not meeting clinical diagnostic criteria or at least not having been clinically diagnosed) to investigate psychological traits. A number of studies have used such a strategy. For instance, a pool of non-diagnosed undergraduate students was screened for attention-deficit hyperactivity disorder (ADHD) and then sub-sets were selected to examine differences in suppression impairment by T/NT (Depue et al., 2010). Those who scored high on the testing battery and met the diagnostic criteria for ADHD were selected as the experimental group (ADHD group). The control group was selected from the same pool of participants who did not meet the ADHD diagnostic criteria. The ADHD group showed impairment in inhibitory control via No-Think suppression compared to the control condition. From this study, inferences regarding difficulty in memory inhibition were made regarding ADHD condition in general. Subsequently, Depue (2011) speculated that the lack of behavioural control in ADHD can be extrapolated to explain a lack of behavioural control in non-motor psychological conditions such as PTSD (in terms of flashbacks) and OCD (in terms of executive dysfunction).

Several PTSD studies have also used subclinical samples. In the previously mentioned study by Streb et al. (2016) that examined a deficiency in retrieval suppression as a risk factor for subsequent PTSD, not only did they induce analogue (artificial) trauma in their subjects, but also made sure that the subjects did not suffer from anxiety or related disorders. Yet, they made inferences regarding PTSD from this experiment. Other examples of analogue trauma studies examining differences in various aspects of cognition include Halligan et al. (2002), Clohessy and Ehlers (1999), and Nixon et al. (2009). In addition, Kindt and van den Hout (2003) screened healthy subjects to estimate individual differences in the relationship of PTSD and dissociation with memory. PTSD studies have demonstrated a continuous spectrum of severity of symptoms for clinical and subclinical cases (Maes et al., 1998), where clinical samples had more severe symptoms than subclinical samples, and there were no symptoms at the lower end of the spectrum. It has also been established that individuals with subclinical PTSD, based on scores from Composite International Diagnostic Interview, PTSD module, are at risk of developing clinical PTSD (Mylle & Maes, 2004). All these studies justify the use of a PTSD scale to screen subjects and recruit those at both ends of the spectrum as two experimental groups for the T/NT task.

Abramowitz et al. (2014) reported surveys showing that up to 90% people from the general population reported OCD-like thoughts, while only 26% scored above the cut-off for OCD clinical diagnosis. They also compared clinical and sub-clinical OCD samples indicating that OCD symptoms, similar to PTSD, occurred over a continuous spectrum of severity. Moreover, studies showed that obsessions (Garcia-Soriano et al., 2011) and compulsions (Flament et al., 1988; Henderson Jr & Pollard, 1988) were so similar in clinical and sub-clinical samples that trained clinicians could not distinguish between the two samples (Rachman & De Silva, 1978). In addition, Abramowitz et al. (2014) noted that results of experiments with clinically diagnosed OCD samples could not be generalised as it has been established that a majority of OCD-predisposed individuals would not seek clinical help due to various epidemiological factors (Abramowitz et al., 2014; Grabe et al., 2000). Morover, the results based on clinical samples could be confounded due to types, effects, and duration of treatment, as well as various comorbidities in diagnosed OCD conditions (Abramowitz et al., 2014). Therefore, according to Abramowitz et al. (2014), it is more plausible to screen healthy subjects and examine them for differences based on the outcomes of screening.

Various scientific surveys have pointed to a relatively high percentage of OCD symptoms in the general population, with 10—26% scoring above the diagnosis cut-off (Abramowitz et al., 2014; Barlow et al., 2016) and, as mentioned, there are similarities between clinical and subclinical OCD samples. Moreover, students could be vulnerable to PTSD (Nixon et al., 2007) and PTSD-prone subjects are potentially less likely to be able to suppress intrusive memories (Streb et al., 2016). It has also been found that trauma-exposure predicted impairment in memory suppression regardless of a PTSD diagnosis (Sullivan et al., 2019). Considering all these pieces of evidence, it was deemed sensible to screen university students with YBOCS and

PCLC to find the target subjects: those with the highest and the lowest scores on the YBOCS and on the PCLC (Hi YBOCS, Lo YBOCS, Hi PCLC, and Lo PCLC, hereafter) would be recruited to examine differences in memory suppression ability with No-Think manipulation. The Hi YBOCS and the Hi PCLC might or might not have been diagnosed with OCD or PTSD, but the aim of this screening was not diagnosis. The goal was to find those with the highest scores on each of these scales, so their capability to suppress memories with No-Think suppression could be compared with those who scored the lowest on each scale. The present studies, therefore, aimed to examine whether No-Think manipulations in Hi YBOCS and Hi PCLC samples would show impairment in suppression capabilities compared to those with few to no symptoms (Lo YBOCS and Lo PCLC).

Chapter 3

Literature Review: Brain Fingerprinting

3.1 Description

Wrongful conviction has been a serious problem as well as a topic of interest to researchers over the past several decades. Figures from the mid-20th century until recently show that hundreds of innocent people were convicted in West Germany during the 1950s and 1960s (Nose et al., 1981) and the United States (The National Registry of Exonerations, 2020). Such wrongfully convicted prisoners spent an average of nine years in United States prisons before being acquitted (D. T. Johnson, 2020). The Michigan Law Innocence Clinic (2021) lists 'Junk science' ("untested or unproven theories when presented as scientific fact" (Stevenson, 2010)) as one of the underlying causes of false convictions, along with problems with the eyewitness testimony, wrongful confessions, state misconduct to push for convictions despite weak evidence, prosecutorial misconduct in exercising the discretion to prosecute despite weak evidence, dishonest informants, and inadequate representation by counsel. They contend that many forensic methods have no scientific authentication and possess poor validity, which results in incorrect testimonies by forensic experts leading to false convictions.

These needs have led to the development of a variety of techniques that have been used in attempts to detect the presence, or absence, of guilty knowledge in suspects of crime. Some of these tools rely on physiological responses, such as the polygraph (National Research Council, 2003), while others are based on electroencephalograms (e.g., Brain Electrical Oscillation Signature (Mukundan et al., 2017)) or event-related potentials (ERP), such as Brain Fingerprinting (Farwell, 2009; Farwell & Smith, 2001; Farwell & Donchin, 1991) and the Complex Trial Protocol (Rosenfeld et al., 2008). Technologies that use electroencephalographic measures can be categorised under the term forensic brainwave analysis.

Historically, Brain Fingerprinting (BFP) is a type of Concealed Information Test or the Guilty Knowledge Test. In these tests, a subject is presented with facts related to a criminal incident, and electrophysiological or behavioural measures data are collected to determine whether a subject recognises these pieces of information (Lykken, 1959, 1960). The scientific community values Concealed Information Tests higher than the famous autonomic lie-detector, the polygraph (Ben-Shakhar, 2012; Ben-Shakhar & Elaad, 2003; Gamer, 2011; Iacono, 2008; MacLaren, 2001; Meijer et al., 2007; Verschuere et al., 2011) because the accuracy of the latter has been reported to be as good as tossing a coin (Lykken, 1998).

BFP is used to detect the presence or absence of concealed knowledge related to an incident in a person's brain by using an extension of the P300 component of the ERP, known as P300-MERMER (Farwell, 2012; Farwell & Smith, 2001; Farwell & Donchin, 1991). This use of BFP (known as specific issue test) should be distinguished from another use of BFP, specific screening. Specific screening is used to detect knowledge pertaining to specific training or expertise (e.g., being an FBI agent, possessing US Navy medical information, or possessing unique knowledge of making explosives) (Farwell, 2012; Farwell et al., 2013; Farwell et al., 2014).

The P300 is a positive brain potential elicited maximally at the mid-line parietal zone (Pz) from 300–800 ms post-stimulus when a subject is presented with familiar substantial information placed within frequent non-substantial stimuli (Donchin et al., 1986; R. Johnson, 1986; Sutton et al., 1965), resembling the oddball paradigm (Squires et al., 1975). The MERMER (memory and encoding related multifaceted electroencephalographic response) is a late negative potential following the P300 that extends to 1200–1500 ms post-stimulus (Farwell, 2012; Farwell et al., 2013; Farwell et al., 2014; Farwell & Smith, 2001). Initial BFP research had been based on P300 only (Farwell & Donchin, 1991). Farwell and Smith (2001) introduced P300-MERMER and the BFP literature since then is based on it. Farwell argues that the use of BFP in real-life incidents would usually require the use of long words such as full names and the use of entire phrases as stimuli. This needs longer cognitive processing time, which in turn requires longer intervals between stimuli presentation and recording of a longer segment of brainwave response data. Therefore, the additional MERMER should be recorded alongside P300 (Farwell, 2012; Farwell et al., 2013; Farwell et al., 2014; Farwell & Smith, 2001).

Theoretically, the items that are salient to a subject in a specific context, for instance, a weapon used to hit a victim during a crime (Berlad & Pratt, 1995; Gray et al., 2004), should elicit a P300 response, but they should not elicit a similar response in those with no knowledge of the incident. When salient items are presented amongst a series of irrelevant pieces of information in a criminal incident setting, details of a committed crime should elicit a P300 only in a subject with the possession of knowledge about that crime either by the means of committing the crime or due to witnessing it. Early P300 research by Farwell and Donchin (1991) and Rosenfeld et al. (1988) confirmed these characteristics. They showed that 'guilty' subjects who participated in a mock-crime later displayed P300 to crime-relevant stimuli, whereas subjects who did not participate in the mock-crime produced no P300 to the crime-relevant stimuli (Farwell & Donchin, 1991; Rosenfeld et al., 1988).

BFP compares the ERP of three categories of stimuli: *probes*, *targets*, and *irrelevants*. For crime incidents, probes are produced from the items of information from a crime-scene that should be specifically known to someone who committed, witnessed, or investigated the crime. Targets are produced from items of information that a subject knows regardless of involvement in the crime, because targets are specifically taught to potential subjects prior to testing. Irrelevant stimuli are formulated for the purposes of the experiment, are equally plausible as probes and targets, but are unrelated to the incident in question. Hence, targets provide a baseline of calibration (a P300-MERMER response) in all subjects with knowledge of the crime that has been taught to them, whereas probes will elicit similar responses but only in subjects with concealed knowledge of the crime (known as Information Present, or IP). On the other hand, responses to probes by innocent (Information Absent, or IA) subjects should be similar to the response to irrelevant stimuli, as innocent subjects would not be able to differentiate the two.

Since the target information is known to both IP and IA subjects, both elicit P300-MERMER responses to targets (Farwell, 2012; Farwell et al., 2013; Farwell & Smith, 2001; Farwell & Donchin, 1991).

The ERPs are compared using a bootstrapped (1000 iterations) double-centred correlation grand-mean method that results in either an Information-Present classification (IP_C), an Information-Absent classification (IA_C), or Indeterminate. For an IP_C, there must be at least 90% bootstrapping probability that probes and targets elicited similar ERPs. Mathematically, this would demonstrate that the correlation between probe and target ERPs is higher than the correlation between probe and irrelevant ERPs. For an IA_C classification, there must be a 30% or lesser bootstrapping probability that the correlation between probe and target ERPs is higher than the correlation between probes and irrelevant ERPs. As a result, there should be 70% or higher bootstrapping probability that the correlation between probe and irrelevant ERPs is higher than the correlation between probe and target ERPs. This would indicate that probes and irrelevants elicited similar responses and the suspected perpetrator knows no more about a crime than the information made available to them by the tester. If the bootstrapping probability of ERPs does not match that of an IP_C or an IA_C, these subjects are designated Indeterminate, meaning BFP cannot determine whether or not a subject possesses information about the incident in question (J. Allen & Iacono, 1997; Farwell, 2009; Farwell et al., 2013; Farwell & Smith, 2001; Farwell & Donchin, 1991; Rosenfeld & Donchin, 2015; Wasserman & Bockenholt, 1989).

All BFP studies conducted by Farwell and his colleagues reported no false negative or false positive determinations (Farwell et al., 2013; Farwell et al., 2014; Farwell & Smith, 2001; Farwell & Donchin, 1991). Notably, none of the previous BFP studies that used P300-MERMER reported any Indeterminate classifications (Farwell et al., 2013; Farwell et al., 2014; Farwell & Smith, 2001). However, there have been Indeterminate classifications with P300 only (300 - 900 ms post-stimulus), as in Farwell and Donchin (1991). Farwell and Donchin (1991) showed in a series of two experiments — a mock-espionage scenario (Experiment-1, n = 20) and a real-life small legal transgression (Experiment-2, n = 4) — that BFP could be used as a guilt detection test in controlled laboratory conditions. Each subject was tested on one IP and one IA incident, resulting in twice as many BFP tests: 40 in Experiment-1 and 8 in Experiment-2.

In Experiment-1, five (two IP and three IA) classifications were Indeterminate and the rest were correct classifications of IP_C and IA_C, with no false-positives and no false-negatives. In Experiment-2, BFP resulted in one Indeterminate (of an IA subject) and the rest were correct IP_C and IA_C classifications (Farwell & Donchin, 1991). Further, Farwell and Smith (2001) tested real-life incidents in six subjects. Each subject was tested with an IP as well as an IA incident by a blinded tester. All subjects were correctly classified according to their ground-truth conditions with high bootstrapping probability, no false positives, no false negatives, and no Indeterminates.

More recently, Farwell et al. (2013) conducted two studies on felony crimes of subjects conducted in a way that did not have any judicial consequences for them (Study-1, 17 IP and 3 IA subjects) and on subjects who were suspects in criminal investigations or convicted criminals who were claiming innocence, with some facing life imprisonment or the death penalty (Study-2, 9 IP and 5 IA). The stimuli of Study-2 were produced using witness and accomplice interviews, crime-scene inspection, and the use of police and court records. In Study-1, three IA and 17 IP subjects were tested, with all being correctly determined. Fourteen subjects were tested in Study-2, with nine being IP and five IA. The IP subjects were offered US$100,000 if they could get the BFP system to produce a false negative result (i.e., an incorrect IA_C) (Farwell et al., 2013). These subjects were encouraged to use countermeasures similar to those investigated by Rosenfeld et al. (2004) and Mertens and Allen (2008) such as covertly wiggling the big toe in the right or left shoe, or imagining being slapped in the face by the experimenter. Regardless of these countermeasures, all subjects were correctly classified according to their ground-truth. Countermeasures were found to be ineffective, despite the large incentive to counter the system. Considering there have been no Indeterminate classification with P300-MERMER, Farwell conducted further tests and has shown that analysing the full P300-MERMER epoch (300 – 1800 ms post-stimulus) resulted in higher accuracy, higher bootstrapping probability, and no Indeterminates (Farwell, 2012; Farwell et al., 2013; Farwell et al., 2014). On the other hand, focusing on P300 (300 - 900 ms post-stimulus) only, could result in Indeterminates as reported in Farwell and Donchin (1991), though, still with a 100% accuracy.

Despite being publicised as a highly accurate Forensic Brainwave Analysis technology by Farwell, BFP has not yet gained wide acceptance as a forensic tool. Notwithstanding, Farwell (2009) reported use of the BFP in the Iowa District Court in which BFP showed that the convicted criminal Terry Harrington was IA_C for the crime incident and IP_C for his alibi incident, *Harrington vs. State*, 659 N.W.2d 509 (Iowa, 2003, as cited in Farwell et al. (2014)). Nevertheless, the Court upheld the conviction and did not change the ruling based on BFP. It was the Appeal Court that later acquitted Harrington based on evidence other than Farwell's findings.

In addition, BFP was used to test the specific information related to the rape and murder of Julie Henton on the perpetrator, James Grinder (Farwell, 2012; Farwell et al., 2013; Moenssens, 2001). Grinder was classified as IP_C with 99.9% bootstrapping probability. Due to the presence of other, non-BFP implicating evidence, he pled guilty as the perpatrator a week after the BFP test (Farwell, 2012; Farwell et al., 2013; Moenssens, 2001).

It is crucial to note that all published articles on BFP to date have not been independent of Farwell. J. Allen and Iacono (1997) applied BFP's mathematical algorithm to data from one of their own studies (J. Allen et al., 1992) to compare the accuracy of BFP's algorithm to that of their Bayesian-based algorithm. They reported very high classification accuracies for both the BFP algorithm and their own algorithm. On the other hand, the Complex Trial Protocol has been independently tested on multiple occasions (Funicelli et al., 2021; Lukács et al., 2016). Moreover, previous BFP studies have not recruited convicted criminals as their study subjects except for the testing of some suspects and criminals in Farwell et al. (2013). The nature of the examined crimes and the exact number of subjects in each sub-condition (being a suspect, a convict claiming innocence, facing life-imprisonment or death penalty) was, however, not reported by Farwell et al. (2013). These factors necessitated testing the accuracy of BFP on subjects with criminal histories, and independent of Farwell, to substantiate the claims of BFP's high accuracy in the relevant population.

The New Zealand Law Foundation funded two studies designed by scientists and law experts at the University of Canterbury to independently examine the accuracy of BFP. Research students (including myself) contributed substantially to these studies and authored the mentioned manuscript (i.e., Afzali et al. (2022) — mentioned in the Preface of the current dissertation. Study-1 in Afzali et al. (2022) examined the accuracy of BFP in university students and resulted in (many correct classifications, but also a false positive – contrary to all previous studies reported by Farwell. Study-2 of Afzali et al. (2022) is the very Study-3 of the current dissertation.

3.2 Brain Fingerprinting and Think/No-Think

In addition to the above-mentioned controversies, researchers have also attempted countering BFP with the use of behavioural as well as cognitive countermeasures. Rosenfeld et al. (2004) conducted a countermeasure study similar to the Farwell and Donchin (1991) BFP experiment. They divided the subjects into three groups: guilty (participated in a mock-crime), innocent (did not participate in the mock-crime in question), and countermeasure (participated in the mock-crime, but guided to engage in specific covert acts). These covert acts included wiggling the big toe inside the shoe, subtly pressing a finger on the leg during the test, or imagining being slapped by the experimenter. The outcome of countermeasure subjects was similar to innocents, meaning these countermeasures were effective against ERP-based forensic brainwave analysis measures (Rosenfeld et al., 2004).

Bergström et al. (2013) conducted a burglary simulation study with the Complex Trial Protocol guilt detection technique of Rosenfeld et al. (2008) to investigate the potential effectiveness of the Think/No-Think (T/NT) paradigm (Green and Anderson, 2001) as a countermeasure in Complex Trial Protocol. Complex Trial Protocol (Rosenfeld et al., 2008) is an ERP-based forensic brainwave analysis system used for guilt detection, although it differs from BFP in some methodological and data analytic aspects. To comply with the T/NT task, subjects were trained with reminders to the stimuli of burglary simulation, as these reminders would function as cue words for the T/NT task (as part of cue-response pairs), while the stimuli (probes) functioned as response words. For instance, if *wrist watch* was a probe in the Complex Trial Protocol test, the subject would learn a word or phrase that should remind them of the wrist watch during the subsequent No-Think manipulation during the Complex Trial Protocol test. Bergström et al. (2013) divided the subjects into three groups: guilty cooperative (participated in the mock-crime and were in the Think condition), guilty uncooperative (participated in the mock-crime and were in the No-Think condition), and baseline (participated in the mock-crime but functioned as ground-truth IA subjects). Subjects in the Think condition were instructed to think about a probe stimulus (response word) when they were presented with a cue word (the earlier learned reminder, or the cue) during the Complex Trial Protocol test, and remember as much information about it as possible. The No-Think subjects were instructed to avoid thinking about the probe (the response word) when they were presented with the cue. The control subjects were tested on a different incident. They found that the subjects in the Think condition were classified guilty 22% more than the subjects in the No-Think condition, leading to the conclusion that the No-Think manipulation was an effective countermeasure to Complex Trial Protocol. They further implied that the No-Think component of the T/NT paradigm could be used as an effective countermeasure against all P300-based Forensic Brainwave Analysis measures, including BFP (Bergström et al., 2013).

In a subsequent study, Hu et al. (2015) used mock-crime scenarios alongside the autobiographical Implicit Association Test to evaluate after-effects of the No-Think suppression manipulation. Two groups of subjects, "guilty" and "suppressed-guilty" committed the mock-crime. Only "suppressed-guilty" were instructed to engage in No-Think suppression during the subsequent Complex Trial Protocol test. The third group consisted of "innocent" subjects who did not participate in the mock-crime. All subjects participated in Complex Trial Protocol, which was followed by the autobiographical Implicit Association Test. During the autobiographical Implicit Association Test, subjects were asked to classify factual and mock-crime-related sentences as true or false. The results of the Complex Trial Protocol indicated that the "suppressed-guilty" subjects, who underwent the No-Think manipulation, were disproportionately misclassified as innocent, consistent with Bergström et al. (2013). Additionally, the autobiographical Implicit Association Test showed that only subjects in the "suppressed-guilty" condition had delayed responses to the previously suppressed stimuli. This demonstrated that not only the recall of unwanted memories was impaired under the No-Think suppression instructions, but so was their automatic influence, as indicated by the delayed access to those memories that had undergone suppression during the autobiographical Implicit Association Test (Hu et al., 2015).

Collectively, Bergström et al. (2013), Hu et al. (2015), and Rosenfeld et al. (2004) have contended that, similar to Complex Trial Protocol, all P300-based forensic brainwave analysis techniques (including BFP) would be susceptible to behavioural or cognitive countermeasures.

Farwell et al. (2013), however, contested these findings on the basis that the designs, procedures, and data analysis algorithms used in these studies were critically different from BFP (Farwell et al., 2013; Farwell & Richardson, 2013). More specifically, Farwell et al. (2013) devised twenty scientific standards (20SS hereafter – see Appendix A) which require specific guidelines to be followed in order for any test to qualify as Brain Fingerprinting and asserting that any substantial deviations from this protocol would not be considered 'Brain Fingerprinting'. Since these standards were not followed by Bergström et al. (2013) or Rosenfeld et al. (2004), Farwell et al. (2013) stated that their speculations could not and should not be generalised to BFP. This assertion also appeals to more recent work (Funicelli et al., 2021; Hu et al., 2015; klein Selle et al., 2021) all of which have reasserted claims about the susceptibility of P300-based forensic brainwave analysis techniques to countermeasures.

In the light of disagreements between the proponents and opponents of BFP, one aim of the current project was to focus in more detail on the Farwell et al. (2013)'s critique of Forensic Brainwave Analysis countermeasure studies (Bergström et al., 2013; Funicelli et al., 2021; Hu et al., 2015; Rosenfeld et al., 2004). In particular, and for the first time, the cognitive countermeasures against BFP were independently examined while adhering to the 20SS. However, a procedural clash between No-Think suppression inducement and BFP was noticed in this pursuit. The No-Think suppression manipulation requires a subject to directly suppress responses to a "reminding cue" in order to stop the response from entering to consciousness. On the other hand, with BFP, these reminders (cues) cannot be used as stimuli. According to the 20SS, only probes themselves (the response words in the T/NT context) can be presented on the screen during the BFP test. In addition, before each block of BFP, subjects are prompted with short descriptions (the incident-related information) corresponding to the critical stimuli that furthers their memory of probes/responses. Thus, the No-Think instruction could not be used to suppress the visible probes (responses) on the screen. As a result, incorporating No-Think suppression with BFP seemed to contradict fundamental procedural constraints inherent in both T/NT and BFP.

However, as mentioned in Section 3.1, since the P300-MERMER is developed for probes that are salient to a subject in a specific context (Farwell, 2009; Farwell et al., 2013; Farwell & Smith, 2001; Farwell & Richardson, 2013), it was decided to investigate if dissociating from the very context of an incident might be useful in countering BFP. Therefore, it was decided that instead of asking subjects to suppress a critical stimulus (probe) in the suppression manipulation, they should be instructed to completely suppress the whole autobiographical incident in question during each BFP test block in Study-4. Such complete suppression, known as direct-suppression, conforms with the definition of No-Think suppression wherein a subject is asked to stop thinking about a piece of information by directly suppressing it at the moment it tries to enter awareness, without replacing it with any other stimulus, thought, or idea (Bergström et al., 2009). Direct-suppression of unwanted memories has successfully been applied to diverse content, including autobiographical memories (Noreen & MacLeod, 2013; Noreen et al., 2016; Stephens et al., 2013).

In addition, another potential countermeasure known as thought-substitution was tested. During thought-substitution, a subject is instructed to stop thinking about a piece of information by generating alternative thoughts to occupy awareness (Bergström et al., 2009; Hertel & Calcaterra, 2005; Levy & Anderson, 2002). As mentioned in Section 2.3, direct-suppression has been reported as a more effective temporary amnesia inducer than thought-substitution (Bergström et al., 2009; Gagnepain et al., 2014). However, Benoit and Anderson (2012) presented evidence of successful thought-substitution achievement when subjects were asked to retrieve a previously memorised alternative memory to substitute the unwanted memory during manipulation. This very approach was used in the thought-substitution manipulation of Study-4 (detailed further in Chapter 8).

Chapter 4

Aims and Hypotheses

4.1 Study-1: T/NT-Extension

4.1.1 Hypothesis-1

Following Section 2.3, it has not been established whether decreasing the frequency of No-Think suppression trials (e.g., 12) would result in a decreased recall of suppressed responses. In addition, Yale-Brown Obsessive Compulsive Scale (YBOCS) and PTSD CheckList - Civilian Version (PCLC) scores have not been investigated in previous Think/No-Think (T/NT) studies. Hereafter, this study will be referred to as T/NT-Extension.

Hypothesis-1

A decreased frequency of No-Think suppression trials would result in recall impairment and a diverging trend in the recall percentage of No-Think and Think trials is anticipated. That is, compared to to the Baseline (trials that are not presented in Phase 2), 12 No-Think trials are predicted to produce fewer No-Think words at recall, and compared to the Baseline, the 12 Think trials are predicted to produce more Think words at recall.

Rationale

According to predictions derived from previous T/NT research (Anderson, 2003; Anderson & Green, 2001; Levy & Anderson, 2012), the more often the response of a cue is suppressed, the poorer the memory recall is for that response. However, independent behavioural studies, conducted by researchers unassociated with Anderson, reported failed replications of the No-Think suppression effect with a frequency of No-Think suppression trials smaller than 16 (e.g., 12) (Hertel & Calcaterra, 2005; Hertel & Mahan, 2008) as well as with 16 trials (Bulevich et al., 2006; Wessel et al., 2020). In addition to fewer No-Think suppression trials, these unsuccessful replications could be due to a variety of reasons, such as, sleep deprivation, neglecting experimental instructions, length of trials, fatigue, etc. (Anderson & Huddleston, 2012; Harrington et al., 2021; Liu et al., 2021; van Schie & Anderson, 2017). Hence, this does not necessarily indicate that the T/NT paradigm cannot be independently replicated.

As T/NT is arduous and taxing on a subject's attention due the requirements of constant suppression or retrieval, it would be useful to find a smaller frequency of suppression trials that would lead to temporary amnesia of suppressed responses, which could be usefully employed in future T/NT studies. To prevent effects of the confounds mentioned above, any such replication would need very close adherence to the T/NT protocol devised by Anderson.

Previous meta-analyses that utilised studies with different frequencies of manipulation trials reported around 6% - 8% reduction in recall of No-Think responses compared to Baseline (Levy & Anderson, 2008; Stramaccia et al., 2021). Therefore, a significant decrease in recall of No-Think responses was anticipated for 12 No-Think trials.

Significance

T/NT-Extension would confirm that the No-Think component of the T/NT paradigm is effective in suppressing unwanted memories, even with a lower frequency of No-Think trials. It would also provide a working comparison to Study-2 (T/NT-Traits) in terms of YBOCS and PCLC scores. The scores on these two measures will be statistically controlled to explore any possible changes in the patterns hypothesised above. The YBOCS and PCLC scores obtained in T/NT-Extension would provide an indication of the quality of No-Think suppression effectiveness in subjects who score over the continuum of these scales, which would be further explored in Study-2 (T/NT-Traits).

Proposed study

The design will be similar to the standard T/NT by Anderson and Green (2001), but cues in the Think condition will be typed in green text, whereas No-Think trials will be typed in red text similar to Bergström et al. (2009). The experiment will consist of three phases: training, T/NT manipulation, and recall. Subjects will be trained until they achieve 50% recall accuracy before the T/NT manipulation. The recall of response words will be tested with both same-cue and independent-cue test types. The YBOCS and PCLC scores will function as covariates.

4.2 Study-2 Experiment-1: Think/No-Think with YBOCS

4.2.1 Hypotheses-2a and 2b

As mentioned in Section 2.6, it has not been established whether or not the No-Think manipulation in subjects with the Hi YBOCS scores (those with a propensity for obsessive-compulsive disorder (OCD)) would be as effective as in subjects with the Lo YBOCS scores. Hereafter, Study-2 will be referred to as T/NT-Traits.

Hypothesis-2a

Subjects with a propensity for OCD (Hi YBOCS) demonstrate impaired No-Think suppression capabilities. For the Hi YBOCS group, reduction or even elimination of the significant effect of No-Think suppression is predicted, meaning that the Baseline and 12 No-Think trials will produce, on average, a similar percentage of recall for the No-Think items.

Hypothesis-2b

For the Lo YBOCS group (i.e. no propensity of OCD), the results are predicted to be as those of T/NT-Extension (presence of a No-Think suppression effect). Overall, no difference between the results of T/NT-Extension and Lo YBOCS are predicted, but the Hi YBOCS results are predicted to be significantly different from T/NT-Extension. Alternatively, if subjects in the Hi YBOCS group were to show comparable results for No-Think condition that happen to be not statistically different from those in the Lo YBOCS group, it would imply that people with only a propensity for OCD have intact inhibitory processing capabilities. These hypotheses were pre-registered at OSF.

Rationale

As discussed in Sections 2.2 and 2.5, the T/NT paradigm very likely involves the executive function systems of the brain, and people with OCD might be impaired in areas involving executive functioning and response inhibition. This is further likely based on the executive deficit hypothesis. Therefore, it is anticipated that people in the Hi YBOCS group would struggle with No-Think suppression during the No-Think manipulation due to their neural resemblance to OCD subjects.

Significance

If Hypothesis-2a is supported, it would imply that high YBOCS scores interfere with the No-Think manipulation since both employ executive control function systems. Such a pattern of results would confirm the presence of impaired suppression. It would mean that the high YBOCS scorers possess different cognitive mechanisms than the low YBOCS scorers which interfere with their ability to perform the suppression component of the T/NT task. On the other hand, if the No-Think results of Hi YBOCS group are comparable to T/NT-Extension, it would indicate that people in the Hi YBOCS group are unimpaired in their abilities to suppress memories via the T/NT paradigm. Such an outcome would potentially question the speculation of Anderson and Green (2001) regarding the role of executive function centres in the T/NT paradigm.

Although not anticipated, an interesting outcome would be further No-Think suppression in Lo YBOCS scorers (i.e., a lower percentage of No-Think recall than T/NT-Extension). In other words, if the impairment of recall due to No-Think suppression is more extreme in the Lo YBOCS scorers than T/NT-Extension, it would be suggestive of Lo YBOCS scores being an additional factor to consider in the ability to suppress unwanted memories. If this happens, it would imply that screening out moderate and especially Hi YBOCS (i.e., people who ostensibly have problems suppressing) may heighten the magnitude of suppression observed, compared to T/NT-Extension.

Proposed study

The experiment will be conducted in two stages. Stage-1 (screening) will be conducted using YBOCS (Goodman et al., 1989) to identify Hi YBOCS and Lo YBOCS groups. Those who score at the higher end of YBOCS will be placed in the Hi YBOCS group and those who score at the lower end of YBOCS will be placed in the Lo YBOCS group. Both Hi and Lo YBOCS groups will be recruited for Stage-2. Stage-2 has a similar design and procedure as T/NT-Extension. Recall will be tested with both same-cue and independent-cue testing types. The pattern of results is predicted to be similar in both test types.

4.3 Study-2 Experiment-2: Think/No-Think with PCLC

4.3.1 Hypotheses-3a and 3b

As mentioned in Section 2.6 it has not been established whether or not the use of emotionally neutral stimuli in the No-Think manipulation in subjects with Hi PCLC scores (those with a propensity for post-traumatic stress disorder (PTSD)) would be as effective as in subjects with Lo PCLC scores.

Hypothesis-3a

Subjects with a propensity for PTSD (Hi PCLC) will demonstrate impaired No-Think suppression capabilities. For the Hi PCLC group, reduction or even elimination of a significant effect of No-Think suppression is predicted, meaning that the Baseline and 12 No-Think trials would produce a similar percentage of recall for the No-Think items.

Hypothesis-3b

For the Lo PCLC group (i.e. no propensity of PTSD), the results are predicted to be comparable to T/NT-Extension. Overall, no difference between the results of T/NT-Extension and Lo PCLC are predicted, but the Hi PCLC results are predicted to be significantly different from T/NT-Extension. Alternatively, if subjects in the Hi PCLC group were to show comparable results for No-Think condition that happen to be not statistically different from those in the Lo PCLC group, it would imply that people with only a susceptibility for PTSD are unimpaired in their memory suppression capabilities. These hypotheses were pre-registered at OSF.

Rationale

Based on the executive deficit hypothesis, and as mentioned in Section 2.6, PTSD-prone individuals might be impaired in their ability to suppress memories due to executive deficit and due to a possible defect in their neural inhibitory control mechanisms. Since the T/NT paradigm involves suppressing unwanted memories, it is likely that people in the Hi PCLC group might struggle with No-Think suppression during the T/NT task.

Significance

If Hypothesis-3a is supported, it would imply that the possible defect of a neural inhibitory control mechanism results in Hi PCLC scorers producing reduced or no effect of No-Think suppression. This pattern of results would provide evidence of impaired suppression. On the other hand, if No-Think manipulation in the Hi PCLC group produces comparable results with

T/NT-Extension, it would indicate that people in the Hi PCLC group are unimpaired in their abilities to suppress memories via the T/NT paradigm. Although not anticipated, an interesting outcome would be further No-Think suppression in Lo PCLC scorers (i.e., more No-Think suppression in the recall of suppressed words than T/NT-Extension). In other words, if the impairment of recall due to No-Think suppression is more extreme in the Lo PCLC scorers than T/NT-Extension. It would be suggestive of Lo PCLC scores being an additional factor to consider in the ability to suppress unwanted memories. If this happens, it would imply that screening out moderate and Hi PCLC (i.e., people who ostensibly have problems suppressing) may increase the magnitude of suppressed words, compared to T/NT-Extension.

Proposed study

Similar to T/NT-Traits Experiment-1, this experiment will be also conducted in two stages. Stage-1 (screening) will be completed using PCLC (Weathers et al., 1993) to identify Hi PCLC and Lo PCLC groups. Those who scored at the higher end of PCLC will be placed in the Hi PCLC group and those who score at the lower end will be placed in the Lo PCLC group. These groups will then be recruited for Stage-2. Stage-2 has a similar design and procedure as T/NT-Extension. Recall will be tested with both same-cue and independent-cue testing types.

4.4 Study-3: BFP-Parolees

4.4.1 Hypothesis-4

As mentioned in Section 3.1, Brain Fingerprinting (BFP) studies have rarely had subjects for whom the technology has been primarily designed and marketed (those processed in the criminal justice system). In addition, most of BFP studies have been conducted by Farwell and his colleagues (Farwell et al., 2013; Farwell et al., 2014; Farwell & Smith, 2001; Farwell & Donchin, 1991), and not by independent researchers. Therefore, it is necessary to examine the accuracy of BFP in parolees to find out if it could be successful in revealing crime-related information in parolees' brains.

Hypothesis-4

Parolees with the ground-truth Information Present (IP) status will be classified as IP_C and those in the ground-truth Information Absent (IA) condition will be classified as IA_C. That is, the P300-MERMER for individual determinations will be 90% or above to result in IP_C, and below 30% (above 70% in the opposite direction) resulting in an IA_C determination.

Rationale

With the evidence provided in Section 3.1 (Farwell et al., 2013; Farwell et al., 2014; Farwell & Smith, 2001; Farwell & Donchin, 1991), it was considered that BFP would be as accurate for parolees as it has been shown for general population.

Significance

If Hypothesis-4 is supported, it would imply that BFP is as equally accurate for general population and for subjects who have been processed in the criminal justice system. This would provide scientific evidence that BFP can be usefully employed as in information detection tool instead of lesser accurate measures such as the polygraph.

Proposed study

Parolees will be interviewed and the critical stimuli will be developed. The subjects will be blind tested by testers who do not interview them. The BFP tests will be conducted within a week of the interviews. The experimental and data analysis protocols will be the same as those in previous BFP studies by Farwell and colleagues (Farwell et al., 2013; Farwell & Smith, 2001; Farwell & Donchin, 1991).

4.5 Study-4: BFP-Countermeasures

4.5.1 Hypotheses-5a, 5b and 5c

As mentioned in Section 3.2, studies that employed T/NT as a countermeasure in Forensic Brainwave Analysis systems did not have access to the BFP system; and the mentioned endeavours did not follow the 20SS of BFP (Farwell et al., 2013). Taking into consideration the limitations in using the standard T/NT paradigm while engaging in BFP experiments (Section 3.2), could any modifications to the T/NT procedure, such as direct-suppression of the incident, be used as a countermeasure in BFP? In addition, could thought-substitution function as a countermeasure in BFP?

Hypothesis-5a

In BFP-Countermeasures Experiment-1, subjects from the general population with the ground-truth IP status would be classified as IP_C and those in the ground-truth IA condition would be classified as IA_C.

Hypothesis-5b

In BFP-Countermeasures Experiment-2, when a previously categorised IP_C subject from BFP-Countermeasures Experiment-1 employs direct-suppression to conceal the information that BFP tries to expose, they would still be classified as IP_C despite the manipulation.

Hypothesis-5c

In BFP-Countermeasures Experiment-2, when a previously categorised IP_C subject from BFP-Countermeasures Experiment-1 uses thought-substitution to conceal the information that BFP tries to expose, they would still be classified as IP_C.

Rationale

Although studies detailed in Section 3.2 (Benoit & Anderson, 2012; Bergström et al., 2013; Hu et al., 2015) point to the possibility of BFP being countered with direct-suppression and/or thought-substitution, there were at least two differing factors. First, BFP relies on real-life incidents while Complex Trial Protocol (employed by Bergström et al. (2013) and Hu et al. (2015)) uses fabricated incidents that are not necessarily salient to a subject. Secondly, the experimental protocol of BFP with the use of 20SS (that requires the use of probe and target items as stimuli) could very well counter the suppression efforts exerted as a result of No-Think suppression. This being so, it seemed likely that neither of the manipulations would render BFP ineffective. Notably, the mentioned studies preferred direct-suppression over thought-substitution, though, another type of thought-substitution (retrieving a previously learned alternative memory (Benoit & Anderson, 2012)) could successfully be used too. On the other hand, BFP is designed in a way that a subject normally has to think about (be reminded of) the incident while going through the experimental procedure. This implies that a previously decided alternative event to retrieve during thought-substitution may be more effective in stopping the initial incident in question from coming to mind than direct-suppression – where one has to suppress the context but there is nothing else they could think about.

Significance

If Hypothesis-5b and 5c are supported, it would imply that neither of the countermeasures, direct-suppression or thought-substitution, could be used as potential countermeasures in BFP, and the BFP is resistant to these countermeasures as Farwell has argued (Farwell et al., 2013; Farwell & Richardson, 2013).

Proposed study

The subjects will be interviewed and the critical stimuli will be developed. A standard BFP test will be employed to confirm that the ground-truth IP subjects are IP_C with >90% bootstrapping probability, and the success with control subjects (IA being classified as IA_C with >70% bootstrapping probability) would confirm that the BFP tests are accurate (BFP-Countermeasures Experiment-1). IP_C subjects will be asked to attend BFP-Countermeasures Experiment-2 wherein they will participate in the BFP test again — making sure that they suppress the context of the event during the BFP testing blocks (in the case of direct-suppression). In the case of thought-substitution, subjects will be interviewed about another incident from their life. This alternative incident (Event 2) will be given a specific name that subjects will recognise which will be used as the alternative event. Subjects will participate in the BFP test again – making sure that they substitute the context of the incident with the alternative event during the BFP testing blocks. The subjects will be informed that they will be rewarded an extra $20 voucher on top of their participation incentive if results show that they were successful in countering BFP, which would be demonstrated as an IA_C or Indeterminate outcome during BFP-Countermeasures Experiment-2.

Chapter 5

Study-1: T/NT-Extension

5.1 Introduction

Study-1 (T/NT-Extension) was designed in the pursuit of finding a more efficient and less arduous Think/No-Think (T/NT) paradigm. Instead of the formerly used 16 repetitions of No-Think suppression trials, this repetition was decreased to 12 in T/NT-Extension. Notably, with 16 repetitions, the total suppression time of each unwanted memory word is above one minute (16 repetition * 4.0 s for each = 64 s). With 12 repetition, each response is suppressed for 48 s. Therefore, 12 repetitions not only decreases the overall time taken to complete the experiment, but also decreases the total suppression time for each response word. It was hypothesised that, compared to the Baseline, the 12 No-Think trials would produce fewer No-Think items at recall and the 12 Think trials would produce more Think items at recall (Section 4.1.1). This would be reflected as a significant difference between Baseline and No-Think recall conditions. For the Think condition, a significant difference between the recall of Baseline and Think was anticipated, with Think trials being recalled more than Baseline. In addition, it was decided to use Yale-Brown Obsessive Compulsive Scale (YBOCS) and PTSD CheckList - Civilian Version (PCLC) scales as covariates in relation to No-Think suppression capability. This would highlight whether the suppression capability changes as a result of statistically controlling YBOCS and PCLC scores.

5.2 Method

5.2.1 Participants

Forty students from the Introductory Psychology course at University of Canterbury participated in the study, each for 4% course credit. Ages of subjects ranged from 18 to 44 years old ($M = 22.45$, $SD = 6.88$). Of these, 31 (78%) were female and 9 (22%) were male. Sixteen subjects (40%) were excused due to inability to recall at least 50% of responses in the feedback session during Phase 1 of the experiment. The rest of analysis is based on those $n = 24$ subjects who successfully completed the experiment. All subjects were recruited by advertising and volunteered to participate. Exclusion criteria were an attention-deficit hyperactivity disorder (ADHD) diagnosis, as the T/NT task needs constant attention, and colour blindness, as three colours, blue, red, and green, were used during the T/NT experiment. The study was approved by the Human Ethics Committee of the University of Canterbury (HEC 2019/41/LR-PS).

5.2.2 Materials and Apparatus

The T/NT experimental protocol and stimuli were provided by Prof Michael Anderson of the MRC Cognition and Brain Sciences Unit of the University of Cambridge. Matlab (R2019b) was used for presenting stimuli on a Windows PC Philips RGB SDR colour monitor 24–inch display with a 1920 * 1080 resolution and 59.94 Hz refresh rate. All instructions, three T/NT phases, and screening measures (YBOCS and PCLC) were presented on a computer screen. Subjects memorised 66 word pairs (48 for experimental manipulation and 18 filler pairs for practice purposes) (See Appendix B).

YBOCS is a 10-item standard obsessive-compulsive disorder (OCD) screening scale with acceptable interrater reliability and internal consistency (Goodman et al., 1989). It is scored based on a 5-point Likert scale from 0 (none) to 4 (extreme). The rating scale appeared opposite each question. A sample question of the obsessive component is: "How much do your obsessive thoughts interfere with functioning in your social, work, or other roles"? A sample question of the compulsive component is: "How much of an effort do you make to resist the compulsions"?

The standard scoring instructions of Goodman et al. (1989) were used to categorise subjects into the highest and the lowest OCD categories. See Appendix C for all items and scoring instructions.

PCL-C is a 17-item standard post-traumatic stress disorder (PTSD) screening scale with acceptable reliability and validity (Weathers et al., 1993). It is scored based on a 5-point Likert scale from 1 (not at all) to 5 (extremely). The rating scale appeared opposite each question. A sample item is, "Repeated, disturbing *memories*, *thoughts*, or *images* of a stressful experience from the past?" The standard scoring instructions of Weathers et al. (1993) were used to categorise subjects into the highest and the lowest stress categories. See Appendix D for all items and scoring instructions.

5.2.3 Procedure

All subjects read the information sheet and granted informed consent to participate in the study. They were asked to turn their mobile phones off as the task needed their full attention. All subjects complied. This was followed by phases of the experiment as below.

Phase 1

Subjects were trained on 48 word pairs (+18 filler pairs) so they could recall the right-hand member of the pair (response) when presented with the left-hand member of the pair (cue). Filler pairs would later be used for training and practice purposes. At the start of a trial, a fixation point appeared on the screen for 1.0 s, followed by a word pair (e.g., ORPHAN – LAMB) displayed in the centre of the screen. The pair stayed on screen for 4.0 s. This was followed by another fixation point for 1.0 s, followed by another cue-response pair. This phase continued until all 66 word pairs were presented. All stimuli were presented in white text on a grey background.

This was followed by the *Test-feedback Session-1* wherein a cue word (e.g., ORPHAN) was presented in the centre of the screen in white text on a grey background and the subject was asked to remember and say the response word (LAMB) aloud. These cues were presented for

4.0 s or until a subject could say the response word. Regardless of a correct or wrong response, the response word was displayed in blue text on a grey background following each cue word for 1.0 s so the subject could use it as feedback. If a subject could not recall responses to at least 24 (50%) of the critical word pairs (fillers excluded), this session was repeated in *Test-feedback Session-2*. If a subject could not recall 24 responses by the end of *Test-feedback Session-2*, they were excused and could not participate in the rest of the experiment. Those who could recall 50% responses, either at the end of first or second test-feedback session, entered the criterion-feedback session. In the criterion-feedback session, only cues were presented and the subject's task was to say the response word. They were not provided with any feedback in the criterion-feedback session.

Phase 2

Subjects were instructed that they would see cue words in one of two colours in a random order. For the cue words typed in red text on the background (displayed for 4.0 s), their task was to not allow the corresponding response word from coming to mind. If the response word was to automatically enter awareness, their task was to push it away from mind and keep doing that until the cue word disappeared from the screen. They were instructed not to think about another image, word, or idea during red trials and to focus on pushing away the response word only. The red trials were one third (16) of memorised word pairs and constituted the No-Think condition.

For another one third of the trials (16 word pairs) that constituted the Think condition, cues were in green text on grey background and displayed for 4.0 s each. The subject's task was to think about the response words to the cues. The final one third of cue-response pairs were not presented and served as the Baseline condition, to which the recall of Think and No-Think was compared after Phase 3. The Think and No-Think cue words were presented in randomly intermixed order. The Think, No-Think and Baseline pairs were equally counterbalanced between all subjects such that if 16 cue-response pairs were presented as Think for the first subject, they were presented as No-Think for the second subject, and they were used as Baseline for the third subject. This cycle repeatedly continued until all subjects were tested.

Subjects practised the task with filler cue words (T/NT Practice 1). Before each trial, a fixation cross appeared for 1.0 s, followed by a cue for 4.0 s and a following fixation point for 1.0 s. This continued until the end of the practice session. After the practice session, a T/NT Diagnostic Questionnaire (Appendix E) was administered to ensure that subjects were complying with the instruction and were not engaging in active deception such as thinking about other ideas during No-Think suppression, or not reading the cues presented on the screen. Based on the answers to the diagnostic questionnaire items, subjects were provided with additional feedback when necessary so they could complete the task as required. This was followed by another similar practice session (T/NT Practice 2) followed by the T/NT Diagnostic Questionnaire once again. By this time, all subjects thoroughly knew the nature of the task and could execute it correctly.

The practice tasks were followed by the T/NT manipulation session where the critical (Think and No-Think) cue words were presented. Each of 16 Think and 16 No-Think cue words were presented 12 times (total 384 trials) in a random fashion. The T/NT manipulation session was divided into 4 equal blocks each taking about 8 min to complete. After the first block, a subject would take a 30-40 s break so that they could relax their mind, but were not to turn their phones on or to get into any discussions outside the instructions of the task. After the second block, the T/NT Diagnostic Questionnaire was administered once again to ensure that the instructions were still being followed correctly. The third block was followed by a 30-40 s mental rest and Phase 2 ended after the fourth block.

Phase 3

In this phase, the task was to freely recall responses to all cue words that were presented in white text on the grey background. Initially, they were trained for the same-cue testing such that when presented with the original cue words (e.g., ORPHAN for ORPHAN - LAMB) they were asked to remember and say the response, LAMB, aloud. Then, they were trained for the independent-cue testing such that they were presented with independent cues coupled with the first letter of the response word (e.g., ANIMAL - L for ORPHAN – LAMB) and were asked to recall and say the response, LAMB, aloud. After training, both same-cue and independent-cue testing recall sessions took place one after another. For half of the subjects, the same-cue testing happened before, and for another half, it happened after the independent-cue testing. Similar to Phase 1, the cue word was displayed on the screen for 4.0 s or until the response was given.

A follow up post-experimental questionnaire (Appendix F) was administered to assess if a subject deliberately attempted not to follow the instructions. Based on *a priori* definitions, if the total score of a subject for all three items in Question 2 summed up to 4 or more, the subject's data would be disregarded. In addition, all subjects were reminded to sleep at least 7 hours the night before testing. If a subject reported sleeping less than four hours, their data would also be disregarded. Finally, subjects filled in the YBOCS and PCLC questionnaires and provided data on their age and sex via a Qualtrics survey. The whole experiment took between 90 and 105 min. Subjects were debriefed before leaving.

5.2.4 Design

The independent variable was the frequency of trials (0 for Baseline and 12 for manipulation) and whether the responses were suppressed or retrieved. The dependent variable was the percentage of correct response retrieval during the final recall test, averaging conditionalized and unconditionalized recall types. It was a within-subjects design and for each subject, the average recall of response words in the Baseline was compared with the average recall of responses in the Think and the No-Think conditions.

5.2.5 Data Analysis

A Python code was developed by myself to compare the recall rate between pre- and post-manipulation response words. For each test type, same-cue and independent-cue, the recall percentage was calculated in two ways: unconditionalized recall and conditionalized recall. In unconditionalized recall, the Phase 3 recall rate of Think, No-Think, and Baseline was calculated as a factor of 16 (16 being the total number of cue-response pairs in each manipulation condition). For instance, if a subject's recall for No-Think words was 12, their unconditionalized recall would be 75%. In conditionalized recall, on the other hand, the recall rate was calculated as a factor of response words that a subject was able to memorise during Phase 1. In the example of 12 No-Think words at recall, if the subject memorised 15 No-Think responses, for example, (that could be obtained from the criterion-feedback) their conditionalized recall rate would be 80%.

A repeated-measures ANOVA was conducted considering the following variables: Think and No-Think manipulations compared with Baseline and both same-cue and independent-cue test types were added as within-subject factors. The unconditionalized and conditionalized recall types were averaged. This ANOVA was a 2 (Baseline compared with Think or No-Think) * 2 (same-cue test, independent-cue test) factorial design. This analysis would determine whether or not there was a generalised No-Think suppression and Think facilitation effect. However, the results would only be acceptable if manipulation (being Think, No-Think, or Baseline) did not significantly interact with the test types (same-cue and independent-cue). If manipulations significantly interacted with the test type, this would mean that the effect of the manipulations was different for the same-cue test than the independent-cue test. When the test types do not significantly interact with the T/NT manipulations, this would result in a more sensitive test affirming that there are not different levels of recall at the different levels of test types. Considering that this study, on one hand, matches the standard T/NT design (Anderson & Green, 2001) with $n = 24$ subjects, but on the other hand, has fewer suppression trials (12 in T/NT-Extension versus 16 in Anderson and Green (2001), it cannot be expected with certainty to provide sufficient statistical power (i.e., 80%) to demonstrate a significant suppression effect. In other words, although the factors that potentially failed previous independent replications (e.g., sleep deprivation, neglecting experimental instructions, fatigue, etc.) were addressed in the robust T/NT procedure outlined above (e.g., the use of *diagnostic* and *post-experimental* questionnaires, and ensuring enough sleep the night before), it cannot, however, be anticipated that the sample size would be sufficient to detect a significant suppression effect.

To control for the effects of YBOCS and PCLC scores, the above analysis was repeated again, controlling for YBOCS and PCLC scores. In addition, descriptive statistics of YBOCS, PCLC, and demography variables were calculated. Jamovi (v. 1.6) and RStudio (v. 3.6.3) were used to conduct statistical analyses. The effect size, where applicable, is reported as partial eta squared ($\eta_p{}^2$).

5.3 Results

In this section, the effects of T/NT manipulations are addressed first. This is followed by using YBOCS and PCLC as covariates in T/NT manipulations presented with descriptive statistics pertaining to YBOCS and PCLC scores in T/NT-Extension subjects. It is worth noting that no subjects were excluded due to required sleep criteria (at least 7 hours the night before testing) or deliberate attempts of deception (a sum of 4 or more on Question 2 of the post-experimental questionnaire (Appendix F)).

Suppression and facilitation scores

Table 5.1 represents descriptive statistics of suppression and facilitation scores. Suppression scores were calculated by subtracting the average No-Think recall of each subject from their average Baseline recall (suppression score = Baseline − No-Think). Some subjects had around 20% decrease in recall of responses in the expected direction (the max score), whereas others showed around 20% increase in recall (the min score). However, the overall average suppression (Baseline minus No-Think) was just above 3% (Table 5.1). The suppression scores boxplot (Figure 5.1) shows that there were no outliers.

Facilitation scores (Table 5.1) were calculated by subtracting the average Baseline recall of each subject from their average Think recall (facilitation score = Think - Baseline). Some subjects showed above 20% increase in recall of responses in the expected direction (the max score), whereas others showed above 20% decrease in recall (the min score), however, the overall average facilitation (Think minus Baseline) was -0.85% (Table 5.1). Facilitation scores demonstrate some outliers at both ends based on the boxplot (Figure 5.2).

Table 5.1: Descriptive statistics for suppression and facilitation scores

	Suppression Score	Facilitation Score
Mean	3.21	-0.85
Median	1.76	-2.82
SD	9.81	9.59
Min	-19.59	-21.55
Max	19.38	21.43

SD = Standard deviation. Min = minimum. Max = Maximum.

Figure 5.1: Boxplot of Suppression scores

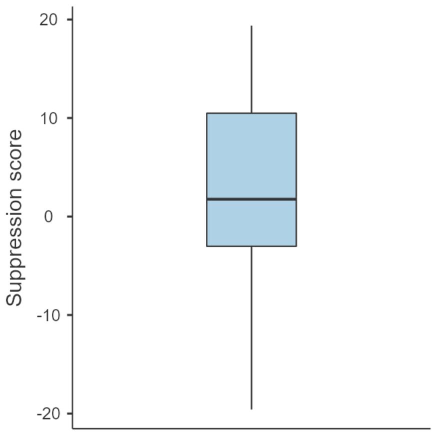
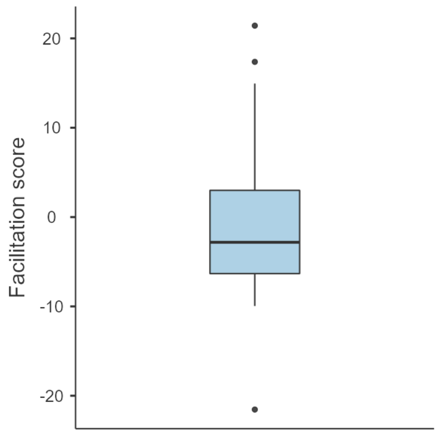


Figure 5.2: Boxplot of Facilitation scores



The No-Think effect

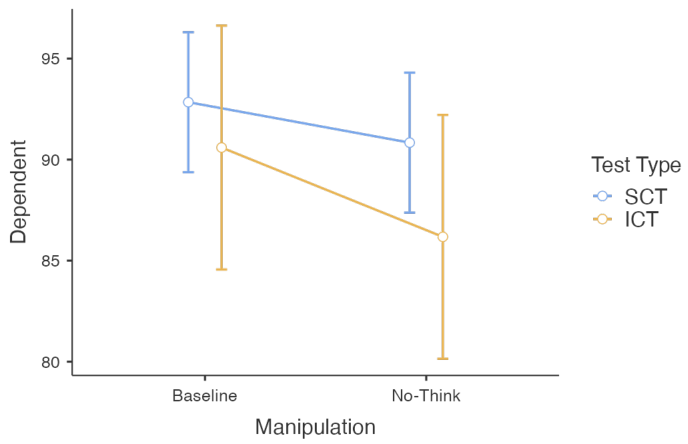
There was no significant difference between the Baseline and No-Think conditions with a negligible effect size demonstrated as the partial eta squared values (Table 5.2 and Figure 5.3, error bars indicating confidence intervals), hence the 3.2% decrease of recall from Baseline to No-Think condition was not significant. As a result, Hypothesis-1 was not confirmed. Notably, the suppression scores in previous T/NT studies have been reported between 6% - 8%. In addition, there was no significant interaction between the suppression manipulation and within-subject factors (same-cue test and independent-cue test). This signifies that the suppression effect, albeit non-significant, was consistent in terms of within-subject factors (same-cue and independent-cue tests).

Table 5.2: The No-Think suppression effect

	Manipulation	Interaction with test type
M_{Baseline} (%)	91.72	
$M_{\text{No-Think}}$ (%)	88.51	
Suppression score (%)	3.21	
p	.178	.636
F	1.87	0.23
$\eta_p{}^2$	0.04	0.00

M = Mean. p = p value. F = F ratio. $\eta_p{}^2$ = Partial eta squared.

Figure 5.3: Marginal mean plots of No-Think manipulation



SCT = same-cue test. ICT = independent-cue test.

The Think effect

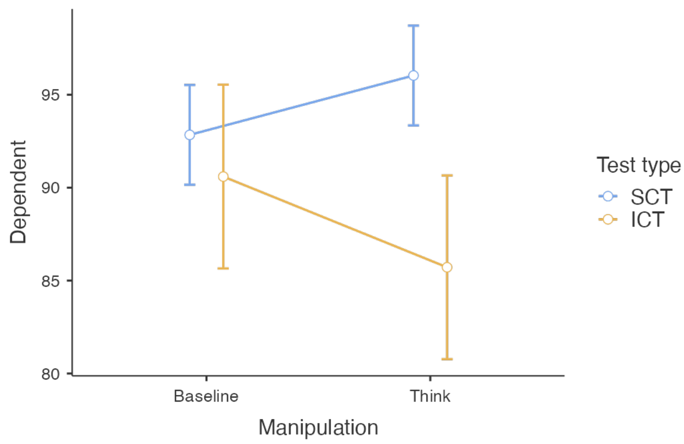
The Think effect was expected to show an increase in recall compared to the Baseline (facilitation score = Think – Baseline), and be a positive number. As Table 5.3 and Figure 5.4 (error bars indicating confidence intervals) show, the difference between the Baseline and Think conditions was not significant, and there was no facilitation effect, with a negligible effect size. On the contrary, the -0.85% difference showed that there was a decrease in recall due to the Think manipulation. In addition, the Think manipulation had a marginally significant interaction with test types (same-cue and independent-cue) (p = .066). Table 5.4 and Figure 5.4 (error bars indicating confidence intervals) clarify these differences further. There seems to be a facilitation effect due to same-cue testing (>3% increase in recall) and almost a 5% decrease in recall due to independent-cue testing. In this case, the decrease was comparable to the No-Think decrease percentage wise.

Table 5.3: The Think facilitation effect

	Manipulation	Interaction with test type
M_{Baseline} (%)	91.72	
M_{Think} (%)	90.87	
Facilitation score (%)	-0.85	
p	.639	.066
F	0.22	3.53
$\eta_p{}^2$	0.00	0.07

M = Mean. p = p value. F = F ratio. $\eta_p{}^2$ = Partial eta squared.

Figure 5.4: Marginal mean plots of Think manipulation



SCT = same-cue test. ICT = independent-cue test.

Table 5.4: Interaction between Think and test type

Test Type	Manipulation	M (%)
Same-cue	Baseline	92.84
	Think	96.03
Independent-cue	Baseline	90.60
	Think	85.72

M = Mean.

YBOCS and PCLC

Table 5.5 shows descriptive statistics of YBCOS and PCLC, followed by histograms (Figures 5.5 and 5.6). Subjects scored over the continuum of these scales and no outliers were detected in YBOCS and PCLC scores based on boxplots (displayed in Appendix G).

Table 5.5: Descriptive statistics for YBOCS and PCLC

	YBOCS	PCLC
Mean	11.08	32.83
Median	10.00	32.00
SD	5.44	11.33
Min	0.00	18.00
Max	23.00	57.00

SD = Standard deviation. Min = minimum. Max = Maximum

Figure 5.5: Histograms of YBOCS scores

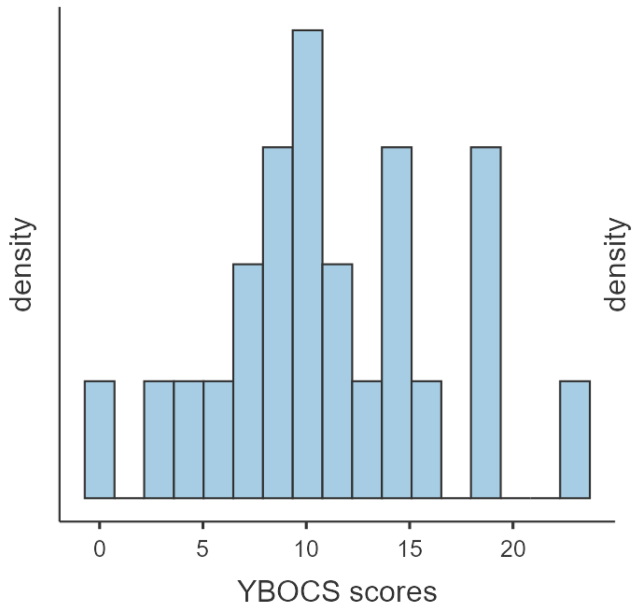
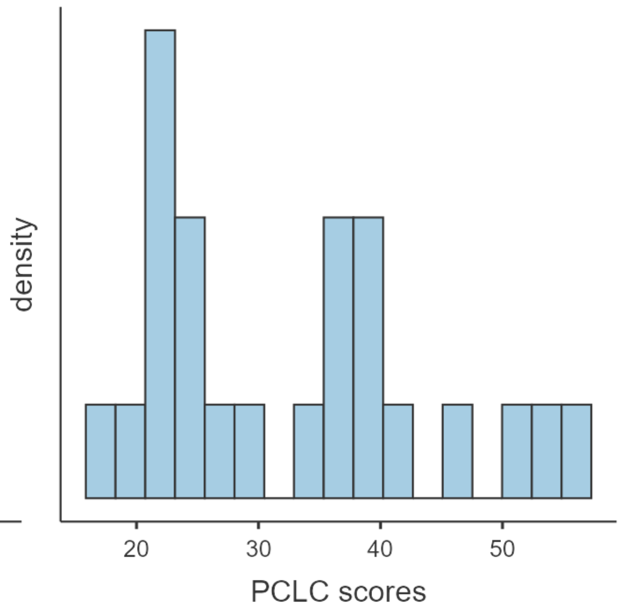


Figure 5.6: Histograms of PCLC scores



YBOCS and PCLC as covariates

YBOCS was used as a covariate to control for the effects of OCD scores on the No-Think manipulation. It did not change the previous conclusions. The difference between No-Think and Baseline was not significant (Table 5.6). The same was true when PCLC was used a a covariate as shown on Table 5.6.

Table 5.6: No-Think manipulation with YBOCS and PCLC

	Suppression	YBOCS	Suppression	PCLC
F	1.88	1.28	1.89	1.58
p	.177	.263	.176	.216
η_p^2	0.04	0.03	0.04	0.03

F = F ratio. η_p^2 = Partial eta squared.

Similar analyses were conducted for the Think manipulation. The conclusions stayed the same as before (Table 5.7). Neither YBOCS nor PCLC as covariates changed previous findings.

Table 5.7: Think manipulation with YBOCS and PCLC

	Facilitation	YBOCS	Facilitation	PCLC
F	0.22	1.05	0.22	0.26
p	.639	.311	.642	.612
η_p^2	0.00	0.02	0.00	0.01

F = F ratio. η_p^2 = Partial eta squared.

YBOCS and PCLC scores had a moderate significant correlation (r = .59, p = .003), see Figure 5.7, suggesting that some subjects scored simultaneously high or low on both scales. On the other hand, neither YBOCS nor PCLC scores significantly correlated with suppression or facilitation scores (Table 5.8), strengthening the previous findings that neither YBOCS nor PCLC affect suppression or facilitation scores in T/NT-Extension subjects.

Figure 5.7: Scatterplot of YBOCS and PCLC scores

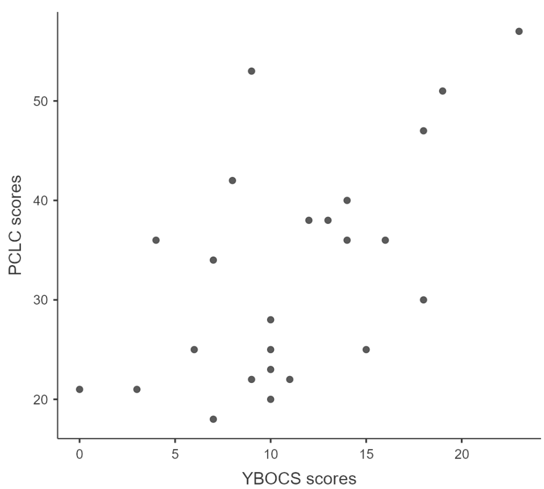


Table 5.8: Correlation matrix of YBOCS and PCLC with suppression/facilitation

		YBOCS	PCLC
Suppression score	Pearson's r	-.17	-.14
	p value	.428	.524
Facilitation score	Pearson's r	-.30	-.27
	p value	.149	.202

5.4 Discussion

T/NT-Extension was designed to investigate whether or not a smaller repetition of No-Think suppression trials (12 repetitions comprising 48 s total suppression time for each word) would lead to a No-Think suppression effect. To achieve this, $n = 24$ subjects were recruited for the T/NT test. Another aim of this study was to identify if YBOCS or PCLC scores affected the performance of a subject in the T/NT test. After initial analyses of Think and No-Think effects, YBOCS and PCLC functioned as covariates to statistically differentiate the performance of subjects at different levels of these scales.

Contrary to the first T/NT study (Anderson & Green, 2001) that used 16 repetitions, a significant suppression effect due to a No-Think manipulation with 12 repetitions was not found. Therefore, Hypothesis-1 was not supported. The difference between No-Think and Baseline was minimal (3.21%) with 12 repetitions compared to previous studies reporting 6% - 8% differences with different levels of repetitions (Levy & Anderson, 2008; Stramaccia et al., 2021).

An important feature of No-Think manipulation, however, was no significant interaction between the types of testing (same-cue and independent-cue). This means whether one used same-cue or independent-cue testing, the outcome of No-Think suppression would likely be the same.

Considering the small effect size, it is possible that a significant suppression effect might be detected with a larger sample size. It could be that since the total suppression time decreased from 64 s (with 16 repetitions) to 48 s (with 12 repetitions), the suppression effect might be too small to be captured by a study with $n = 24$ subjects. Therefore, a study with a larger n might be needed. This motivated Study-2 (T/NT-Traits) to look further at the possibility of a

No-Think suppression effect with a larger subject pool.

Another motivation for T/NT-Traits was the absence of a No-Think suppression effect despite controlling for trait scores in T/NT-Extension. Based on the executive deficit hypothesis (Levy & Anderson, 2008), those at the lower end of trait scales (YBOCS and PCLC) should demonstrate a more effective suppression capability. Therefore, it might be that the suppression effect with 12 repetition still exists, but since T/NT-Extension had a mix of Lo, medium, and Hi trait scorers, the average suppression effect was confounded by medium and Hi scorers – who were potentially subject to executive deficit. The presence of medium and Hi scorers was substantiated by the descriptive statistics of trait scores. However, the sample size was too small to have randomly picked a substantial number of Hi scorers. In addition, there were no updated data on the distribution of trait scores in the current cohort of study subjects (young students of psychology at the University of Canterbury). It would have been inappropriate to speculate on these without follow-up studies with clear extreme trait scorers (Hi and Lo) and discounting medium scorers. Based on the executive deficit hypothesis, the suppression effect should be strong in Lo scorers (with intact executive function) and weak or absent in Hi scorers (poor executive function = executive deficit), whereas medium scorers could sway either way (average executive function). So, T/NT-Traits was designed to compare Lo trait scores directly with Hi, each group having 24 subjects — as normally required for a standard T/NT experiment.

In T/NT-Extension, the Think manipulation did not result in a facilitation effect. In other words, there was no increase in recall of Think words as a result of the Think manipulation. If anything, Think trials produced a numerical decrease in recall post-manipulation, albeit not statistically significant. Importantly, however, there was a marginally significant interaction of test type (same-cue and independent-cue) with the Think manipulation. Only the same-cue test showed an increase in recall due to the Think manipulation. It might be that same-cue and independent-cue testing could involve different processing mechanisms in the brain. However, such an argument should not be made based on only one study which did not show an overall significant Think effect to begin with. Therefore, T/NT-Traits would potentially highlight this effect further.

In the light of all presented results, arguments, and speculations, T/NT-Traits was purposely designed to set apart Hi scorers based on each of the scales because of a possible defect in their ability to suppress unwanted information. If that was the case, there would be an enhanced opportunity for the Lo scorers on each of the scales to show a significant suppression effect. T/NT-Traits should also clarify if same-cue and independent-cue testing with the Think manipulation results in opposite outcomes again. Finally, due to significant correlation between YBOCS and PCLC, it was anticipated that some subjects in T/NT-Traits would simultaneously score Hi on YBOCS and PCLC, whereas others would score simultaneously Lo on both scales.

Chapter 6

Study-2: T/NT-Traits

6.1 Introduction

Study-2 (T/NT-Traits) involved a follow up based on the previous Think/No-Think (T/NT) study, T/NT-Extension. It was designed to examine if high scoring subjects on obsessive-compulsive disorder (OCD) and post-traumatic stress disorder (PTSD) psychological traits would have impaired No-Think suppression capability, borrowing from the executive deficit hypothesis suggested by Levy and Anderson (2008).

This study consisted of two experiments: Experiment-1 with Yale-Brown Obsessive Compulsive Scale (YBOCS) and Experiment-2 with PTSD CheckList - Civilian Version (PCLC). For Experiment-1, it was hypothesised that Hi YBOCS subjects would demonstrate an impaired No-Think suppression effect and, hence, impaired suppression ability. However, Lo YBOCS subjects were hypothesised to demonstrate a No-Think suppression effect (Section 4.2). For Experiment-2, it was hypothesised that Hi PCLC subjects would demonstrate an impaired No-Think suppression effect compared to Lo PCLC subjects (Section 4.3).

In addition, T/NT-Traits was aimed to further explore the diverging outcome of the Think manipulation in T/NT-Extension. More specifically, it was aimed to examine whether or not the Think manipulation would result in opposing findings from same cue testing versus independent cue testing.

6.2 Method

Experiment-1 and Experiment-2 study subjects were recruited from the same pool of screened students and participated in the experiment based on their availability during 15 weeks of data collection without any specific order. The methods were similar for both. In addition, the Materials and Apparatus of T/NT-Traits were similar to T/NT-Extension (see Section 5.2.2), so they are not repeated again in this section. These studies were designed in two parts: Stage-1 (trait screening) and Stage-2 (participating in the attention task experiment).

6.2.1 Participants

For Stage-1 (screening), $n = 367$ students from University of Canterbury were screened using YBOCS and PCLC scales. The age of subjects was reported 16–60 years ($M = 21.18$, $SD = 6.11$), of which 21% ($n = 76$) were male, 78% ($n = 286$) were female, $n = 4$ were non-binary, and n = 1 wished not to declare their gender. Eighty percent ($n = 292$) opted to participate in Stage-2. $N = 296$ subjects from the Introductory Psychology course at University of Canterbury received 1 research participation credit for screening and $n = 71$ other University of Canterbury students went into a draw to receive one of three $20 gift vouchers. Those who participated in Stage-2 received 3 additional research participation credits or a $20 gift voucher as gratuity. The exclusion criteria were attention-deficit hyperactivity disorder (ADHD) diagnosis, as the T/NT task requires constant attention, and colour blindness, as three colours, blue, red, and green, were used during the T/NT experiment. The study was approved by the Human Ethics Committee of the University of Canterbury (HEC 2020/45).

6.2.2 Procedure

Stage-1 was advertised in the research participation pool for Introductory Psychology students and on social media for the rest of the subjects. The questionnaire was provided on Qualtrics that consisted of YBOCS and PCLC scales, demography data, as well as asking subjects if they wanted to participate in Stage-2. The YBOCS and PCLC composite scores were calculated for all subjects, but only those who opted to participate in Stage-2 were contacted to attend the next stage. The procedure of Stage-2 was identical to T/NT-Extension (see Section 5.2.3) except that the YBOCS and PCLC scores were obtained at the end of T/NT-Extension, whereas they were obtained during Stage-1 of T/NT-Traits. Out of $n = 292$ subject who opted to participate in Stage-2, only those who met the criteria for Hi or Lo YBOCS or PCLC were contacted to participate.

6.2.3 Design

The independent variables were frequency of trials (0 for Baseline and 12 for manipulation), whether the responses were suppressed or retrieved, and the position of subjects on scales (Hi YBOCS, Lo YBOCS, Hi PCL-C, Lo PCL-C). The dependent variable was the percentage of correct response retrieved during the final recall test, averaging conditionalized and unconditionalized recall types. It was a mixed design and for each subject, the average recall of response words in the Baseline was compared with the average recall of responses in the Think and the No-Think conditions.

6.2.4 Data Analysis

After screening, the composite scores of YBOCS were calculated by summing up scores of all 10 items (min = 0 and max = 4 for each item), according to the YBOCS guidelines (Goodman et al., 1989). The same applied to PCLC, a 17-item scale (Min = 1 and Max = 5 for each item) (Weathers et al., 1993). The recommended cut-off values of YBOCS and PCLC (Appendices C and D) and distance from the mean scores (z scores) were considered for deciding Hi YBOCS, Lo YBOCS, Hi PCLC, and Lo PCLC threshold values. The data analysis for Stage-2 (the T/NT task) was similar to T/NT-Extension (Section 5.2.5).

6.3 Results

No subjects were excluded due to required sleep criteria (at least 7 hours the night before testing) or deliberate attempts of deception (a sum of 4 or more on Question 2 of the post-experimental questionnaire (Appendix F)).

6.3.1 Deciding Lo and Hi groups

Table 6.1 shows the recommended cut-off values for YBOCS and PCLC, based on Appendices C and D.

Table 6.1: YBOCS & PCLC cut-off values

YBOCS		PCLC	
8 - 15	Mild OCD	17 - 29	No severity (of PTSD)
16 - 23	Moderate ODC	28 - 29	Some symptoms
24 - 31	Severe OCD	30 - 44	Moderate to moderatly high
32 - 40	Extreme OCD	45 - 85	High severity

The average and max scores of YBOCS were relatively higher in T/NT-Traits than T/NT-Extension (Table 6.2, T/NT-Extension scores are presented with blue text), and Figure 6.1 shows that there were no outliers. Similarly, the average score of PCLC in T/NT-Traits was higher than T/NT-Extension and so was the max score (Table 6.2). Figure 6.2 shows that there were no outliers in PCLC either. In both scales, a sufficient number of subjects scored at both extremes evident from comparing the descriptive statistics of T/NT-Traits and T/NT-Extension (Table 6.2).

Trait scores were changed to z scores and compared with the recommended cut-off values (Table 6.1) to decide Lo and Hi scorers. Although n = 24 was the estimated minimum number of subjects required for each group (Hi YBOCS, Lo YBOCS, Hi PCLC, and Lo PCLC), a higher number was recruited to cater for those who would fail Phase 1 of the T/NT task

Table 6.2: Descriptives for YBOCS & PCLC

	YBOCS		PCLC	
Mean	14.24	11.08	42.13	32.83
Median	14.00	10.00	40.00	32.00
SD	6.32	5.45	15.43	11.33
Min	0.00	0.00	17.00	18.00
Max	29.00	23.00	85.00	57.00
25th percentile	10.00	7.75	30.00	22.75
75th percentile	18.50	14.25	53.00	38.50

Blue text represents T/NT-Extension scores. *SD* = Standard deviation. Min = minimum, Max = Maximum.

Figure 6.1: T/NT-Traits YBOCS boxplot

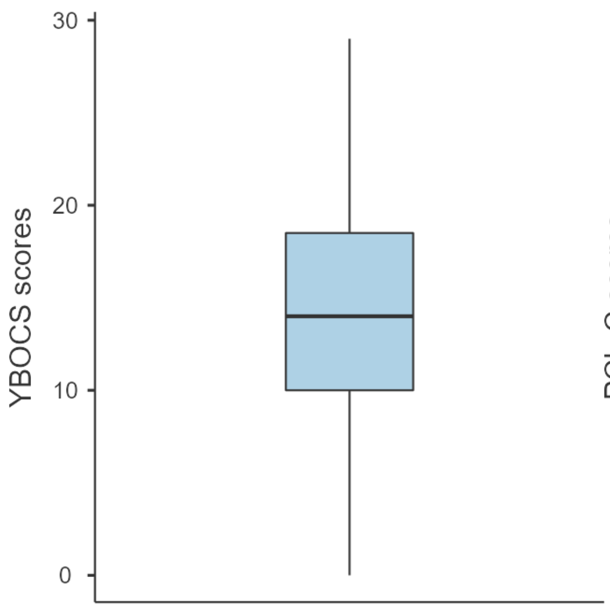
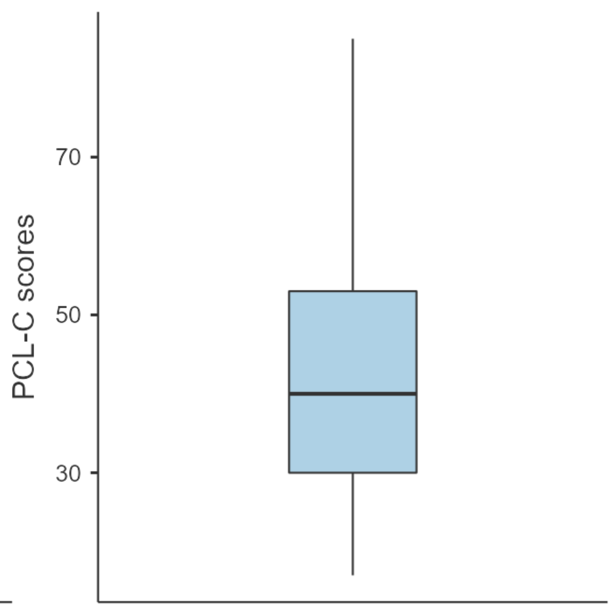


Figure 6.2: T/NT-Traits PCLC boxplot

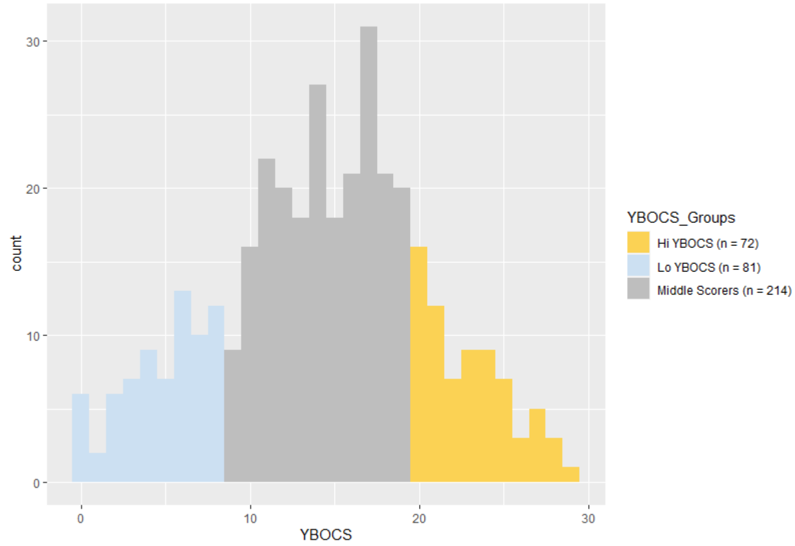


(around 40% according to the T/NT-Extension) and those who would not attend Stage-2 despite volunteering in the first place.

The cut-off for Lo YBOCS was set at 9 (<-0.8 *SD*) which included n = 81 subjects, all located at the lower end of Mild OCD category. The YBOCS score of 20 (>0.9 *SD*) was set as the cut-off for Hi YBOCS and included n = 72 subjects. This left many subjects (n = 214) between the two extremes. Figure 6.3 shows a histogram of YBOCS scores with different colours representing the extreme scorers.

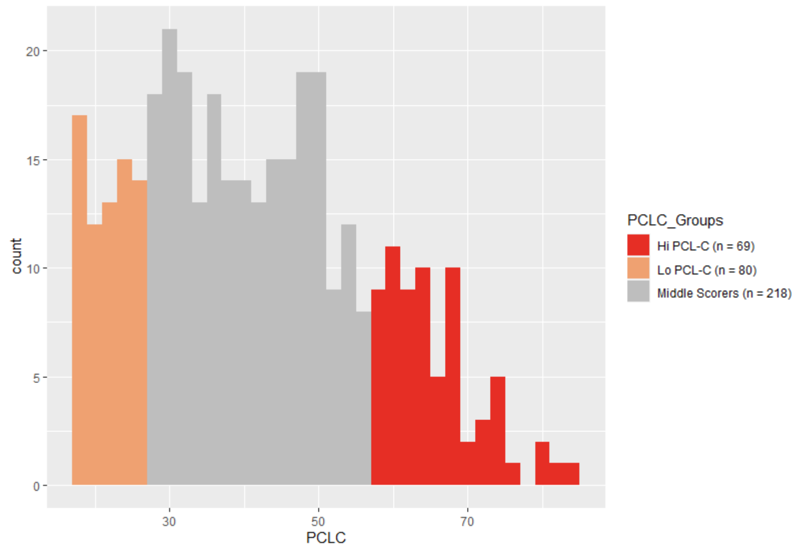
The cut-off for Lo PCLC was set at 28 (<-0.9 *SD*) which included n = 80 subjects, and

Figure 6.3: T/NT-Traits YBOCS Groups



58 (>1 *SD*) was set for Hi PCLC which included $n = 69$ subjects. This division left $n = 218$ between subjects the two extremes. Figure 6.4 shows a histogram of PCLC scores with different colours for the extreme scorers.

Figure 6.4: T/NT-Traits PCLC Groups



Tables 6.3 and 6.4 contain a comparison between traits scores in T/NT-Extension and T/NT-Traits. For the purposes of this table, YBOCS and PCLC scores of Hi and Lo groups were also aggregated. These groups are named Agg-YBOCS and Agg-PCLC. Although these tables show that the averages of aggregated scores were similar to T/NT-Extension, Lo and Hi groups demonstrate the real differences. The Lo YBOCS and Lo PCLC had low average trait scores compared to T/NT-Extension. On the other hand, the Hi groups had much higher trait scores than T/NT-Extension. Comparing these and considering Figures 6.3 and 6.4, shows that

more than $n = 210$ middle scorers on each scale were left out. Hence, it can be said with a high confidence that Lo and Hi groups consisted of extreme scorers on both scales.

Table 6.3: YBOCS scores comparison

	T/NT-Extension	Hi YBOCS	Lo YBOCS	Agg-YBOCS
M_{YBOCS}	11.08	23.03	4.77	13.77
SD_{YBOCS}	5.44	2.44	2.58	9.53
$\text{Min}_{\text{YBOCS}}$	0.00	20.00	0.00	0.00
$\text{Max}_{\text{YBOCS}}$	23.00	27.00	9.00	27.00

M = Mean. *SD* = Standard deviation. Min = Minimum. Max = Maximum.

Table 6.4: PCLC scores comparison

	T/NT-Extension	Hi PCLC	Lo PCLC	Agg-PCLC
M_{PCLC}	32.83	66.12	22.77	44.13
SD_{PCLC}	11.33	6.44	3.12	22.39
Min_{PCLC}	18.00	58.00	17.00	17.00
Max_{PCLC}	57.00	80.00	28.00	80.00

M = Mean. *SD* = Standard deviation. Min = Minimum. Max = Maximum.

All subjects who signed up to participate in Stage-2 and met the inclusion criteria — being at either extreme — were invited to participate. Ninety-nine among these volunteered and subsequently showed up to participate in the T/NT experiment. Two of them were excluded as they were not 18-year-old and $n = 22$ subjects failed Phase 1 of the experiment, resulting in 75 subjects who satisfactorily completed the T/NT task. Due to a moderate correlation between the YBCOS and PCLC scores from T/NT-Extension ($r = .59$, $p = .003$), it was anticipated that some subjects maybe included as an extreme scorer in both scales. This turned out to be correct in the T/NT-Traits as the correlation between both scales was moderate ($r = .53$, $p < .001$). As a result, there were $n = 21$ subjects who overlapped in Hi YBOCS and Hi PCLC, and similarly, $n = 18$ subjects were simultaneously in Lo YBOCS and Lo PCLC groups. This explains why the total number of subjects was $n = 75$, and not 96 (24 subjects in each of YBOCS and PCLC groups).

Finally, $n = 25$ from Hi YBOCS, $n = 28$ from Lo YBOCS, $n = 27$ from Hi PCLC, and $n = 29$ from Lo PCLC completed the T/NT experiment. Considering the cut-offs, T/NT-Extension had $n = 1$ in Hi YBOCS and $n = 9$ in Lo YBOCS, with $n = 14$ scoring in between – who also participated in the T/NT experiment. Similarly, T/NT-Extension had $n = 0$ Hi PCLC and $n = 11$ Lo PCLC subjects, with $n = 13$ middle scorers who also participated in the T/NT experiment.

6.3.2 Suppression scores

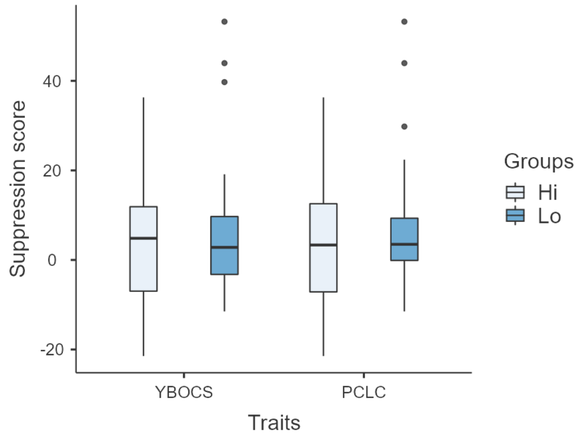
Table 6.5 represents descriptive statistics of suppression scores in all four groups, followed by Figure 6.5 showing the corresponding boxplots. Both Hi groups had a relatively smaller suppression score at around 3% - 4% whereas both Lo groups had a larger score, between 6% - 7%. Hi groups also had a smaller max score (less decrease in No-Think recall) than the Lo group – whereas some subjects showed suppression scores above 40%. However, considering the boxplot (Figure 6.5), these were outliers with a potentially high suppression capability. On the other hand, Hi subjects also showed relatively more increase in recall due to No-Think suppression (min score -20) compared to -10 in Lo groups. These statistics show that Lo groups generally showed a higher suppression capability than Hi groups. However, further statistical analyses are needed to ascertain whether or not these differences are significant.

Table 6.5: Descriptive statistics for suppression scores

	Hi YBOCS	Lo YBOCS	Hi PCLC	Lo PCLC
Mean	3.30	6.40	3.93	7.08
Median	4.830	2.80	3.33	3.48
SD	12.49	15.41	12.90	14.76
Min	-21.48	-11.51	-21.48	-11.51
Max	36.31	53.23	36.31	53.23

SD = Standard deviation. Min = Minimum. Max = Maximum.

Figure 6.5: Suppression scores boxplot



6.3.3 The No-Think effect

Hi versus Lo groups: Combined within Traits

These analyses were conducted to determine if the suppression in Hi YBOCS and Hi PCLC was significantly different from Lo YBOCS and Lo PCLC groups, respectively. First, however, Hi and Lo YBOCS groups were combined to create a new variable (Combined-YBOCS, n = 53) to explore the overall effect of No-Think suppression in the combined pool of Hi and Lo YBOCS subjects. Subsequently, an ANOVA was conducted, similar to previous analyses, with two levels of YBOCS being considered between-subject factors. As Table 6.6 shows, there was an overall suppression effect with an almost 5% decrease in recall of No-Think compared to Baseline with a medium effect size and the suppression effect did not significantly interact with test types (same-cue and independent-cue). However, when the suppression scores in Lo YBOCS (6.40%) were compared with Hi YBOCS (3.30%), the Mann-Whitney U test[1] showed that these differences were not significant (U = 355.00, p = .903), with a small effect size (d = 0.035).

Similar analyses were conducted by first combining the Hi and Lo PCLC groups (Combined-PCLC, n = 56) (Table 6.6). There again was an overall suppression effect that behaved similar to the overall-YBOCS results. The difference between Baseline and No-Think was 5.50% indicating a medium effect size, with no interaction of the suppression effect with test types. However, the difference between the suppression score in Lo PCLC (7.08%) versus

[1]The Mann-Whitney U non-parametric test was chosen over t - test because the suppression scores were not normally distributed.

Table 6.6: No-Think suppression in overall scores

	Combined-YBOCS	Combined-PCLC
M_{Baseline} (%)	92.25	92.45
$M_{\text{No-Think}}$ (%)	87.40	86.95
Suppression score (%)	4.85	5.50
p	.015	.011
F	6.06	6.76
$\eta_p{}^2$	0.06	0.06

M = Mean. p = p value. F = F ratio. $\eta_p{}^2$ = Partial eta squared.

Hi PCLC (3.93%) was not significant ($U = 369.50$, $p = .724$). The effect size was small ($d = 0.097$).

Collectively, there seems to be an overall suppression effect when Hi and Lo groups are aggregated. This itself is substantial since a suppression effect was not present in T/NT-Extension with the current T/NT experimental protocol that used a smaller number of trials than previous T/NT studies. With a glance at Table 6.5, it can be seen that Lo groups generally showed higher suppression percentages than Hi groups, albeit not significant based on analysis with the U test. This being so, all four groups were also separately analysed.

No-Think effect: separate groups

There was a significant suppression effect in Lo YBOCS and Lo PCLC groups with medium effect sizes (demonstrated as the partial eta squared values) (Table 6.7). In addition, neither Hi YBOCS nor Hi PCLC showed a significant suppression effect. However, since the direct comparison between Lo and Hi groups did not result in a significant difference (see Section 6.3.3, it cannot be claimed that Hypotheses-2a, 2b, 3a, and 3b are supported. If anything, it can be said that these results are suggestive of potential differences between Lo and Hi scorers that can be further substantiated with a larger sample size in the future studies. Nonetheless, Lo YBOCS showed very similar results as Lo PCLC, whereas suppression in the Hi YBOCS group was similar to Hi PCLC. In all of the above analyses, there were no significant interactions between suppression scores and test type (same-cue, independent-cue). This signifies that the suppression effect was consistent in terms of within-subjects factors.

Table 6.7: No-Think suppression separate groups

	Hi YBOCS	Lo YBOCS	Hi PCLC	Lo PCLC
M_{Baseline} (%)	90.23	94.10	91.56	93.34
$M_{\text{No-Think}}$ (%)	86.93	87.70	87.63	86.26
Suppression score (%)	3.30	6.40	3.93	7.08
p	.279	.016	.185	.024
F	1.20	6.19	1.80	5.40
$\eta_p{}^2$	0.02	0.10	0.03	0.09

M = Mean. p = p value. F = F ratio. $\eta_p{}^2$ = Partial eta squared.

Figures 6.6 (error bars indicating confidence intervals) show the estimated marginal means of each group. As a result, there seems to be a significant suppression effect with Lo trait scorers and no suppression effect with Hi trait scorers. In addition, there is an overall suppression effect when data from Hi and Lo scorers are combined, though this suppression effect is not significantly different between Hi and Lo scorers.

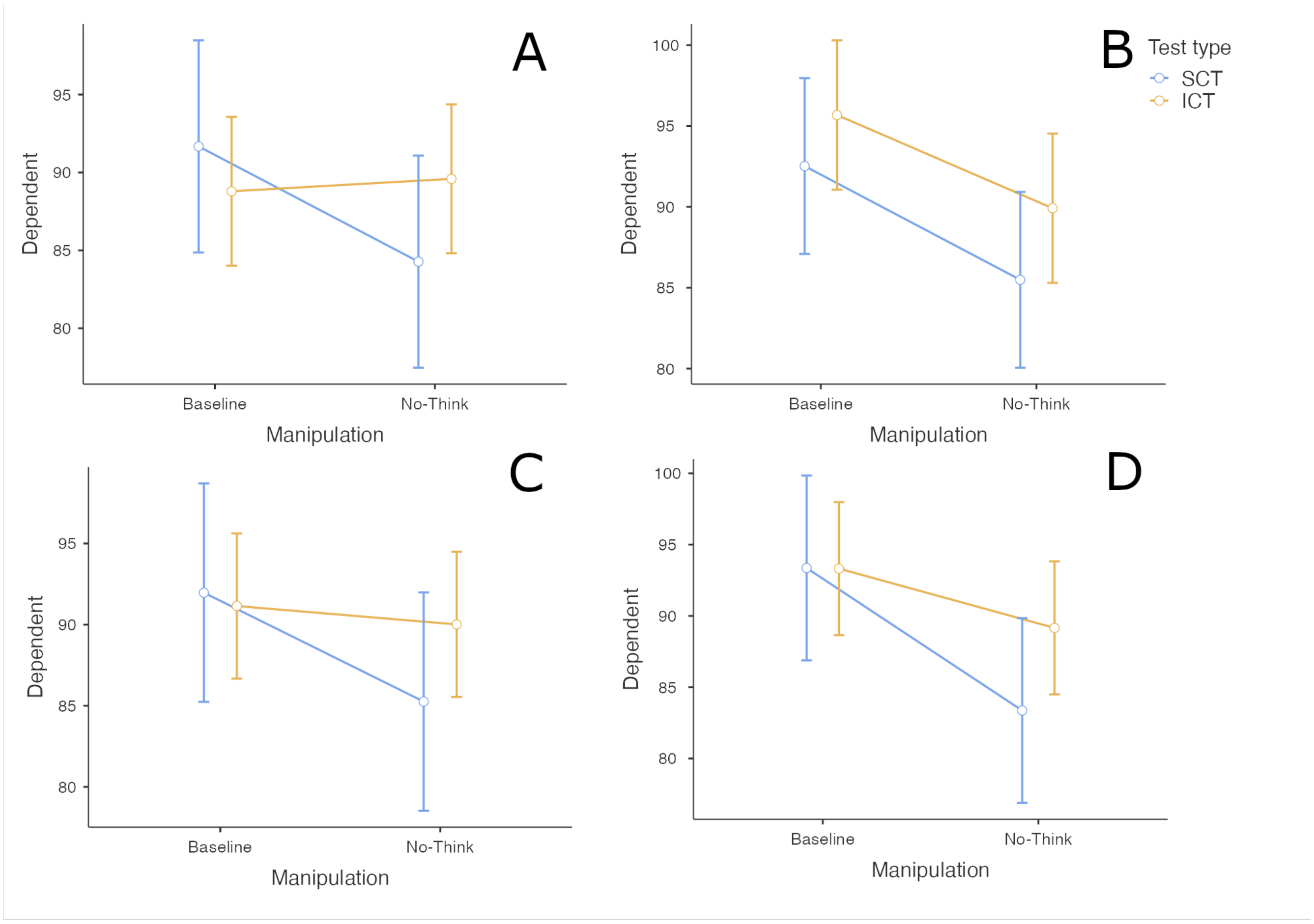
6.3.4 Facilitation scores

Table 6.8 represents descriptive statistics of facilitation scores followed with Figure 6.7 showing the corresponding boxplots. Although some subjects show high recall due to the Think manipulation (max scores above 20%), there are also subjects who demonstrated low recall (min scores at -15%). The averages are either negative – which shows a reverse effect of facilitation; or positive with small values highlighting the possibility of a non-significant difference. Since no differences were anticipated between Lo and Hi groups due to the effect of Think manipulation, each group's facilitation scores were analysed separately. These findings were then compared with the Think effect in T/NT-Extension to examine if that pattern (increase in recall with same-cue test and decrease with independent-cue test) is repeated again.

6.3.5 The Think effect

The Think effect was expected to result in an increased recall compared to the Baseline (facilitation = Think – Baseline), and this difference to have been a positive number. As

Figure 6.6: No-Think condition marginal means. A: Hi YBOCS, B: Lo YBOCS, C: Hi PCLC, D: Lo PCLC



SCT = same-cue test. ICT = independent-cue test.

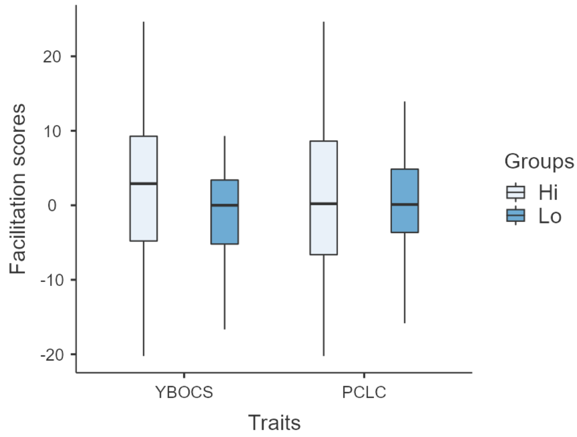
Table 6.8: Descriptive statistics for facilitation scores

	Hi YBOCS	Lo YBOCS	Hi PCLC	Lo PCLC
Mean	2.33	-1.79	0.94	-1.34
Median	2.90	0.00	0.21	0.10
SD	10.82	7.26	12.24	8.05
Min	-20.24	-16.67	-20.24	-15.84
Max	24.65	9.30	24.65	13.94

SD = Standard deviation. Min = minimum. Max = Maximum.

Table 6.9 shows, the differences between the Baseline and Think conditions were not significant in any of the four groups in T/NT-Traits, with some showing a reversal (decreased recall). Interestingly, as was the case in T/NT-Extension, the significant or marginally significant p values on interaction between manipulation and test type (same-cue and independent-cue) are

Figure 6.7: Facilitation scores boxplot



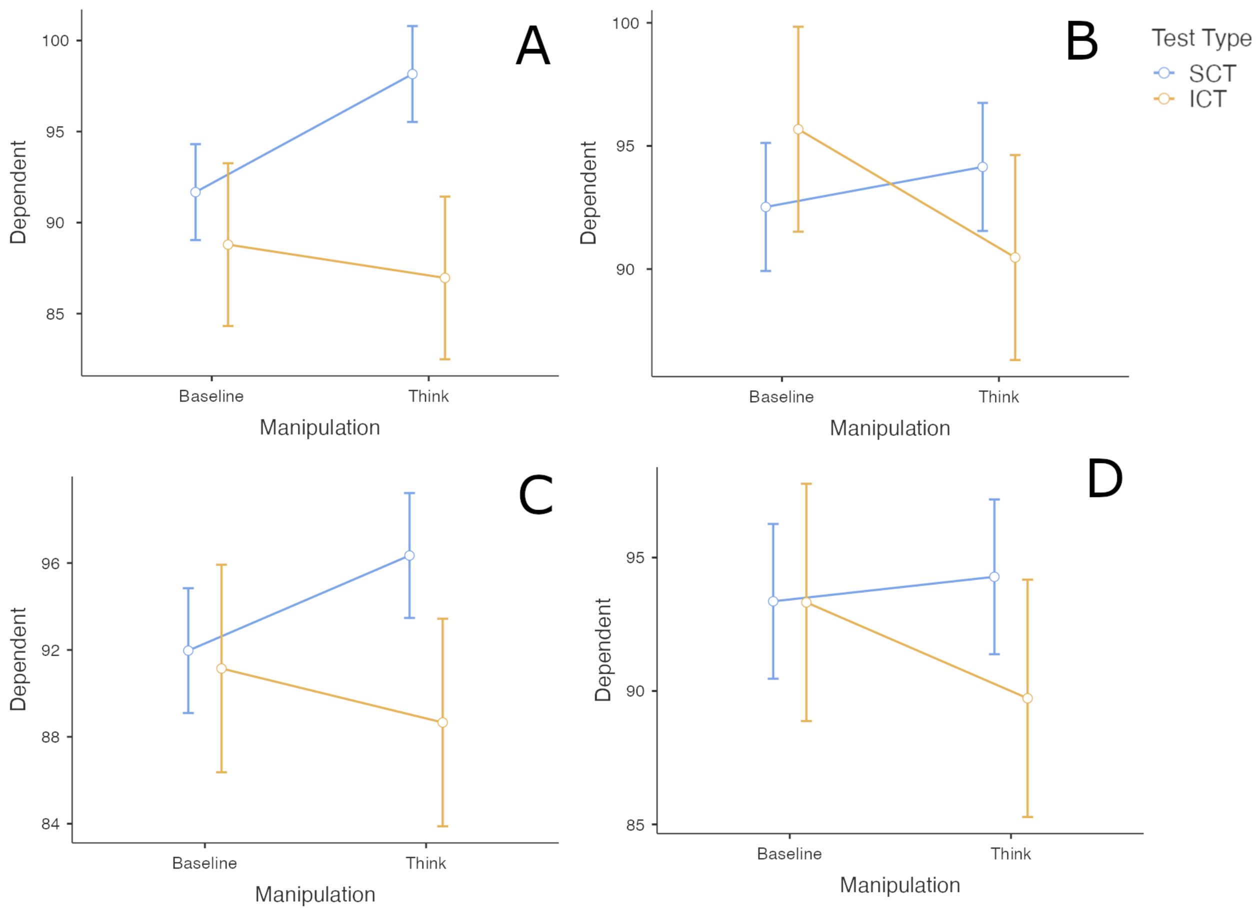
suggestive of different patterns in recall due to Think manipulation for each test type. These observations are further highlighted by estimated marginal means graphs (Figures 6.8, error bars indicating confidence intervals) (cf. the No-Think manipulation never interacted significantly with the test type). Based on these, it can be suggested that there was an increase in recall due to Think manipulation with same-cue testing, and that the decrease in Think recall was only inherent to the independent-cue testing type.

Table 6.9: Think facilitation separate groups

		Hi YBOCS	Lo YBOCS	Hi PCLC	Lo PCLC
Manipulation	M_{Baseline} (%)	90.23	94.10	91.56	93.34
	M_{Think} (%)	92.56	92.31	92.50	92.00
	Facilitation score (%)	2.33	-1.79	0.94	-1.34
	p	.244	.241	.652	.454
	F	1.39	1.41	0.21	0.57
	η_p^2	0.03	0.02	0.00	0.01
Manipulation*test type	p	.016	.082	.068	.257
	F	6.26	3.14	3.48	1.31
	η_p^2	0.12	0.05	0.06	0.02

M = Mean. p = p value. F = F ratio. η_p^2 = Partial eta squared.

Figure 6.8: Think condition marginal means. A: Hi YBOCS, B: Lo YBOCS, C: Hi PCLC, D: Lo PCLC



SCT = same-cue test. ICT = independent-cue test.

6.4 Discussion

T/NT-Traits was built on T/NT-Extension and aimed to investigate if Hi scorers on psychological traits of OCD and PTSD would show impaired No-Think suppression ability compared with Lo scorers. Similar to T/NT-Extension, T/NT-Traits also used 12 repetitions of No-Think and Think manipulations (48 s total suppression or facilitation time for each word, respectively). Another aim of T/NT-Traits was to take a closer look at the difference of the Think effect with same-cue test versus independent-cue test as a consequence of finding a difference between them in T/NT-Extension. This was the first behavioural T/NT study to have directly compared Hi and Lo scorers on psychological traits: propensity for OCD and PTSD. This was also the second study following Lambert et al. (2010) to further explore the potential differing effects of a Think manipulation with same-cue and independent-cue testing.

In Stage-1 of T/NT-Traits, n = 367 subjects were screened using YBOCS (Goodman et al., 1989) and PCLC (Weathers et al., 1993) scales to identify and recruit Hi and Lo scorers for Stage-2. The recommended cut-off values as well as z scores were used to decide Hi and Lo scoring subjects. In Stage-2, Hi and Lo scorers of each scale were recruited for the T/NT test in two experiments (Experiment-1 with YBOCS and Experiment-2 with PCLC). T/NT-Traits ended up with n = 25 subjects in Hi YBOCS, n = 28 subjects in Lo YBOCS, n = 27 subjects in Hi PCLC, and n = 29 subjects in Lo PCLC groups.

Contrary to T/NT-Extension that did not demonstrate the No-Think suppression effect, T/NT-Traits demonstrated this effect with 12 repetitions of the No-Think manipulation in both the YBOCS and the PCLC groups. In both cases, a significant suppression effect was demonstrated, but only when Hi and Lo trait scoring subjects were considered as one large group (n = 53 in YBOCS and n = 56 in PCLC). The combined groups showed about 5% decrease in recall with the No-Think manipulation. These findings confirm that the No-Think suppression effect can be achieved with a smaller frequency of repetition (12 repetitions totalling 48 s suppression time) with a sufficiently larger number of subjects. Although Hi and Lo groups were expected to have different level of executive deficit, the average scores of aggregated traits (Tables 6.3 and 6.4) were comparable with those in T/NT-Extension. Therefore, it can be said with some level of confidence that the suppression effect was replicated and these findings were consistent with Anderson and Green (2001) and Levy and Anderson (2008). These findings, in addition, might also suggest that T/NT-Extension had too low of a statistical power to demonstrate the suppression effect, as speculated.

To test the executive deficit hypothesis (Levy & Anderson, 2008) in accordance with the current research on psychological traits and T/NT (Anderson & Hanslmayr, 2014; Anderson et al., 2004; Benoit & Anderson, 2012; Catarino et al., 2015; Depue et al., 2007; Gagnepain et al., 2014), No-Think suppressions in Hi groups were analysed directly in comparison with suppressions in Lo groups. Although, with separate analyses, there was a significant suppression effect in Lo groups (suppression scores: 6.40% in YBOCS and 7.08% in Lo PCLC), and no suppression effect in Hi groups (suppression scores: 3.30% in Hi YBOCS and 3.93% in Hi PCLC); Hi versus Lo suppression scores were not significantly different. These findings do not confirm Hypothesis-2a, Hypothesis-2b, Hypothesis-3a, and Hypothesis-3b. This, coupled with findings discussed in the previous paragraph, suggest the following:

1. There was a significant No-Think suppression effect with 12 repetitions when Hi and Lo trait scorers were combined. Notably, this involved about twice as many subjects as previous T/NT studies with 16 repetitions.

2. There was a significant No-Think suppression effect in Lo YBOCS and Lo PCLC groups that resembles the suppression scores (decrease in the recall of No-Think items) reported in previous studies (Levy & Anderson, 2008; Stramaccia et al., 2021).

3. There was no significant suppression effect in Hi YBOCS and Hi PCLC groups.

4. However, the difference between the suppression ability of Hi and Lo groups is so minimal that it could not be statistically substantiated. This is furthered by reported low effect sizes and high variability in suppression scores of in both Hi and Lo groups (Figure 6.5). Quite a few subjects show superior No-Think suppression in both Lo and Hi groups of both YBOCS and PCLC. This variability may highlight the existence of different levels of executive deficit within Lo and Hi groups such that some in Hi groups, unexpectedly, do demonstrate a decline in No-Think recall by as much as 30%, whereas some in Lo groups demonstrate a reversal (increase in recall of No-Think by as much as 10%). This means that not only may Hi and Lo groups have different levels of executive function, but even those within these groups show high variability.

5. These analyses do not substantiate the conjectures of former T/NT research suggesting that those with higher levels of executive deficit (analogous to Hi YBOCS or Hi PCLC) would demonstrate less suppression ability (Anderson & Hanslmayr, 2014; Anderson et al., 2004; Benoit & Anderson, 2012; Catarino et al., 2015; Depue et al., 2007; Gagnepain et al., 2014; Levy & Anderson, 2008).

6. In general, there appear to be some differences at the level of suppression capability in Hi groups versus Lo groups. Based on the present evidence, however, a very large sample would likely be needed to show statistical evidence of this difference. This is because some subjects who might be characterised as Hi trait scorers could show better suppression capability than Lo scorers. On the other hand, some Lo scorers might demonstrate poorer

suppression capability than Hi scorers. Although there might be differences between Hi and Lo groups at the neurophysiological level, such differences were not demonstrated in this behavioural study (cf. Anderson & Hanslmayr, 2014; Anderson et al., 2004; Benoit & Anderson, 2012; Catarino et al., 2015; Depue et al., 2007; Gagnepain et al., 2014; Levy & Anderson, 2008).

Similar to T/NT-Extension, the Think manipulation did not result in a facilitation effect. In each of four groups, there was either a negative or a small positive facilitation score. Therefore, the differences between the recall of Baseline and Think trials were not significant. Think manipulation interacted with the test types (same-cue and independent-cue) in most of these four groups again, similar to T/NT-Extension. As Table 6.9 and Figure 6.8 demonstrated, there has been a recurring pattern of increased recall with same-cue testing with the Think manipulation, but a decreased recall with independent-cue testing. Notably, test type did not interact with the No-Think manipulation, implying that it is only the Think manipulation that results in opposite effects due to same-cue versus independent-cue testing.

An interesting finding in T/NT-Traits was relatively higher PCLC scores than T/NT-Extension, so much so that it seemed as if a lot of subjects would meet the diagnostic criteria for PTSD. This may reflect the effect of the Covid-19 pandemic to increase anxiety scores particularly in women (Brivio et al., 2021) who comprised 78% of T/NT-Traits subjects. Whereas, studies from the pre-Covid-19 era that collected data from a similar sample (undergraduate psychology students) reported a much smaller PCLC score (e.g., M = 28.1 in Adkins et al. (2008)).

Chapter 7

Study-3: BFP-Parolees

7.1 Introduction

Study-3 (BFP-Parolees) was designed to examine the accuracy of Brain Fingerprinting (BFP) by testing criminals on their own or other criminals' confessed crime incidents. It was deemed appropriate to recruit criminals who had already faced the consequences of their crimes, so that the findings could not affect them in any way. If BFP is as reliable and accurate as claimed by Farwell and colleagues, it was hypothesised that the ground-truth Information Present (IP) subjects would be classified as IP_C and that the ground-truth Information Absent (IA) subjects would be classified as IA_C by the BFP system, with no false positives and no false negatives (see Section 4.4).

7.2 Method

7.2.1 Participants

BFP-Parolees had $n = 17$ male adult ex-prisoners from the Salisbury Street Foundation half-way house in Christchurch, New Zealand. They were aged 27–75 years ($M = 47.5$) and were all convicted criminals on parole from Christchurch Men's Prison for separate serious crimes including homicide, robbery, arson, assault, and sexual offences. No exclusion criteria were applied although subjects were required to have a minimum standard of reading comprehension, and be confined to, residents of, or had linkage to the half-way house. A University of Canterbury staff member with connections to the half-way house was appointed to help with identifying, recruiting, and escorting the subjects. All subjects volunteered to participate. They were given an information sheet several days prior to testing, and those who agreed to take part in this study signed consent to participate in the study. Subjects received a NZ$100 voucher as gratuity and the study was approved by the Human Ethics Committee of the University of Canterbury (HEC 2019/152).

7.2.2 Materials and Apparatus

The BFP software and hardware were leased from Brain Fingerprinting, LLC. (Seattle). Cognionics (San Diego) software was employed to measure electrode impedances on the EEG-headset. The experiment was carried out on a Windows PC screen placed at 60 cm in front of a subject. The event-related potential (ERP) data were collected with a custom-made, wirless headset that recorded EEG from three midline dry electrodes on the scalp: frontal = Fz, central = Cz, and parietal = Pz (International 10-20 system). Electrooculogram (EOG) signals were used to detect eye-blink artefacts and were collected from Fp1 and Fp2. Linked mastoid electrodes were used as the signal reference. EOG signals and the EEG data from the mid-line parietal (Pz) electrode were amplified, analog low-pass filtered at 30 Hz, digitally low-pass filtered at 6 Hz (3 dB cutoff), and trials with an EOG range greater than 400 μV and/or an EEG range greater than 150 μV were excluded from analysis. An Xbox controller was used to collect behavioural responses from the subjects.

7.2.3 Design

The ground-truth status (IP versus IA) was the between-subjects independent variable and the stimulus type (probe versus target and irrelevant) was the within-subjects independent variable. The ERP response leading to a BFP classification (IP_C, IA_C, and Indeterminate) was the dependent variable.

Subjects were divided into three groups, being tested with BFP by three different testers. One group was assigned to each BFP tester (6 subjects in Test Group A, 6 in Test Group B, and 5 in Test Group C). All subjects were interviewed on one of their confessed crimes, selected using their criminal records, that involved no other subject within their test group. The stories told by these subjects were corroborated with their corresponding police files to ensure accuracy. Initially, three of these incidents, *Flatmate Assault*, *Revenge*, and *Robbery*, were randomly chosen and a BFP test was formed for each of them. Later, two more tests were added: *The Armour Guard Heist* incident replaced *Revenge*. The reason being that the IP subject of the *Revenge* incident failed to attend the experiment. Since other subjects of this incident had not been tested at that stage, it was replaced with the *Armour Guard Heist* incident. The second added test was *Stolen Dog* incident. It was used to re-test one of the subjects (details in Results).

To ensure tester blindness, subjects were interviewed and the BFP test stimuli were formulated for each incident only by testers who would not go on to administer the BFP test to the subject in question. For each incident, one subject with the knowledge of the event in question (IP) was tested, and either four or five subjects with no knowledge of the event (IA) were tested. The BFP testers had been trained and certified by Dr Farwell and followed the BFP testing manual and 20SS to ensure consistency and robustness of the testing procedure.

7.2.4 Stimuli

Subjects were interviewed by two trained BFP testers. To ensure tester blindness, the specific BFP tester assigned to test any given subject was not permitted to be present during that subject's interview. During the interview session, subjects were prompted to recount a "memorable event" from their lives with what, when, where, who, and how questions. Subjects recounted a wide variety of different events. They were also advised that, if they chose to disclose an event involving serious criminal behaviour, they should choose a crime for which legal repercussions had already been faced, to avoid a conflict of interest for interviewers in keeping their stories confidential. Incidents that were randomly selected for incorporation into

BFP tests included serious criminal conduct such as heist, homicide, and arson.

The incidents used in BFP testing tend to be quite idiosyncratic and subjective to subjects' experiences. That is, an incident being tested for one group of participants (one IP and several IAs) in a study would usually be very different from another incident in the same study. This could create questions of inconsistency between incidents from a scientific methodological point of view. Because multiple incidents were being tested in each study, all subjects could not have been tested on one incident. However, it was ensured that the stimuli were developed in a systematic and objective manner. These following measures were taken to ensure this consistency:

- The stimuli were developed by two testers and were peer-reviewed by another team member to ensure consistency and objectivity.

- The irrelevant items for the human names were formulated based on a database that lists names and surnames in terms of popularity. For instance, if a name narrated by a subject was Martin Jackson, the database shows popularity ranks of 190 and 13, respectively. A suitable irrelevant for this would be Johnny Anderson – ranked 184 and 11, respectively, with a similar number of syllables.

- A similar consistency was ensured for names of vehicles and places.

According to 20SS (Farwell et al., 2013), a standard BFP test requires 6 probe, 6 target, and 24 irrelevant stimuli that would ensure embedding the incident-related information (probes and targets) within irrelevants to be presented in an oddball (Squires et al., 1975) order. As per definition, the probe stimuli would be recognised as substantial to the incident in question by someone who participated, witnessed, or investigated the incident. Targets were also formulated from the facts that were substantial to the incident, but all subjects would be exposed to them so that they can recognise them later during the test, and the resulted ERP would form a baseline calibration comparison for probe and irrelevant ERPs. Irrelevant stimuli matched probes and targets in familiarity and the number of syllables, though, they were non-substantial to the incident in question (see Appendix H).

7.2.5 Procedure

The interviews and BFP testing were carried out on the campus of the University of Canterbury in Christchurch. Subjects in residence at the half-way house were escorted to the campus by the half-way house staff members, and subjects based in the community made their own way to the University for testing by appointment. The testing took place at a designated testing space at the University.

The BFP tests were carried out within 5 to 25 days following subject interviews, and it took place with strict adherence to the 20SS. A key procedural requirement of 20SS is to divide the stimuli (Appendix H) into two sets: Set 1 and Set 2. Hence, each set consisted of 3 probes, 3 targets and 12 irrelevants. Each of these stimuli were presented 20 times during the BFP test that resulted in 120 probe trials, 120 target trials and 480 irrelevant trials (total of 720). In case any trials were rejected due to artefacts (eye blinks during trials or head/body movement), additional trials were automatically added by the BFP system to replace them. The BFP 20SS require at least 100 artefact free trials from each of the probe, target, and irrelevant stimuli for analysis. Sixteen blocks of trials were presented with each block consisting of 72 trials, and each stimulus of the set being presented at least 4 times. Set 1 and Set 2 stimuli were presented in an alternating order.

Prior to the BFP test proper, a procedure knows as *information confirmation* was administered. During this phase, each subject was met by one of the testers who had interviewed them for the incident. The IA (ground-truth IA) subjects were presented with a list of all target stimuli and were instructed to familiarise themselves with these items. IP (ground-truth IP) subjects were presented with a list of the target and probe stimuli, which of course were produced by the information that the IP subjects provided. They were instructed to review all items and ensure that they would recognise them later during the BFP test. This information confirmation procedure was employed to prevent against the possibility of any subject guessing non-relevant information, manipulating, or lying if they could not remember the incident narrated during their interview. Following this, they also participated in a practice BFP test without ERP data being collected to familiarise them with the experimental procedure. They were instructed to recognise the target stimuli and press the left-hand button on the Xbox controller; and to press the right-hand button for any other stimuli (either probe or irrelevant).

It is worth noting that the information confirmation procedure was added for lab testing purposes (i.e., the current project) only. The field use of BFP for detecting concealed knowledge would be slightly different. There, the stimuli would be formulated from the information collected from a crime scene by the investigators and witnesses, and police evidence would also be used. Therefore, the stimuli would be verified from those resources rather than using information confirmation.

Brain Fingerprinting Testing

By this time, subjects were familiar with the task in that they had to sit still, look at the stimuli, read and recognise targets (that were described as "items relevant to the situation under investigation" in the experimental instructions) and press left-hand button of the Xbox controller. They were also to read and recognise non-targets and press the right-hand button. Irrelevant items were read but required a right-hand button press since they are unrelated to the incident.

As part of the experimental procedure, the list of all probes, randomly intermixed with irrelevant stimuli and their short descriptions were presented (e.g., The stolen item the subject put in this pocket: Wristwatch, Wallet, Necklace). Only an IP subject, due to their previous involvement with the incident, would recognise the the relevant stimulus among these three. Following this, a list containing all irrelevant stimuli was briefly presented to subject to identify if any item was substantial to them for a reason unrelated to the incident in question. Such personally substantial stimuli were then removed and replaced with other irrelevant items. For instance, if "Dunedin" was an irrelevant stimulus, but a subject said that it was substantial to them as they were raised in Dunedin, it would be replaced with another less-substantial city. The data acquisition started after ensuring that a subject understood the experimental procedure and that their relevant questions were answered.

The overt behavioural aspect of data acquisition (i.e., pressing a button on the Xbox controller) ensured that subjects were paying attention to, and understood, the stimuli by pressing the appropriate button, otherwise, it was not relevant to the P300-MERMER generation. It has been referred to as *behavioural accuracy* in this thesis and the frequency of correct behavioural response (i.e., pressing the left button for targets and the right button for probes and irrelevants) is converted to a percentage score that the BFP software calculates for each block, and also as an average of all blocks for a subject. This behavioural accuracy is implicit in the 20SS, but has not been reported in published BFP articles. An *a priori* criterion of 80% behavioural accuracy for each block for target and irrelevant stimuli was set, considering that sometimes a wrong button might be pressed mistakenly. Blocks with less than 80% behavioural accuracy were rejected and subjects would be excluded if their overall behavioural accuracy was below 80%. The 80% rule was not imposed on probes because although IA subjects would press the correct button (the right-hand button) for probes, it is possible that an IP subject might confuse probes with targets due to their own prior knowledge (because of participation in the incident) and press the left-hand button. If any blocks were supposed to be rejected, they were replaced by new blocks to ensure adequate data acquisition.

The BFP test was divided into 16 blocks and for most of the subjects, each block of the BFP test took up to 5 min and comprised probes, targets, and irrelevants, presented one at a time, randomly intermixed oddball (Squires et al., 1975) order in white text at the centre of a blue computer screen. Each block contained a minimum of 72 trials, 1/6 (16.67%) of which were targets, 1/6 (16.67%) were probes, and 4/6 (66.67%) were irrelevant trials. As mentioned earlier, all stimuli were divided into two sets. One stimuli set was displayed in odd numbered blocks and the other set was displayed in even numbered blocks; while odd and even blocks alternated (i.e., Block 1 = Set 1, Block 2 = Set 2, Block 3 = Set 1, Block 4 = Set 2… etc).

Prior to each block, subject viewed and heard (read by the experimenter) the following instructions to highlight the relevance of the target items, and potential relevance of probe items (which should only be recognised by IP subjects due to their involvement): "Here are the items you will see in this test that are related to the investigated situation. Push the left-hand button for the items that were on the short list of things you know about the situation, and the right-hand button for anything else". Then a list of three descriptions for targets and three descriptions for probes (see Appendix H, column: Description) was presented to the subjects. The *short list* mentioned in the instructions is a reference to the list of targets introduced to the subjects at the beginning of the tests. It is important to note that only descriptions, and *not* the corresponding stimuli (probes, targets, and irrelevants) were presented. For example, "In this test you will see: Name of the subject's sister, Name of the subject's girlfriend, The place where the robbery incident happened..." etc.

Before each stimulus, a fixation cross appeared in the centre of the screen for 1.0 s, followed by a stimulus (target, irrelevant, or probe) displayed for 0.3 s. Then a blank screen appeared for 1.7 s followed by another fixation cross for 1.0 s that was followed by the next stimulus. This sequence continued until the end of each block. Subjects were supposed keep their eyes open and to sit still and quietly. If they needed to blink, they could blink during the fixation cross.

An amplitude >400 μV in the Fp1 channel during a trial would demonstrate disruption due to the extraneous artifact of eye movement. Similarly, an amplitude >150 μV at Pz would demonstrate disruption due to head or body movement. Such trials were rejected and replaced with artefact-free trials until there were a total of at least 12 probes, 12 target, and 48 irrelevant artefact-free trials collected, which would automatically end the block. Therefore, a minimum of 192 probes, 192 targets, and 768 irrelevants were collected over the 16 blocks (20SS only requires a minimum 100 of each trials). Data were digitized at 100 Hz. Electrode-scalp impedances were confirmed less than 10 kΩ at the beginning of testing and were rechecked during the test if necessary.

Data Analysis

The BFP software does not provide information on baseline correction, eye-movement correction, correction for amplifier drift, flatlining, etc., nor pre-stimulus activity. The analysis report produces an *html* file that describes the number of blocks, data on behavioural accuracy, and BFP determination, and displays an ERP graph. As this project was an independent, yet direct, replication of Farwell's BFP technology, it was deemed inappropriate to analyse and report aspects that could not be obtained from the BFP software. To analyse P300 with MERMER, the analysis epoch was defined as 300 – 1500 ms post-stimulus.

As targets would produce large P300-MERMER amplitude due to being recognised by a subject, the BFP data analysis was aimed to decide if probes also produced large P300-MERMER, or they lacked a high P300-MERMER amplitude (similar to irrelevants). A double-centred correlation and a bootstrapping procedure (Farwell et al., 2013; Farwell et al., 2014; Farwell & Donchin, 1991; Wasserman & Bockenholt, 1989) were used to decide statistically if probe response ERPs were closer in similarity to target response ERPs (resulting in an IP_C classification) or irrelevant response ERPs (resulting in an IA_C classification). The bootstrapping procedure controlled for variability across trials since each stimuli type ended up more than 100 required trials needed for BFP analysis (Farwell et al., 2014).

Each stimuli type (probe, target, and irrelevant) was randomly sampled P, T, and I times, respectively, wherein P equalled the total number of probes, T equalled the total number of targets, and I equalled the total number of irrelevants in each subject. This process was repeated 1000 times and in each iteration, the probe-target time-series correlation was compared with probe-irrelevant time-series correlation and the number of times when the probe-target correlation was higher than the probe-irrelevant correlation was counted as a percentage (Prob%). This Prob% was considered the probability (termed bootstrapping probability) that probe ERPs were more similar to target ERPs than to irrelevant ERPs, or the probability of the subject being classified as IP_C. 100 - bootstrapping probability determined the probability of probe ERPs being similar with irrelevant ERPs, or the subject being classified as IA_C (Farwell et al., 2013; Farwell et al., 2014; Farwell & Donchin, 1991).

According to BFP 20SS, the *a priori* cut-off of IP_C was set at 90%, and the cut-off of IA_C was 70% in the opposite direction (i.e., 100 – Prob%). For instance, a subject with a 95% Prob% would be classified as Information Present (IP_C) with a bootstrapping probability of 95%. This subject, by definition, would have a 5% bootstrapping probability of being classified as Information Absent (IA_C). Similarly, a subject with a 10% Prob% would be classified as Information Absent (IA_C) with a bootstrap probability of 90%. Subjects who did not meet either of these criteria would be classified as Indeterminate (Farwell & Donchin, 1991). The BFP software, unfortunately, does not provide any more descriptive data on the nature of the bootstrapping procedure except that mentioned in Farwell's published articles, as described above.

7.3 Results

7.3.1 Exclusions

One subject (C17) never started the test. Another subject (C04) had started the experiment, but did not continue to the end, which prevented recording a sufficient number of trials (100 trials required for each stimulus type, probe, target, and irrelevant according to 20SS). Thus, his incomplete dataset could not be analysed and was excluded. Three subjects withdrew due to uncontrollable excessive eye-blinking leading to eye fatigue at the time of testing (C05, C06, and C12). C12 was the IP subject of the *Robbery* incident and the other two were IAs of the *Flatmate Assault* incident.

Excessive eye-blinking resulted in large numbers of trials being rejected and blocks taking more than 10 min, resulting in eye fatigue just after 2–3 blocks. The remaining subjects ($n = 12$) satisfactorily completed the BFP testing and their BFP findings are detailed below, followed by the discussion of behavioural accuracy.

7.3.2 Brain Fingerprinting Findings

Individual data for all subjects were analysed as per *Classification Concealed Information Test bootstrapping* procedure that has been explained in detail in the Data Analysis section. Of the 12 remaining subjects, both IP subjects were correctly classified as IP_C, with a mean bootstrapping probability of 98.8%, and 6 of 10 IA subjects were correctly classified as IA_C, with a mean bootstrapping probability of 99.4%. One IA subject (C11) was misclassified as IP_C, with a bootstrapping probability of 93.5%, and three IA subjects (C10, C15, and C16) were Indeterminates (see Table 7.1).

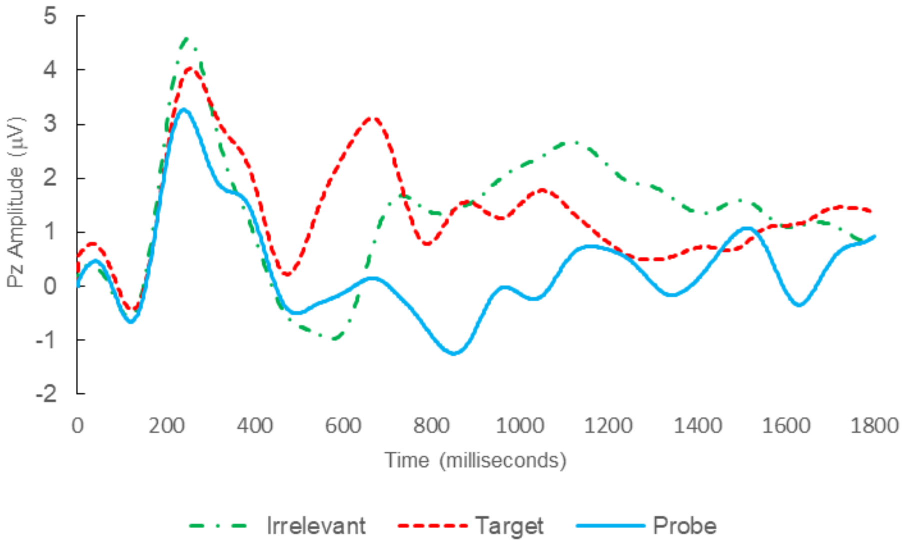
Table 7.1: Summary of Brain Fingerprinting Results for BFP-Parolees

Incident	Subject ID	Ground-truth	BFP Determination	Bootstrapping Probability (%)
Flatmate Assault	C01	IP	IP_C	99.9
	C02	IA	IA_C	92.6
	C03	IA	IA_C	99.9
	C04	IA	Excluded (<100 trials)	
	C05	IA	Withdrew due to eye fatigue	
	C06	IA	Withdrew due to eye fatigue	
Armour Guard Heist	C07	IP	IP_C	98.5
	C08	IA	IA_C	98.4
	C09	IA	IA_C	98.7
	C10	IA	IND[a]	53.7
	C11	IA	IP_C[b]	93.5
Robbery	C12	IP	Withdrew due to eye-fatigue	
	C13	IA	IA_C	99.9
	C14	IA	IA_C	99.7
	C15	IA	IND[a]	67.5
	C16	IA	IND[a]	56.2
Revenge	C17	IP	Never participated	

BFP = Brain Fingerprinting, IP = Ground-truth Information-Present, IP_C = Classified as Information-Present, IA = Ground-truth Information-Absent, IA_C = Classified as Information-Absent, IND = Classified as Indeterminate.
[a] Blue font shows an Indeterminate classification.
[b] Red font shows a false positive classification.

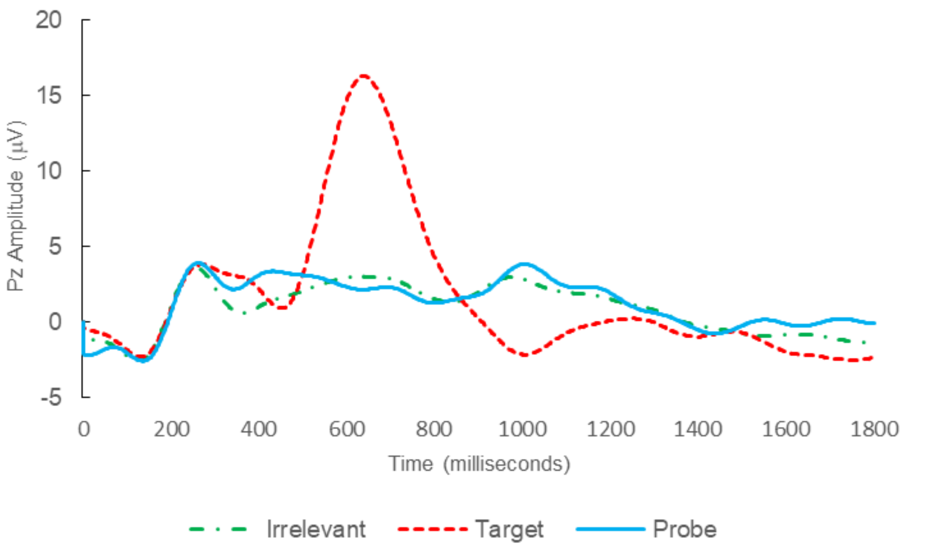
Thus, 8 out of 12 classifications were correct (accuracy of 91.7% discounting Indeterminates), and consistent with ground-truth, with one false positive, three Indeterminates and no false negatives, with a mean bootstrap probability for correct determinations of 99.3%. Figures 7.1, 7.2, 7.3 and 7.4 show ERP waveforms for C01 (IP_C), C02 (IA_C), C10 (Indeterminate) and C11 (false positive), respectively. ERP waveforms for the rest of the subjects are in Appendix I.

Figure 7.1: BFP Response Waveforms of C01 in “Flatmate Assault” (IP→IP_C)



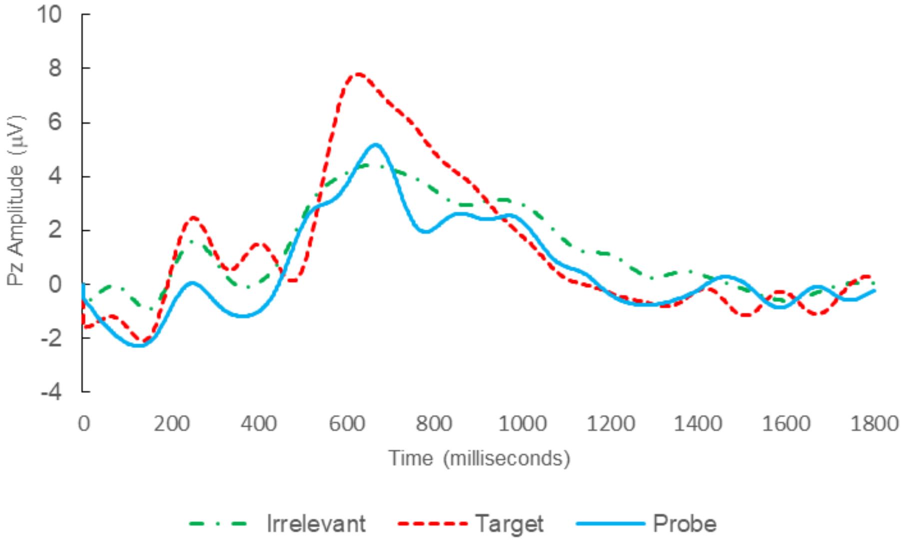
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information-Present.

Figure 7.2: BFP Response Waveforms of C02 in “Flatmate Assault” (IA→IA_C)



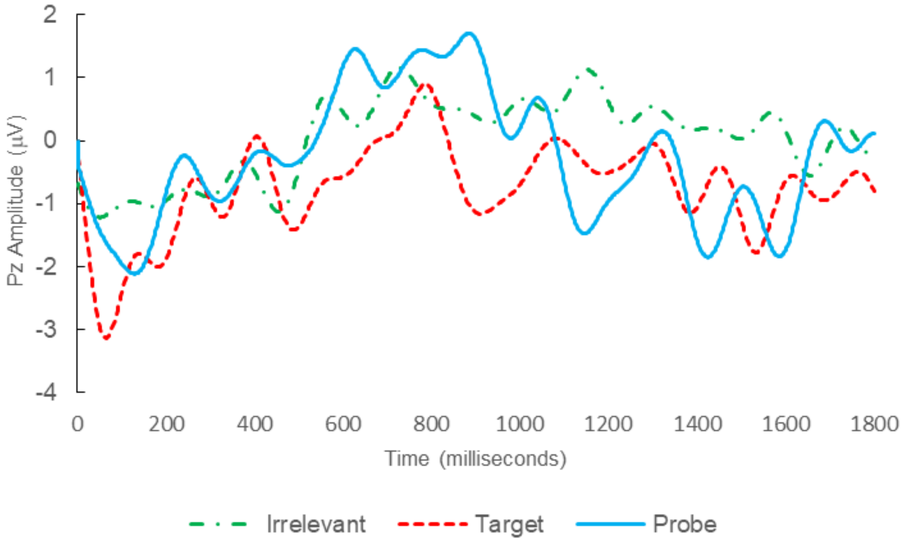
BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent. IA_C = Classified as Information-Absent.

Figure 7.3: BFP Response Waveforms of C10 in "Armour Guard Heist" (IA→Indeterminate)



BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent.

Figure 7.4: BFP Response Waveforms of C11 in "Armour Guard Heist" (IA→IP_C)



BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent, IP_C = Classified as Information-Present.

7.3.3 Further Analysis of C11

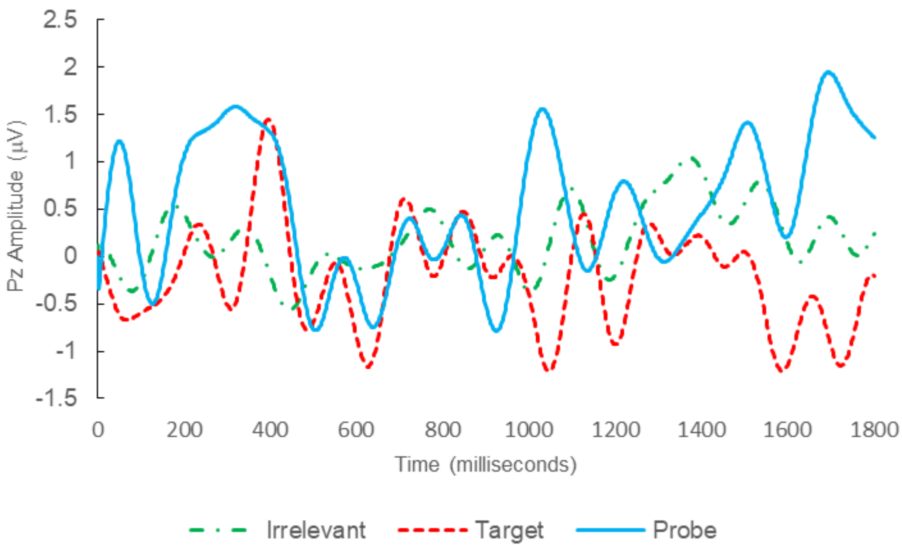
As IA subject C11 was incorrectly classified as IP_C for the Armour Guard Heist incident, it was decided, with his willing consent, to investigate him further. He was retested on the Robbery incident for which he was also IA and for which he was again incorrectly determined as IP_C. He was subsequently tested on his own crime incident: the Stolen Dog. Although now IP, he was classified by BFP as Indeterminate. See Table 7.2 for further details and Figures 7.5 and 7.6 for his ERPs for the IA and IP incidents.

Table 7.2: C11's BFP determination for Different Incidents

Incident	Ground-truth	BFP determination	Bootstrapping probability (%)
Armour Guard Heist	IA	IP_C[a]	93.5
Robbery	IA	IP_C[a]	90.1
Stolen Dog	IP	IND[b]	72.6

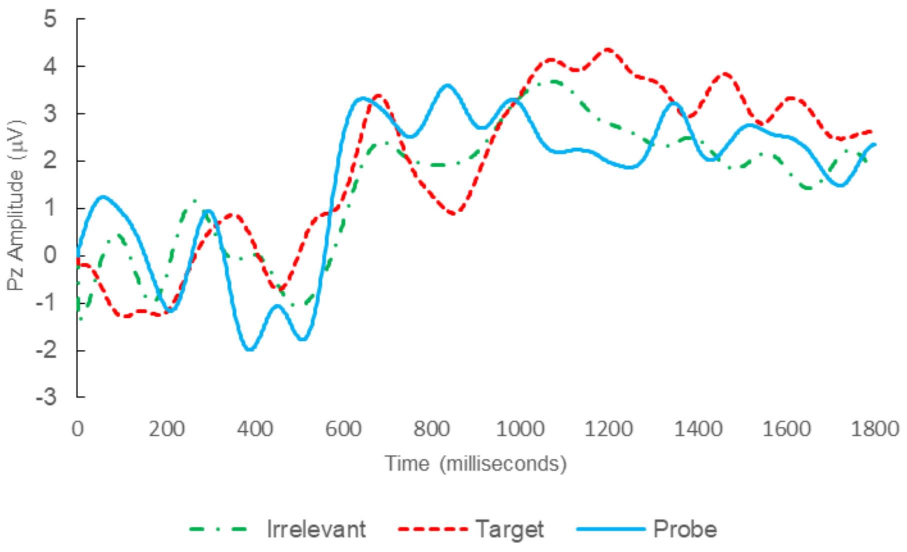
BFP = Brain Fingerprinting, IA = Ground-truth Information-Absent, IP_C = Classified as Information-Present, IP = Ground-truth Information-Present, IND = Classified as Indeterminate.
[a] Red font shows a false positive classification.
[b] Blue font shows an Indeterminate classification.

Figure 7.5: BFP Response Waveforms of C11 in "Robbery" (IA→IP_C)



BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent, IP_C = Classified as Information-Present.

Figure 7.6: BFP Response Waveforms of C11 in "Stolen Dog" (IP→Indeterminate)



BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent.

7.3.4 Behavioural Accuracy

All subjects met the behavioural accuracy criteria: each individual block met the accuracy criterion such that accuracies of target and irrelevant stimuli were above 80%. The behavioural accuracy of 8 correctly classified subjects was compared with the 4 classified otherwise (3 Indeterminates and one false positive). The median behavioural accuracy of the correctly classified group (*Med* = 94.6%) was seemingly higher than those classified otherwise (*Med* = 80.3%). However, the Mann-Whitney U test[1] showed that these differences were not significant, $U = 8.00$, $p = .214$. In addition, the ratio of discarded trials due to artefacts was compared between these two groups. The 'otherwise classified' group had a significantly smaller median for analysed trials (*Med* = 67.5%) than the correctly classified group (*Med* = 90.8%). These differences were significant, $U = 2.00$, $p = .016$, showing that the otherwise classified subjects had a larger ratio of discarded trials than the correctly classified group.

[1]The Mann-Whitney U non-parametric test was used in this and the next analysis since the dependent variable did not meet the assumption of normality.

7.4 Discussion

In this study, BFP was used to determine the presence or absence of concealed knowledge in 12 parolees. This was the first study to have tested convicted criminals on their own crime incidents, rather than suspects or convicted criminals claiming innocence (e.g., Farwell et al., 2013), using a forensic brainwave analysis tool.

This study has demonstrated that BFP testing is independently reproducible with high accuracy in a non-field context. However, these findings do not validate the claims of 100% accuracy made by BFP proponents. One IA subject (possessing no knowledge of the incident on which they were tested), C11, was falsely determined IP_C (classified as possessing knowledge of the incident). This subject was cooperative, had high behavioural accuracy (i.e., was appropriately concentrating and correctly performing behavioural recognition of the probe, target, and irrelevant stimuli), and met all 20SS. Furthermore, the same misclassification was repeated when C11, still as an IA, was tested on a second crime incident. Further enquiries confirmed that this subject had not been aware of these incidents. These findings are inconsistent with previous BFP research (Farwell et al., 2013; Farwell et al., 2014; Farwell & Smith, 2001; Farwell & Donchin, 1991) which reported zero false positives of BFP, and constitute one of the first documented instance of BFP misclassification. Thereofre, Hypothesis-4 was not supported. The study also resulted in three Indeterminate classifications – that have not been reported in the former BFP studies that used P300-MERMER (Farwell et al., 2013; Farwell et al., 2014; Farwell & Smith, 2001).

It is notable that none of the former BFP studies (Farwell et al., 2013; Farwell et al., 2014; Farwell & Smith, 2001; Farwell & Donchin, 1991) reported subjects unable to satisfactorily complete the BFP test. However, this study had three such subjects, all of whom could not complete BFP due to inability to control excessive blinking and/or physical jitteriness. This is important as it reveals that some people are simply unable to satisfactorily meet the requirements of the BFP test.

Optimal signal conditioning is very important in ERP studies. Thus, poor/noisy EEG from some of these subjects is likely to be the cause of at least some of the unexpected classifications. A particularly striking example of this is Subject C11 in this study. Notwithstanding, it is difficult to explain why he was not classified as Indeterminate, nor how such aberrant-looking ERPs could be gained in 3 separate BFP tests from a subject who was so compliant and had no problem with excessive blinking or keeping still.

Evidence shows that the prison population has a higher rate of substance abuse and a higher likelihood of having sustained a traumatic brain injury than that of the general population. Based on figures from National Institute on Drug Abuse (2020), 65% of the United States prison population have substance-use disorder, compared to the much smaller 6% in the general population (Thomas, 2020). Similarly, the traumatic brain injury prevalence is 10–38% in the general population of the United States, while it is 25–87% in prisoners (Im et al., 2014). The traumatic brain injury prevalence is even lower in New Zealand's general population (<1%), while it has been reported as high as 88% in the prison population based on some estimates (Lambie, 2020). Since substance abuse and traumatic brain injury lead to neurocognitive disorders (American Psychiatric Association, 2013), the higher prevalence of these in prisoners means that they are more susceptible to neurocognitive disorders resulting in reduced cognitive efficiency and concentration, cognitive impairment, inability to pay attention, and decline in ability to perform usual cognitive activities (American Psychiatric Association, 2013; Durand et al., 2017; Ziino & Ponsford, 2006). One could argue that declined cognitive performance may have resulted in three Indeterminate and one false positive classifications in the present study. However, there is no objective evidence to support or reject such a claim. It is recommended that any future studies on BFP with prison populations should take these into account and use objective measures to quantify differences in substance abuse and traumatic brain injury in their subjects.

With relatively convincing results from this independent study, it was deemed necessary to address an important critique of opponents of BFP in terms of countermeasures (Bergström et al., 2013; Funicelli et al., 2021; Hu et al., 2015; Rosenfeld et al., 2004). They argued that similar to other P300-based measures, BFP must have been susceptible to behavioural, as well as cognitive countermeasures. Farwell et al. (2013), on the other hand, dismissed these statements as non-substantiated since the opponents of BFP did not have access to BFP and did not follow the required 20SS. Study-4 (BFP-Countermeasures) was designed as the first step in this process, to examine cognitive countermeasures in BFP.

Chapter 8

Study-4: BFP-Countermeasures

8.1 Introduction

Study-4 (BFP-Countermeasures) was designed to examine whether direct-suppression or thought-substitution could render Brain Fingerprinting (BFP) ineffective in revealing concealed knowledge. University students were the target participants. BFP-Countermeasures consisted of two experiments: Experiment-1 and Experiment-2. In Experiment-1, 16 subjects were interviewed and their corresponding real-life BFP tests were developed and tested. Additional 16 control subjects were recruited to function as ground-truth IA. This experiment coupled with BFP-Parolees would reveal individual differences between the use of BFP as an information detection tool for parolees vs. general population. It was hypothesised that the ground-truth Information Present (IP) subjects would be classified as IP_C and that the ground-truth Information Absent (IA) subjects would be classified as IA_C by the BFP system (see Section 4.5 for a refresher).

In Experiment-2, half of the IP subjects of Experiment-1 (now verified as IP_C) were randomly assigned to direct-suppression and the other half were assigned to thought-substitution conditions, and the BFP test was repeated. In the direct-suppression condition, subjects were instructed to suppress (No-Think manipulation) the incident in question when reading the short descriptions before the block and during the whole block. In the thought-substitution condition, subjects were instructed to think about a different unrelated real-life incident when reading the short descriptions before the block and during the block. According to Bergström et al. (2013) and Hu et al. (2015), these manipulations would render BFP ineffective (i.e., subjects would be less likely to be correctly classified as IP_C). However, as mentioned earlier, BFP deals with real-life incidents and follows the 20SS, while Bergström et al. (2013) and Hu et al. (2015) used fabricated incidents and did not adhere to the 20SS advocated by Farwell et al. (2013). Hence, it was hypothesised that despite using direct-suppression or thought-substitution countermeasures, all subjects in Experiment-2 would again be classified as IP_C (Section 4.5).

8.2 Method

8.2.1 Participants

A total of $n = 36$ subjects, 12 males and 24 females aged from 18 to 52 ($M = 22.7$, $SD = 6.0$), were recruited in this study. Due to withdrawals and exclusions, explained in Results, BFP findings from $n = 31$ of them are reported in BFP-Countermeasures. They were students at the University of Canterbury and were recruited through advertisements on social media and posters around the campus. Five subjects were excluded for various reasons (detailed in Results). The only exclusion criterion was a history of traumatic head injury. All subjects volunteered to participate. They were informed about the experimental procedure many days in advance and those who agreed to participate, also completed a consent form. Each subject received a shopping mall gift card as gratuity for their participation. The study was approved by the Human Ethics Committee of the University of Canterbury (HEC 2020/12). The Materials and Apparatus of this study were identical to BFP-Parolees (Section 7.2.2), so are not repeated in this chapter.

8.2.2 Design

In Experiment-1, the ground-truth of a subject (IP versus IA) was the between-subjects independent variable and the stimulus type (probe versus target versus irrelevant) was the within-subjects independent variable. The event-related potential (ERP) response leading to a BFP classification (IP_C, IA_C, or Indeterminate) was the dependent variable. In Experiment-2, the countermeasure condition (direct-suppression versus thought-substitution) was the between-subjects independent variable and the stimulus type (probe versus target versus irrelevant) was the within-subjects independent variable.

Initially, 32 subjects were recruited for Experiment-1. Sixteen were randomly chosen and interviewed about a memorable life incident for the ground-truth IP condition. It was ensured that the incident involved them and no one else in the participation pool. A BFP test for each of these incidents was produced (resulting in 16 BFP tests) and the aim was for each test to be used on the associated ground-truth IP subject and on one ground-truth IA subject. Five subjects were excluded for various reasons and four of these were replaced with new subjects (detailed in Results 8.3.1).

All interviews and test development were completed by the project leader and a tester, both previously trained and certified by Dr Farwell. Each BFP test was conducted by one of two other testers who were not aware of the ground-truth status of their subjects. The testing was strictly monitored by the project leader to ensure that the BFP testing manual and 20SS were adhered to.

8.2.3 Stimuli

Subjects were interviewed about a memorable incident of their life, cued with when, what, how, where, and why questions so they could recount enough details for the test. They recalled positive, fun, emotional incidents, or when they had a minor brush with the law, as they were assured that the tests and results would be anonymous. The incidents narrated by subjects included an academic trip, overseas and local travel, parties, a police chase, a boating incident, etc.

For each incident, a set of stimuli was formed inclusive of 6 probes, 6 targets, and 24 irrelevants according to the 20SS (Farwell et al., 2013). Probes and targets were formed from the information that would be perceived as substantial by a subject who participated or was present during the incident. Irrelevant stimuli were fabricated (2 for each probe and 2 for each target), which were unrelated to the incident in question but equally plausible (see Appendix J for a sample set). The rest of the stimuli development process was similar to BFP-Parolees (see Section 7.2.4).

8.2.4 Procedure

Experiment-1

The interviews were conducted via Zoom and the testing was completed on the University of Canterbury campus. The tests were carried out usually within a week after interviews, and were created in accordance with the 20SS. Each BFP test was made up of 6 probes, 6 targets, and 24 irrelevants. These were divided into two sets (Set 1 and Set 2) each containing 3 probes, 3 targets, and 12 irrelevants (refer to Appendix J).

Similar to BFP-Parolees, each stimulus was presented at least 20 times over 10 blocks (cf. 16 blocks in BFP-Parolees), resulting in up to 120 probe, 120 target, and 480 irrelevant trials. If any trials were rejected due to artefacts such as blinking or excessive head movement, replacements were automatically added. The rest of the procedure and BFP testing was also similar to BFP-Parolees (Sections 7.2.5), except that a more conservative criterion amplitude >200 μV in the Fp1 channel was used for eye blink artefact detection (cf. >400 μV in BFP-Parolees) and subjects were tested within a week of their interviews. Experiment-2 dealt with countermeasures and had a slightly different procedure as below.

Experiment-2

Experiment-2 was conducted on the 16 subjects who were confirmed as IP_C in Experiment-1. It was similar to Experiment-1 except: Prior to presenting and reading aloud the block instructions, the 8 subjects in the direct-suppression group were verbally instructed to not think about the incident in question while looking at and hearing the descriptions, and during the block. It was emphasized that they should try their best to pay attention to the stimuli on the screen, and press the corresponding correct button on the Xbox controller, while actively suppressing the event in question when they read the stimuli, but not by replacing the event in question with any other event or episodic memory. The rest of the experimental procedure was similar to BFP-Countermeasures Experiment-1 as well as BFP-Parolees (Section 7.2.5).

For the 8 subjects in the thought-substitution group, the tester elicited and discussed with them another memorable incident (Event 2) in the subject's life and this was noted. Event 2 was given a specific name that ensured that the subject recognised it when referred to during the experiment. Prior to presenting and reading aloud the block instructions, the subjects were verbally instructed to substitute thinking of Event 1 (i.e., the name of their original incident in Experiment-1) to thinking about Event 2 (i.e., the alternative incident) while looking at and hearing the descriptions, and during the block. It was emphasized that they should try to complete the experiment exactly as before while actively substituting thinking about Event 1 to thinking about Event 2 during the task. Following this, the block of stimuli was presented. After the experiment was concluded, the subjects received their vouchers and were debriefed. The data analysis of BFP-Countermeasures was similar to BFP-Parolees (Section 7.2.5).

8.3 Results

8.3.1 Exclusions

One subject's (S32) data were lost due to a software malfunction. Two subjects (S12 and S27) withdrew during Experiment-1 due to uncontrollable excessive eye-blinking leading to eye fatigue. Three new replacement subjects, S33, S13, and S28 were recruited. However, S28 also had excessive eye-blinking and was excluded. Another subject's (S35) test was determined to be invalid as their behavioral accuracy did not reach the minimum requirement of 80%. Upon further enquiry after the test, they reported being preoccupied with an upcoming job interview. This subject was then replaced by S36. Although the aim was to replace any excluded subjects, S28 was unable to be replaced due to the Covid-19 pandemic restrictions and the available time frame. This resulted in 31 subjects, rather than the desired 32 for 16 tested incidents (see Table 8.1 for details). All remaining subjects met the behavioural accuracy criterion (>80%).

8.3.2 Experiment-1 findings

As displayed in Table 8.1, of the 16 IP subjects, 15 were correctly classified as IP_C, with a mean bootstrapping probability of 93.8%. One subject (S24) was Indeterminate, with a bootstrapping probability of 88.3%. Of the 15 IA subjects, 14 were correctly classified as IA_C, with a mean bootstrapping probability of 93.3%. One IA subject (S30) was misclassified as IP_C with a bootstrapping probability of 98.5%. As a result, the classification accuracy was 96.8%. See Figures 8.1, 8.2, 8.3 and 8.4 for example ERPs for an IP_C (S03), an IA_C (S04), the Indeterminate (S24), and the false-positive (S30), respectively. The rest of ERPs are in Appendix K.

Table 8.1: Summary results of 16 scenarios in Experiment-1

Subject ID	Incident	Ground-truth	BFP determination	Bootstrapping probability (%)
S01	School Contest	IP	IP_C	99.0
S02		IA	IA_C	98.4
S03	Canada Trip	IP	IP_C	99.9
S04		IA	IA_C	99.9
S05	Insect Repellent	IP	IP_C	97.0
S06		IA	IA_C	78.3
S07	Sustainability Prize	IP	IP_C	99.9
S08		IA	IA_C	99.9
S09	Police Car	IP	IP_C	99.9
S10		IA	IA_C	77.3
S11	Bush Fire	IP	IP_C	99.9
S12		IA	Withdrew due to eye fatigue	
S13		IA	IA_C	98.8
S14	Sea Witch	IP	IP_C	99.9
S15		IA	IA_C	99.9
S16	Trip to Queenstown	IP	IP_C	99.6
S17		IA	IA_C	98.6
S18	Street Signs	IP	IP_C	99.9
S19		IA	IA_C	99.6
S20	12 Pubs of Xmas	IP	IP_C	96.3
S21		IA	IA_C	99.4
S22	Motion Sickness	IP	IP_C	99.9
S23		IA	IA_C	90.7

Continued on next page

Table 8.1 – continued from previous page

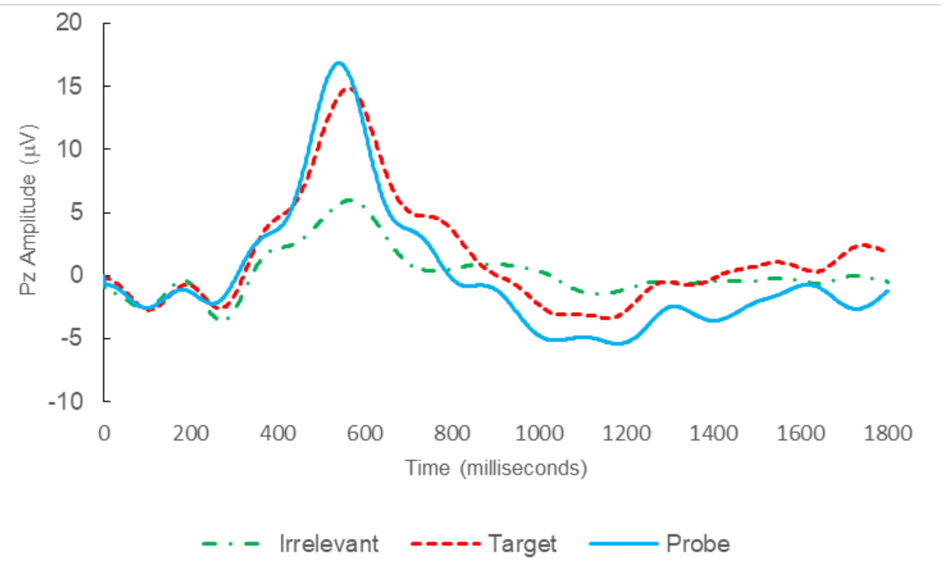
Subject ID	Incident	Ground-truth	BFP determination	Bootstrapping probability (%)
S24	Horse Riding	IP	IND[a]	88.3
S25		IA	IA_C	97.6
S26	House Party	IP	IP_C	99.3
S27		IA	Withdrew due to eye fatigue	
S28		IA	Withdrew due to eye fatigue	
S29	Bad Mosquitoes	IP	IP_C	93.7
S30		IA	IP_C[b]	98.5
S31	Representing UC	IP	IP_C	96.4
S32		IA	Data loss	
S33		IA	IA_C	99.7
S34	Trip to Vietnam	IP	IP_C	92.8
S35		IA	Invalid test	
S36		IA	IA_C	86.9

BFP = Brain Fingerprinting, IP = Ground-truth Information Present, IP_C = Classified as Information Present, IA = Ground-truth Information Absent, IA_C = Classified as Information Absent, IND = Classified as Indeterminate.

[a] Blue font shows an Indeterminate classification.

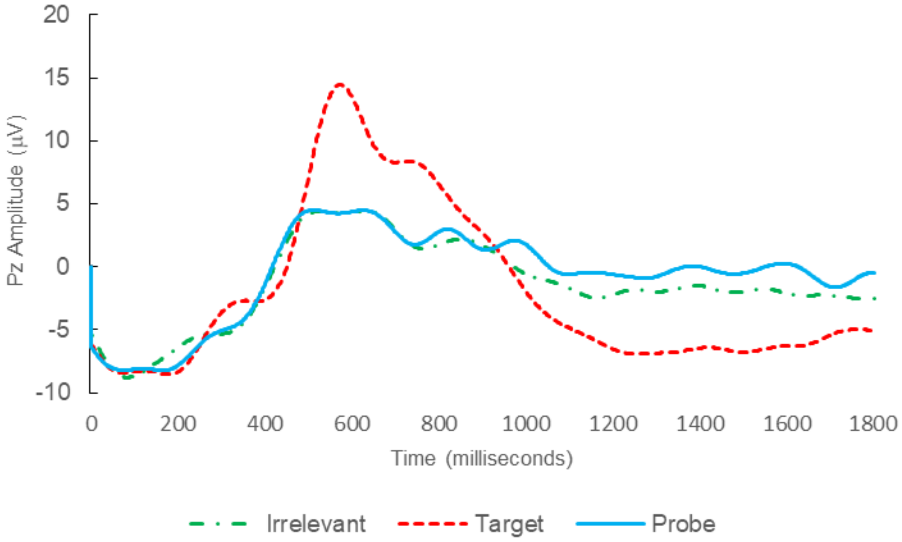
[b] Red font shows a false positive classification.

Figure 8.1: BFP Response Waveforms of S03 in "Canada Trip", Experiment-1 (IP→IP_C)



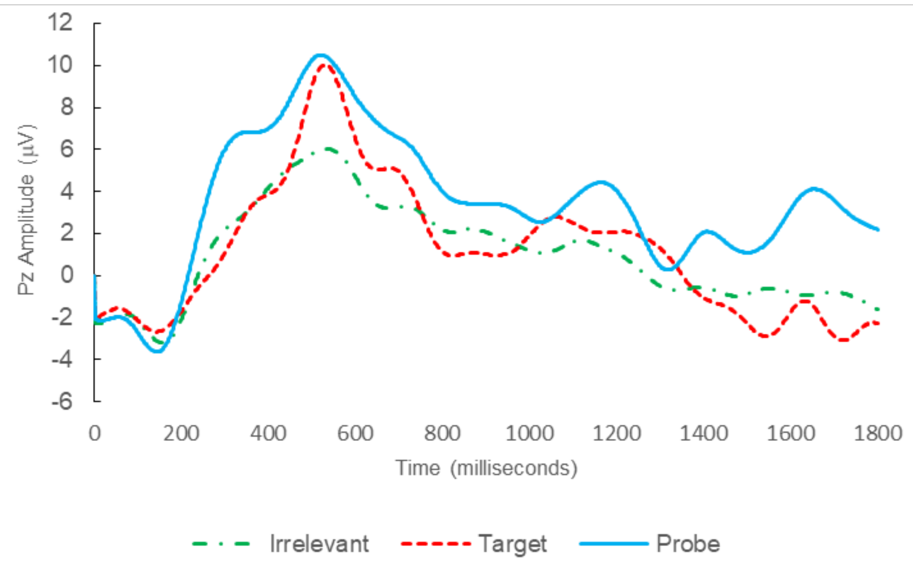
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information-Present.

Figure 8.2: BFP Response Waveforms of S04 in "Canada Trip" Experiment-1 (IA→IA_C)



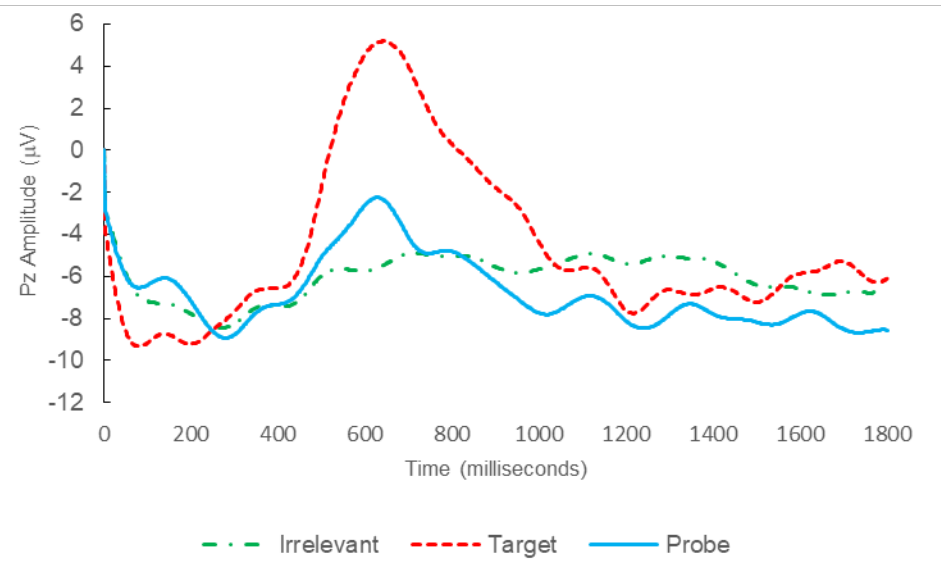
BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent. IA_C = Classified as Information-Absent.

Figure 8.3: BFP Response Waveforms of S24 in "Horse Riding" Experiment-1 (IP→Indeterminate)



BFP = Brain Fingerprinting. IP = Ground-truth Information-Present.

Figure 8.4: BFP Response Waveforms of S30 in "Bad Mosquitoes" Experiment-1 (IA→IP_C)



BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent, IP_C = Classified as Information-Present.

8.3.3 Experiment-2 findings

All IP subjects in Experiment-1 were randomly assigned to either direct-suppression or thought-substitution conditions and were re-tested. As Table 8.2 shows, none of these manipulations were successful at decreasing the BFP bootstrapping probability to less than 90%, which would otherwise be an Indeterminate or a false negative classification. The average bootstrapping probability of IP determination was 98.9%. Notably, the previously Indeterminate subject (S24) was correctly classified as IP_C. Therefore, Hypotheses-5b and 5c are supported, confirming that memory-suppression and thought-substitution countermeasures are ineffective against BFP.

Table 8.2: Summary results of Experiment-2 versus Experiment-1

Subject ID	Incident	Experiments	BFP determination	Bootstrapping probability (%)	Condition
S01	School Contest	Experiment-1	IP_C	99.0	
		Experiment-2	IP_C	99.5	Substitution
S03	Canada Trip	Experiment-1	IP_C	99.9	
		Experiment-2	IP_C	99.9	Substitution

Continued on next page

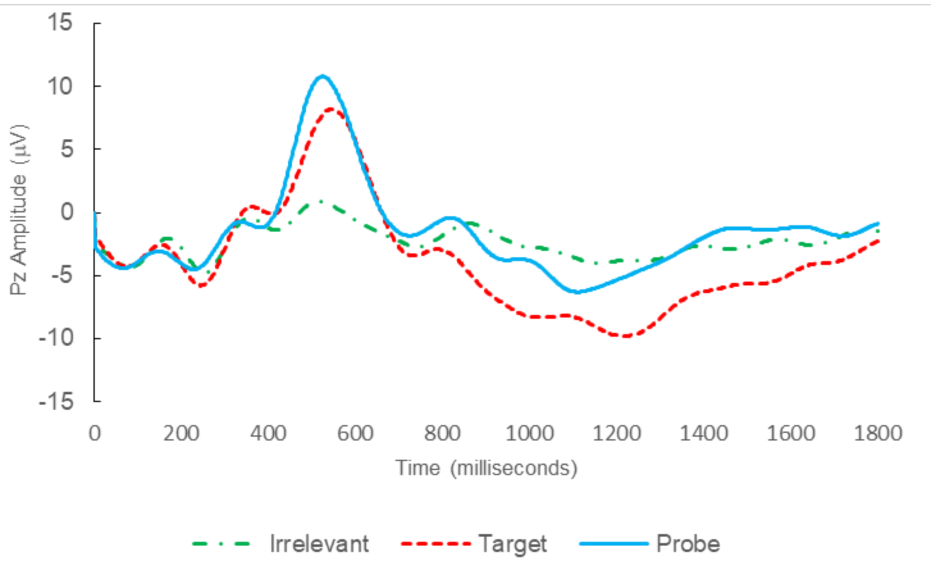
Table 8.2 – continued from previous page

Subject ID	Incident	Experiments	BFP determination	Bootstrapping probability (%)	Condition
S05	Insect Repellent	Experiment-1	IP_C	97.0	
		Experiment-2	IP_C	94.5	Suppression
S07	Sustainability Prize	Experiment-1	IP_C	99.9	
		Experiment-2	IP_C	99.9	Suppression
S09	Police Car	Experiment-1	IP_C	99.9	
		Experiment-2	IP_C	99.8	Substitution
S11	Bush Fire	Experiment-1	IP_C	99.9	
		Experiment-2	IP_C	99.9	Suppression
S14	Sea Witch	Experiment-1	IP_C	99.9	
		Experiment-2	IP_C	99.9	Suppression
S16	Trip to Queenstown	Experiment-1	IP_C	99.6	
		Experiment-2	IP_C	99.9	Suppression
S18	Street Signs	Experiment-1	IP_C	99.9	
		Experiment-2	IP_C	99.9	Suppression
S20	12 Pubs of Xmas	Experiment-1	IP_C	96.3	
		Experiment-2	IP_C	99.8	Substitution
S22	Motion Sickness	Experiment-1	IP_C	99.9	
		Experiment-2	IP_C	99.9	Substitution
S24	Horse Riding	Experiment-1	IND[a]	88.3	
		Experiment-2	IP_C	96.7	Substitution
S26	House Party	Experiment-1	IP_C	99.3	
		Experiment-2	IP_C	99.9	Substitution
S29	Bad Mosquitoes	Experiment-1	IP_C	93.7	
		Experiment-2	IP_C	99.9	Suppression
S31	Representing UC	Experiment-1	IP_C	96.4	
		Experiment-2	IP_C	92.8	Suppression
S34	Trip to Vietnam	Experiment-1	IP_C	92.8	
		Experiment-2	IP_C	99.9	Substitution

BFP = Brain Fingerprinting. IP = Ground-truth Information Present. IP_C = Classified as Information Present. IND = Classified as Indeterminate.
[a] Blue font shows an Indeterminate classification.

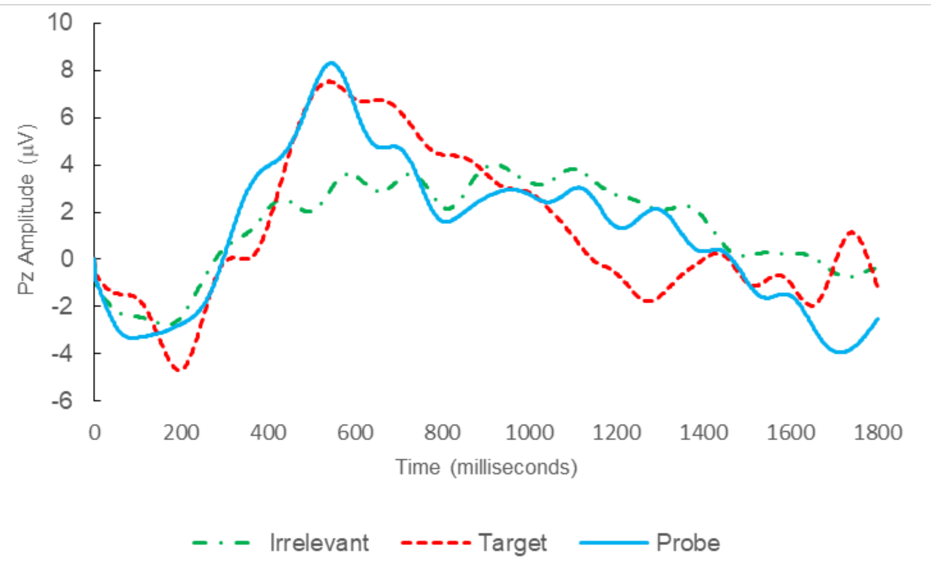
Figures 8.5 and 8.6 show examples of BFP waveforms for S03 and S24. The rest of ERPs are in Appendix K.

Figure 8.5: BFP Response Waveforms of S03 in "Canada Trip", Experiment-2 (IP→IP_C→IP_C)



BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information Present.

Figure 8.6: BFP Response Waveforms of S24 in "Horse Riding", Experiment-2 (IP→IND→IP_C)



BFP = Brain Fingerprinting. IND = Classified as Indeterminate, IP_C = Classified as Information-Present.

8.4 Discussion

This study aimed to examine the effects of potential countermeasures on the standard BFP test. It was the first study to have employed a modification of the Think/No-Think (T/NT) paradigm, as well as thought-substitution with BFP. The thought-substitution manipulattion used in this study was identical to that reported by Benoit and Anderson (2012), asking subjects to retrieve a previously learned alternative memory (Event 2) during manipulation. In addition, this study aimed to test the accuracy of BFP on classifying IP and IA subjects.

In Experiment-1, the BFP system correctly identified 15 IP subjects and 14 IA subjects, with one false positive and one IP with an Indeterminate designation. Despite having a high classification accuracy, BFP did not produce 100% accurate classifications as claimed in previous articles (Farwell, 2009, 2012; Farwell & Makeig, 2019; Farwell et al., 2013; Farwell & Smith, 2001). Therefore, Hypothesis-5a was not supported. These findings, however, are consistent with BFP-Parolees that reported a false positive classification in BFP and three Indeterminates. A distinction should be made that Indeterminates in BFP-Parolees (C10, C15, and C16) were originally ground-truth IA, whereas that of BFP-Countermeasures (S24) was a ground-truth IP.

In Experiment-2, neither direct-suppression nor thought-substitution was effective as a countermeasure against BFP. In addition, the previously Indeterminate (S24) was correctly classified as IP_C in Experiment-2, despite the thought-substitution manipulation. These findings support Farwell's claims that BFP is resistant to cognitive countermeasures (Farwell et al., 2013; Farwell & Richardson, 2013), confirming Hypotheses-5b and Hypotheses-5c. This indicates that the studies that have revealed susceptibility of ERP-based Forensic Brainwave Analysis techniques, such as Bergström et al. (2013) and Hu et al. (2015), should not be generalized to BFP.

It should be noted that the false-positive subject in Experiment-1 (S30) was compliant, had followed instructions, met all BFP Scientific Standards, and showed a high level of behavioral accuracy. The tester confirmed that the subject had not been made aware of the incident in question. On the other hand, the Indeterminate (S24) reported that they were sensitive to the blue colour (the screen background colour during BFP trials). However, since they were correctly classified as IP_C in Experiment-2, this probably indicates that this subject had become so skilled in BFP as they were participating for the second time (in Experiment-2) that offset the effects of the countermeasure manipulation. This is further supported by multiple reports from the rest of the subjects who found BFP relatively easier and more effortless in Experiment-2 than their previous participation in Experiment-1. Another possibility could be overcoming sensitivity of S24 to the blue colour, but that would not explain why countermeasures were not generally effective Experiment-2.

Participating in 10 extra blocks due to participating in Experiment-1 could be considered a possible limitation due to prior practice or the probes having been imprinted more deeply into episodic memory. A future study to replicate Experiment-2 (with countermeasures) without subjects having participated in a prior Experiment-1 would shed light on this possibility.

An important discovery in BFP-Countermeasures was the presence of student subjects who could not complete the BFP test. There were three such subjects who withdrew due to eye fatigue and could not complete the test, showing a similar pattern to BFP-Parolees. As noted in the previous chapter, none of the former BFP studies (Farwell et al., 2013; Farwell et al., 2014; Farwell & Smith, 2001; Farwell & Donchin, 1991) reported subjects who could not satisfactorily complete the test. With this being so, the conjecture from the previous chapter stands that there might be some subjects who cannot complete the BFP test regardless of their background and history (parolees versus university students).

There are some other important distinctions to be made between BFP and other forensic brainwave analysis studies. Except for Farwell and Donchin (1991), all subsequent BFP studies developed critical stimuli from real-life incidents. By contrast, Bergström et al. (2013), Hu et al. (2015), and Rosenfeld et al. (2008) used mock-crime simulated scenarios in their forensic brainwave analysis endeavors. As it stands, the incidents in question are real for BFP studies and fabricated for other P300-based forensic brainwave analysis methods. In addition, as elaborated in the present Method section, before each block of the BFP test, subjects were reminded of the incident by way of short descriptions of the upcoming stimuli during the block. These short descriptions play a crucial role, for if a subject knows the incident by way of participating in it, these short descriptions remind them of that incident and they elicit

P300-MERMER responses to the probe stimuli, as well as the target stimuli, resulting in an IP_C categorization. On the other hand, since an IA subject does not know the incident, the short descriptions only remind them of the target stimuli that they know from common knowledge or have explicitly been made aware of. Consequently, they elicit P300-MERMER responses to the target stimuli only, resulting in an IA_C classification. These differences could potentially explain the failed countermeasure endeavour in the current study. A possible explanation is that the No-Think manipulation only works well when the information is newly learned (as it is in the classic T/NT task), and not when the information is more personal and based on salient real-life situations. This would effectively mean that the countermeasures would not work no matter how much effort a subject applied in suppressing the incident in question or substituting a different incident. Nonetheless, Noreen and MacLeod (2013) as well as Noreen et al. (2016) reported suppression effect due to No-think manipulation in real-life autobiographical memories too. With this being the case, the only viable explanation for failed countermeasure effect is the mechanistic and algorithmic strength of the BFP technique compared to other forensic brainwave analysis approaches.

Therefore, the current study indicates that so long as 20SS are adhered to, BFP is resistant to direct-suppression and thought-substitution countermeasures. These cognitive manipulations were not effective in concealing the information that BFP successfully revealed.

Chapter 9

Discussion

9.1 General Think/No-Think Discussion

The first main aim of this project was to examine potential differences in suppressing unwanted memories with Think/No-Think (T/NT) between individuals who scored high (Hi) or low (Lo) on psychological traits of obsessive-compulsive disorder (OCD) and post-traumatic stress disorder (PTSD). This was investigated in two studies. In Study-1 (T/NT-Extension), it was attempted to find out if a smaller frequency of suppression trials could result in a suppression effect due to the No-Think manipulation. In Study-2 (T/NT-Traits), university subjects were screened with Yale-Brown Obsessive Compulsive Scale (YBOCS) (Goodman et al., 1989) and PTSD CheckList - Civilian Version (PCLC) (Weathers et al., 1993). Once Hi and Lo groups were identified, they went through a similar process as T/NT-Extension subjects.

The T/NT-Extension study did not provide statistically significant evidence of the suppression effect. However, a suppression effect was confirmed by the T/NT-Traits study (with combined trait scores that had around twice as many subjects). This shows that the No-Think suppression effect can be achieved with a smaller frequency of trials, as long as there is a sufficient sample size. These findings contrast with Anderson and Green (2001), Depue et al. (2007), and Hulbert et al. (2016) who reported a suppression effect with $n = 24$ or fewer subjects, whereas $n = 24$ was perhaps not a sufficient sample size to demonstrate a significant suppression effect based on the current findings. Nonetheless, these findings confirm that the No-Think suppression effect can be replicated with the use of direct-suppression (employed in T/NT-Extension and T/NT-Traits) to actively suppress unwanted memories, resulting in a declined recall following the No-Think manipulation. The significant suppression effect in T/NT-Traits also strengthens previous findings (Anderson & Hanslmayr, 2014; Benoit & Anderson, 2012; Depue et al., 2007; Hulbert et al., 2016; Levy & Anderson, 2008) that such an active memory suppression is potentially utilising the cognitive control regions in the dorsolateral prefrontal cortex, as well as inhibiting the hippocampus.

The significant No-Think suppression effect in T/NT-Traits is consistent with the theoretical basis of the T/NT paradigm. Rather than relying on passive mechanisms of forgetting, such as decay over time or interference from cluttering of many similar events in memory (R. Allen & Baddeley, 2009; Anderson, 2003; Anderson & Hanslmayr, 2014), an active and motivated approach of forgetting, No-Think suppression, was successfully employed. This approach stopped the habitual act of *saying the response* to a stimulus, referred to as retrieval suppression (Anderson & Hanslmayr, 2014). This act of retrieval suppression is considered a voluntary form of the Freudian defence mechanism, repression (Anderson, 2003; Anderson & Green, 2001; Freud, 1966), and can also be effective as an emotion regulation technique (Engen & Anderson, 2018). Finally, the effect of No-Think suppression did not differ due to same cue testing versus independent cue testing.

No-Think suppression manipulation took place immediately after cue-response memorisation in the current studies. Perhaps this enhanced the likelihood of obtaining the suppression effect in the T/NT-Traits study. Evidence from former studies show a robust suppression effect immediately after manipulation with a longevity of the effect up to 24 hours post-manipulation (Hulbert et al., 2016; MacLeod & Macrae, 2001).

Many previous studies failed to produce behavioural evidence of No-Think suppression (Bergström et al., 2007; Bulevich et al., 2006; Hertel & Calcaterra, 2005; Hertel & Mahan, 2008; Mecklinger et al., 2009; Wessel et al., 2020) despite some of them being suggestive of this effect on a neurophysiological level (Bergström et al., 2007; Mecklinger et al., 2009). Importantly, three of these studies (Bergström et al., 2007; Bulevich et al., 2006; Mecklinger et al., 2009) used 16 repetitions of Think and No-Think trials during manipulation phase. Two studies that used

12 repetitions (Hertel & Calcaterra, 2005; Hertel & Mahan, 2008) could not produce behavioural evidence of a significant suppression effect despite having a larger sample size than T/NT-Traits. A study that did use smaller repetitions (e.g., 5 and 10) (Depue et al., 2006), was suggestive of higher suppression effect for 10 repetitions than 5, but used a slightly different analysis protocol and stimuli. Benoit and Anderson (2012) used 12 repetitions, and reported a significant suppression effect, but that study was not independent of Anderson. Therefore, T/NT-Traits is the first *independent* study reporting *behavioural* evidence of No-Think suppression effect with 12 repetitions, with an experimental protocol identical with Anderson's studies, using cue-response *word* pairs.

Requiring a larger sample size to produce a suppression effect is not necessarily a major disadvantage. Some previous studies, such as MacLeod and Macrae (2001), also used larger subject pool to demonstrate a retrieval suppression effect. A recent study recruited more more than 400 subjects and used 16 repetitions reporting a suppression effect with the T/NT paradigm (Liu et al., 2021). Importantly, being able to produce a No-Think effect with fewer repetitions means that subjects would not find the manipulation phase, which takes the most effort, as lengthy and arduous. With 12 repetitions (48 s suppression time per word), each of the four blocks in the T/NT manipulation (Phase 2) takes about 7.5 min. This will increase to about 10 min with 16 repetitions (64 s suppression time per word), requiring further consistent suppression efforts.

Notably, the decrease in recall of No-Think items in combined trait scores with 12 repetitions (4.85% in combined-YBOCS and 5.50% in combined-PCLC) was not substantially less than 6% - 8% reported in meta-analyses (Levy & Anderson, 2008; Stramaccia et al., 2021). Interestingly, with Lo YBOCS and Lo PCLC, the decrease in recall of No-Think items was 6.40% and 7.08%, respectively — being more comparable with previously reported decreases in recall of No-Think items (Levy & Anderson, 2008; Stramaccia et al., 2021). This is informative, as it reveals that Lo scorers with 12 repetitions behaved similar to previous T/NT studies in terms of decrease in recall with No-Think suppression.

An important aspect of T/NT-Extension and T/NT-Traits was the evaluation and potential applicability of the executive deficit hypothesis. According to this account, subjects with varied executive control abilities might demonstrate relatively varied degrees of suppression capability with No-Think suppression such that those with higher levels of executive deficit would demonstrate less suppression ability and vice versa (Küpper et al., 2014; Levy & Anderson, 2008). Evidence shows that both OCD and PTSD involve impaired executive control abilities (Anderson et al., 2004; Bannon et al., 2008; Depue et al., 2007; Gagnepain et al., 2014; Menzies et al., 2008; Remijnse et al., 2006). Therefore, Hi and Lo trait groups (Hi YBOCS, Hi PCLC, Lo YBOCS, and Lo PCLC) were identified and recruited for T/NT-Traits. It was expected that Hi scorers, in accordance with the executive deficit hypothesis, would demonstrate impaired No-Think suppression effect. On the other hand, Lo scorers were expected to show a robust suppression effect.

When analysed separately, both Lo trait groups showed a robust suppression effect and No-Think items had significantly lesser recall (Lo YBOCS: 6.40% and Lo PCLC: 7.08%). Hi Trait scorers, on the other hand, demonstrated a non-significant decrease in the recall of No-Think items. Their recall also showed a relatively smaller difference with Baseline compared to Lo trait scorers (3.30% in Hi YBOCS and 3.93% in Hi PCLC). Albeit, a direct comparison between the Lo and Hi trait groups did not reveal a significant suppression impairment in Hi scorers compared to Lo scorers based on the Mann-Whitney U tests. Therefore, there are no objective findings revealing a significant impairment of suppression in Hi scorers compared to Lo scorers, as posited by the executive deficit hypothesis. This perhaps means that Hi scorers who are not diagnosed with OCD or PTSD might not have an overall significant suppression deficit. If we consider these findings *suggestive* of discrepancy between Lo vs Hi trait scorers, then the suppression effect in Lo scorers would be consistent with Anderson and Green (2001) as well as the predictions based on the executive deficit hypothesis (Levy & Anderson, 2008). In addition, the diminished and non-significant suppression capability in Hi scorers would be consistent with the executive deficit hypothesis (Levy & Anderson, 2008) and with previous research involving memory suppression in OCD and PTSD (Benoit & Anderson, 2012; Catarino et al., 2015; Engen & Anderson, 2018; Janeck & Calamari, 1999; Streb et al., 2016; Sullivan et al., 2019; Tolin et al., 2002). Findings pertaining to PTSD would also be suggestive of impaired memory suppression with non-emotional neutral cue-response pairs. Therefore, the impaired memory suppression effect revealed in the previous studies with PTSD or PTSD-prone persons

(Catarino et al., 2015; Depue et al., 2007; Streb et al., 2016) would not necessarily be due to their use of emotion-provoking stimuli. In other words, subjects that resembled diagnosed PTSD persons would show an impaired suppression ability regardless of the emotion-provoking nature of the stimuli. This means, it would be the PTSD that makes them unable to suppress memories and not the stimuli used in the test.

With a closer look at the suppression scores (No-Think minus Baseline) of Hi scorers, it turned out that a variability within the group also existed. Hi scorers were divided into two smaller groups: *Inferior Hi scorers* and *Extreme Hi scorers*. Inferior Hi scorers in Hi YBOCS had a YBOCS score of 22 or lower. Those who scored 23 or higher on YBOCS were put in the Extreme Hi YBOCS subgroup. Inferior Hi scorers in Hi PCLC had a PCLC score of 67 or lower. Those who scored 68 or above were put in the Extreme Hi PCLC subgroup. The Inferior Hi scorers, whose trait scores were closer to Lo groups, had an average suppression score much closer to Lo groups (6.52% in YBOCS and 7.22% in PCLC). On the other hand, Extreme Hi scorers had average suppression scores much further from Lo scorers (1.48% in YBOCS and -.87% in PCLC). This reveals that extreme Hi scorers in fact showed a poorer suppression effect. That effect, however, was offset by Inferior Hi scorers, resulting in a non-significant difference between the suppression scores of Hi versus Lo groups. The impairment of Extreme Hi scorers cannot be confirmed by statistical testing due to a small sample size. However, this revelation can be used as a working hypothesis for the future studies. In order to substantially reveal differences between the suppression capability of Lo versus Hi trait scorers, a much larger pool of subjects should be screened by YBOCS and PCLC (at least twice as many subjects as T/NT-Traits) with the new cut-off values revealed from T/NT-Traits (23 for Hi YBOCS and 68 for Hi PCLC). This would lead to identifying a larger pool of extreme Hi scorers who would potentially show a poor suppression effect, significantly different from Lo scorers. Moreover, Extreme Hi scorers might be closer to the border of actual OCD and PTSD diagnoses.

If the above can be accepted as a working hypothesis, further supported by a close replication with a larger sample size in the future, it can be considered as suggestive preliminary evidence of the executive deficit hypothesis based on T/NT-Traits (Anderson & Hanslmayr, 2014; Anderson et al., 2004; Benoit & Anderson, 2012; Catarino et al., 2015; Depue et al., 2007; Gagnepain et al., 2014; Levy & Anderson, 2008). A significant impaired suppression in Extreme Hi scorers would be further consistent with Depue et al. (2007) highlighting that scoring low on OCD and PTSD scales is more likely to show a suppression effect than scoring high on these traits. Such an outcome would also be consistent with former studies revealing less ability of No-Think suppression in trauma-exposed subjects (Sullivan et al., 2019) and impairment of inhibitory control and deficient memory suppression in PTSD (Catarino et al., 2015). Furthermore, such findings would confirm suppositions by Anderson and Green (2001) that T/NT uses executive control systems of the brain, supported by impaired suppression capability in the Extreme Hi YBOCS group.

Based on the mentioned explanations, besides being a practical paradigm that is used to test active memory suppression in the laboratory, T/NT might usefully be employed to help some persons suffering from OCD or PTSD. It was revealed earlier that Inferior Hi scorers on YBOCS and PCLC had relatively high suppression scores (No-Think minus Baseline). In addition, based on their scores, the Inferior Hi scorers fit in to *Severe* OCD (in the case of YBOCS) and *High Severity* PTSD (in the case of PCLC) according to the cut-off values recommended in the corresponding scales (see Table 6.1). Therefore, although T/NT might not be useful for the Extreme Hi trait scorers, based on preliminary findings from T/NT-Traits, the Inferior Hi trait scorers could use it to suppress disturbing unwanted memories. There are three important findings from previous research that support this notion. Firstly, the No-Think suppression effect is dose-dependent. In other words, the suppression effect results in relatively more forgetting as a factor of an increasing number of active suppression efforts (Anderson & Green, 2001; Anderson & Hanslmayr, 2014; Hulbert et al., 2016). Secondly, those with higher suppression ability could potentially have fewer intrusive thoughts by successfully down regulating them (Streb et al., 2016). Inferior Hi scorers in T/NT-Traits showed better suppression ability compared to Extreme Hi scorers as evidenced by 6.52% and 7.22% suppression scores for Inferior Hi YBOCS and Inferior Hi PCLC, respectively. Thirdly, even if there were intrusions of unwanted memories, they could decline with increased frequency of suppression attempts (Levy & Anderson, 2012). With evidence of the suppression effect capable of continuing for up to 24 hours, for those with *Severe* OCD or *High Severity* PTSD might, with enough suppression attempts, be able to suppress unwanted memories. It is acknowledged that these suggestions are speculations based on the evidence from T/NT-Traits. Unless these findings are replicated, the above claims could not be made with certainty. A future study recruiting subjects based on the cut-off values for Inferior Hi scorers would probe the efficacy of No-Think suppression further.

A plausible reason for the absence of a suppression effect in the Hi groups might be the nature of the stimuli. As noted in the literature review, all studies examining T/NT in PTSD subjects (Catarino et al., 2015; Depue et al., 2007; Streb et al., 2016; Sullivan et al., 2019) used emotionally-valenced stimuli. In the current studies with neutral stimuli, an impaired suppression effect was not detected. It might be that the subjects who are prone to generalised anxiety (e.g., PTSD and OCD) would only show impaired suppression capability if emotionally valenced stimuli are used in the T/NT task. This possibility shall be tested in the future studies.

Applying No-Think exercises could theoretically also be used for any other conditions that need exerting cognitive control over emotionally distressing memories (Depue et al., 2007). However, any such claims need to be substantiated with research. One might also use T/NT to overcome regular upsetting memories[1].

An interesting finding regarding the No-Think manipulation was no significant interaction between the types of testing (same-cue and independent-cue). This means whether one used same-cue or independent-cue testing, the outcome of No-Think suppression is likely to be similar. These findings can guide the future research in terms of simplicity. In other words, one might use either same-cue or independent-cue test type, being confident the effect of No-Think suppression would, regardless, be the same.

T/NT-Extension and T/NT-Traits uncovered an important distinction between the Think effect due to same-cue versus independent-cue test type that has that has rarely been reported in the previous research. With same-cue testing, there was seemingly some facilitation effect. However, with independent-cue testing, a decrease in recall of Think trials was witnessed. This effect was noticed in T/NT-Extension and it was further replicated in T/NT-Traits. Lambert et al. (2010) is one of the rare previous studies that reported a similar effect. There may be at least three explanations for this phenomenon:

[1] I myself benefitted from active suppression of unwanted memories post 15 March shootings in Christchurch. I continuously used retrieval suppression to achieve this. I witnessed the dose-dependent effect of it on a daily basis. In the long-term, many of my Muslim friends developed PTSD. I was not only immune from this, but I could also help others.

The first explanation could be that the same-cue testing of Think manipulation benefits from the rehearsal of Think items during Phase 2, more so than in independent-cue testing. As Lambert et al. (2010) posited too, Tulving's encoding specificity principle could be the mechanistic underpinning of this discrepancy. According to this account, the Think manipulation strengthens the relationship between cue and response, leading to better recollection with the same-cue testing. However, since such a strengthening could not happen, by design, between the independent cue and response, a facilitation effect cannot be witnessed (Tulving, 1979). To elaborate, in independent-cue testing, a subject is asked to come up with an alternative response during the final recall rather than the initial one that was learned in Phase 1 and rehearsed in Phase 2. They are only exposed to the independent-cue test at the beginning of Phase 3 with 9 filler words. On the other hand, in same-cue test, a subject is asked to say the response that was learned in Phase 1 and rehearsed 12 times in Phase 2. As a result, responses to the Think cues might have been more readily accessible during the recall phase (Phase 3) — which is not the case for the independent-cue testing. It can be claimed with high confidence that same-cue testing benefits substantially from Phase 2 of the T/NT test, and therefore, demonstrates an increase in recall for Think items, but the independent-cue testing does not.

The second explanation relates to a cognitive bias known as functional fixedness (Duncker, 1945; Welling, 2011) — that prevents a subject from coming up with another way of solving a problem. In Phase 1 of T/NT, a subject is presented 2 to 3 times with a cue-response pair, required to think about and remember the response word. In Phase 2, this association is reinforced 12 times more for Think cue-response pairs. In Phase 3 (recall), since the same-cue testing is similar to cue-response presentations in the previous phases, there is no decrease in recall. Independent-cue test, on the other hand, requires subjects to come up with an alternative solution — guessing a word based on a different type of association. As an effect of functional fixedness, the subject might be prevented from coming up with responses based on these associations, resulting in a reduced recall during independent-cue testing. This phenomenon would not occur with No-Think cues because their responses are suppressed during the No-Think manipulation which would potentially prevent against functional fixedness. This explanation, if found substantive, together with differences in functional magnetic resonance imaging (fMRI), would indicate that same-cue and independent-cue tests employ different mechanisms in the brain when it comes to the Think manipulation. Functional fixedness also reinforces the explanation in the previous paragraph regarding different retrieval mechanisms for same-cue and independent-cue tests. Interestingly, Anderson and Green (2001) demonstrated a similar discrepancy between 8 versus 16 repetitions (that equally counterbalanced items for 8 and 16 repetitions between subjects). However, it was not elaborated on. Considering the Think manipulation and independent-cue testing in Figure 1 in Anderson and Green (2001), there is a slight decrease in recall for 16 repetitions compared to 8 in Experiment 1, similar recall in Experiment 2 between 8 and 16 repetitions, but again, in Experiment 3, there is a decline in recall for 16 repetitions compared to 8. When averaged across experiments, the Think manipulation produces an increasing recall trend with same-cue test from 8 repetitions to 16, but a decline in recall with independent-cue test from 8 repetitions to 16. This might be suggestive of the effects of rehearsal (those in 16 repetitions were more rehearsed, hence benefit to same-cue test) and functional fixendess (more rehearsal fixed subjects on the rehearsed response only). Therefore, it may be argued that Tulving's encoding specificity principle and functional fixedness function synonymous with each other during Phase 2 of T/NT, resulting in discrepancy between same-cue and independent-cue testing outcomes due to Think manipulation.

Both these explanations could be examined further in future behavioural as well as fMRI T/NT studies. Subjects could be asked to report, after each independent-cue testing instance, as to what they were thinking when they saw the alternative cues in Phase 3. It is not uncommon in T/NT studies to ask subjects to report subjectively during the T/NT experiment. For instance, Levy and Anderson (2012) required subjects to report intrusions of response items during No-Think suppression.

The third explanation could be borrowed from retrieval-induced forgetting (Anderson et al., 1994). In retrieval-induced forgetting, subjects memorize six items within the same category (e.g., six fruits within the FRUIT category) in Phase 1. In a later phase, there is retrieval practice on only three of the fruit items. The main idea underlying retrieval-induced forgetting is that while subjects are retrieving the three target fruits, there is automatic competition from the three non-target fruits, and the brain handles this competition by suppressing the three competing non-target fruits. As a consequence, the three non-target fruits are remembered less often than Baseline concepts (i.e., the initially learned items in a category that did not undergo any retrieval practice in the latter phase). It is also known from retrieval-induced forgetting experiments that if a word like (STRAWBERRY) is one of the initially learned fruits, but not one of the retrieval practiced words, that not only does it undergo suppression/forgetting, but also a word like (BLOOD), because of their shared colour. It is as if the inhibition spreads to related concepts (Anderson et al., 1994).

In the independent-cue testing, when subjects are asked to Think about the response word (e.g., ROACH) to the cue word (ORDEAL), there would also be automatic competition from words related to the response word for the reason stated above. The brain would suppress competing related words during each Think trial. For instance, the related word (INSECT) might occasionally be inhibited due to its unconscious competition with the related word (ROACH), while thinking about (ROACH) during the Think phase. The consequence of this would be that if at the time of recall, a subject is given, for example, (INSECT – R), it might be particularly difficult to use the hint word (INSECT) to get at the target word (ROACH). In any case, further findings in this line of research would potentially reveal mechanisms employed by same-cue versus independent-cue test during the Think manipulation and would help posit new explanatory hypotheses.

The T/NT-Traits study had several novel aspects that contribute to theoretical implications. It was the first independent T/NT behavioural study to show that No-Think suppression can be achieved with a reduced frequency of repetitions. This pattern was repeated twice and was consistent in YBOCS and PCLC groups. It was the first study to provide preliminary evidence of relatively lower recall of No-Think items in Lo YBOCS and Lo PCLC scorers, compared to Hi scorers, respectively. However, it is acknowledged that the direct comparison between Lo and Hi scorers did not show that the recall of No-Think items was significantly different between Lo and Hi groups. Future studies with larger sample sizes could help verify that there is a genuine difference in the recall of No-Think items between Lo and Hi scorers on these traits. Interestingly, it was the second behavioural study to have replicated a pattern of different Think manipulation results as a consequence of same-cue versus independent-cue testing.

9.2 General Brain Fingerprinting Discussion

The second main aim of this project was to examine potential differences in employing Brain Fingerprinting (BFP) as an information detection tool in parolees versus non-parolees. This was achieved by Study-3 (BFP-Parolees) and Experiment-1 of Study-4 (BFP-Countermeasures). In BFP-Parolees, the accuracy of BFP in detecting crime-related information was examined in parolees. In BFP-Countermeasures Experiment-1, a similar examination was repeated for university students, with the distinction that the real-life incidents of students did not necessarily constitute criminal offences. Some of the BFP-Countermeasures subjects narrated incidents that involved minor brushes with the law. However, there were no associated resultant consequences or convictions.

The third main aim of this project was to test the resistance of BFP against direct-suppression and thought-substitution cognitive countermeasures. BFP-Countermeasures Experiment-2 contributed to this aim. Previously classified Information Present (possessing incident-related information) subjects employed either direct-suppression or though-substitution against BFP. BFP-Parolees and BFP-Countermeasures comprise the second and third independent replication evaluations of BFP. The first independent replication of BFP being Study-1 in Afzali et al. (2022) as cited in the Preface section of the current dissertation. Study-1 of Afzali et al. (2022) resulted in all correct classifications, but also a false positive — a pattern also seen in BFP-Parolees and BFP-Countermeasures Experiment-1 of the current dissertation. Another important role of BFP-Countermeasures was to provide a unifying thread for this dissertation. The dissertation focused on two seemingly distinct areas – memory suppression with T/NT and detecting concealed knowledge with BFP. BFP-Countermeasures used a modification of T/NT as a potential countermeasure in BFP, solidifying the connection between cognitive psychology and forensic neuroscience.

Results from BFP-Parolees and BFP-Countermeasures Experiment-1 confirm that the event-related potential (ERP)-based tool, BFP can achieve high accuracy when P300-MERMER (the P300 + late negative potential) are analysed. Farwell and colleagues have shown that analysing the P300-MERMER epoch (300 - 1800 ms post-stimulus) resulted in a higher accuracy, higher boostrapping probability, and zero Indeterminates in ERP-based knowledge detection tests (Farwell et al., 2013; Farwell et al., 2014; Farwell & Smith, 2001). Conversely, BFP research analysing the P300 only resulted in some Indeterminates, although with similar classification accuracy (Farwell & Donchin, 1991). Studies comparing the two types of analyses (P300 versus P300-MERMER) resulted in a 100% classification accuracy for both types (Farwell et al., 2013).

Both BFP-Parolees and BFP-Countermeasures Experiment-1 analysing the entire P300-MERMER epoch resulted in one false positive in each of these, three Indeterminates (originally ground-truth Information Absent (IA)) in BFP-Parolees, and one Indeterminate (originally ground-truth Information Present (IP)) in BFP-Countermeasures Experiment-1. These findings demonstrate that accurate detection of concealed information by Brain Fingerprinting can be achieved, subject to adherence to the 20SS. However, they contradict previous claims of 100% accurate classification by Farwell (Farwell et al., 2013; Farwell et al., 2014; Farwell & Smith, 2001; Farwell & Donchin, 1991) who reported zero false positives in all BFP studies. These findings also do not support claims from previous studies that BFP produces no Indeterminates (Farwell, 2009, 2012; Farwell & Makeig, 2019; Farwell et al., 2013). Notwithstanding, these studies, including the present study, support claims that BFP produces no false negatives.

There is a notable difference between the former BFP research and the current three replications (BFP-Parolees, BFP-Countermeasures Experiment-1, and Study-1 in Afzali et al. (2022)) in terms of Indeterminate classifications. It would appear that this reflects differences between the study cohorts used in previous studies (mostly subjects from general population) versus parolees, although whether this, in turn, is a reflection of time in prison, personality, life-style, genetic, or other differences is unknown. However, this could not explain the presence of Indeterminate classifications in BFP-Countermeasures Experiment-1 (S24: originally ground-truth Information Present). It was not only parolees who resulted in Indeterminates, and also it was not only ground-truth IA subjects. Notably, S24 did report being sensitive to the background colour during their first BFP test, but was later correctly classified as IP_C in BFP-Countermeasures Experiment-2.

The behavioural accuracies were similar between correctly classified subjects and those classified otherwise (Indeterminate + false positive). This was expected as those with lower behavioural accuracies would be excluded based on >80% criterion. However, another important finding *only* in BFP-Parolees was that the correctly classified subjects had fewer discarded trials than other subjects. As reported in the Results section of BFP-Parolees, a significantly smaller number of trials were fit for analyses (not discarded due to artefacts) for those who were Indeterminate or incorrectly classified. This finding may be substantial for future refining of the BFP software such that a criterion (e.g., >80%) could be set for analysed trials. This being said, if less than 80% trials are acceptable in the first two blocks (>20% rejected due to artefacts), those subjects should be declared unfit for BFP.

None of the previous BFP studies reported subjects who could not satisfactorily complete the BFP test. Yet, BFP-Parolees and BFP-Countermeasures Experiment-1 identified three subjects each, who could not complete the BFP test due to excessive, uncontrolled eye blinking. It needs to be emphasised that BFP does not necessarily work for each person. Reasons behind inability to complete BFP are out of the scope of this dissertation as the research team had come across such findings for the first ever time. Carefully designed future BFP studies that collect data on cognitive and personality aspects of test subjects might help explore this mystery further. Nonetheless, it should be added to the conclusions that despite completing the BFP test, a ratio of subjects might not be able to be determined at all (i.e., Indeterminate) or might be wrongly classified (e.g., false positive). Importantly, following up with the solution provided in the previous paragraph regarding exclusion of subjects based on discarded trials, the same solution may apply here. This is because the excessive eye blinking caused many discarded trials in the first few blocks, which discouraged subjects from participating until the end. Based on the >80% rule for analysed trials, they would be declared unfit for BFP.

BFP-Parolees and BFP-Countermeasures Experiment-1 show that although BFP has a high classification accuracy compared to other Forensic Brainwave Analysis techniques, its current accuracy is not 100%. Notwithstanding, this is not considered a major flaw. Iacono (2008) pointed out that that Guilty Knowledge Tests have a false positive rate of 2–5%. It has also been established that, even when administered properly, psychophysiological memory detection techniques can result in false positives. Nevertheless, the scientific community values ERP-based guilt detection tests more highly than autonomic guilt detection measures (Iacono, 2008) such as the polygraph. In addition, to address to second main aim of this project, it could be claimed that except for a larger ratio of Indeterminates in parolees, there are no other distinct individual differences in BFP findings between parolees and non-parolees.

There is another dimension in the testing of parolees. It might be considered that there is little value in determining the presence of information in criminals who have already confessed, completed their time in prison, and for which there are no further consequences. This is recognized, but as BFP has not been established as a robust forensic tool, this population was chosen due to their possessing many of the sociopathological, psychopathological, life-style, and other characteristic traits of the suspects and criminals for whom forensic brainwave analysis will be a primary target.

BFP-Countermeasures Experiment-2 was the first of its kind of cognitive neuroscience study: using a modification of T/NT, as well as thought-substitution as potential countermeasures in BFP. Although opponents of BFP (Bergström et al., 2009; Hu et al., 2015) claimed that BFP would be susceptible to countermeasures, BFP-Countermeasures Experiment-2 showed otherwise. This study also re-classified the previous Indeterminate subject (S24) correctly as IP_C despite the countermeasure.

BFP-Countermeasures Experiment-2 highlights an inherent strength of the BFP protocol. As detailed in Chapter 8, the use of real-life incidents, that are more personal and salient to the ground-truth Information Present subjects, could render cognitive countermeasures ineffective. In addition, strict adherence to 20SS may make BFP more resistant to countermeasures compared to the studies conducted by Bergström et al. (2009) and Hu et al. (2015). An example of this is having to modify the No-Think suppression to *direct-suppression* in T/NT-Countermeasures Experiment-2 (as discussed in Section 3.2). This might have made BFP resistant to the employed countermeasures. In addition, the required behavioural response of pressing a specific button for each stimulus ensures that a subject does pay attention to and reads a stimulus — that would elicit a P300-MERMER response if salient. Finally, requiring subjects to sit quietly, and look at the screen and not to blink are also important deterrents of deception. Unless a subject wants to come across deceptive, when behavioural response is required, BFP would often reveal the presence of concealed knowledge, despite using the cognitive countermeasures employed in BFP-Countermeasures. Notwithstanding, it is also possible that *repeatedly* employing direct-suppression along with thought-substitution might result in a stronger suppression effect as theorised by Engen and Anderson (2018). Such a possibility shall be tested in the future studies.

9.2.1 Legal implications of the Brain Fingerprinting Research

In the lab testing, the tester had the advantage of knowing the ground-truth condition of a subject. More importantly, an IP_C classification in a lab does not carry legal and/or criminal consequences. However, in the field setting, it is impossible for the examiners to know the ground-truth, so it would be unknown if an IP_C is a ground-truth IP or IA. For instance, an IP_C classification might potentially result from police corruption (giving information about the crime incident to a suspect). This is why the testing should not be conducted by the police in the first instance.

When a person is being tested for a crime with the BFP system, they are suspects and generally, there are further police records and history to corroborate their stories. Therefore, it is important to corroborate their test results with their previous records. In case the tester is suspicious of a subject's IP_C status, which is virtually impossible, it is important to not let the police participate in the test, and not to publicise or comment to the police of the outcome of the testing. Such subjects should ideally not be called Indeterminates either. Instead, they should be called "untestable". Finally, it is important to upgrade the system so the classification accuracy could be improved and the chance of false positive outcomes could be decreased.

The relationship between the BFP procedure and suspect's right to silence: According to the New Zealand Bill of Rights Act 1990 (Parliamentary Council Office, 2013), a suspect has the right to remain silent and, importantly, they shall be informed of this right (Section 23). According to Section 21, "Everyone has the right to be secure against unreasonable search or seizure, whether of the person, property, or correspondence or otherwise." Primarily, police would need a warrant to "search" information in a subject's brain as subjects are presumed innocent until they are proven guilty (Section 25). Therefore, even if all other suspects are classified as IA_C the last subject cannot be coerced to take the test unless they volunteer (Section 25). In general, BFP must meet the minimum standards of criminal procedure (Section 25). According to Section 27, a subject has right to justice and fair treatment. This cannot be overridden as of now unless the law changes. When it comes to admissibility in the court, a good example of this might be the phenomenon of "Function Creep", that is, if BFP is allowed to be used for other purposes (e.g., employment checks), and that check leads to a crime-detection, the subject cannot be prosecuted based on that evidence. Finally, subjects' rights are protected under the Privacy Act 2020 (Parliamentary Council Office, 2022) too.

9.2.2 Ethical considerations of the Brain Fingerprinting Research

Based on the American Psychological Association guidelines, the Institutional Review Boards (Human Research Ethics Committee) must be consulted with to ensure that the ethical guidelines are complied with. In addition, the research/experiment participants must be fully informed about the procedure and any physical or psychological risk involved, and be given a chance to ask further questions. An informed consent must be sought, subjects must be not deceived, and they must be debriefed post-experiment. Subjects of some cultures wear head-covering (e.g., Muslim women and people of Sikh religion). They must be explicitly informed that they can refuse to participate in BFP testing if they do not want their head-covering removed, without any legal consequences. In addition, all subjects must be informed that they can withdraw from participating at any stage without facing any legal consequences. The data obtained from subjects must be kept confidential and any data made available to the public must not include any identifying information. In addition, the ethical standards laid out by the American Psychological Association (American Psychological Association, 2022) must be observed.

With the above in mind, the BFP researchers have an added layer of responsibilities so the technology would not be used breaching any of the ethical standards noted above. The BFP testers are supposed to be trained academics with background and experience in research who would ideally follow the ethical guidelines and ensure the integrity of the process.

Chapter 10

Conclusions and Future Research

10.1 The Think/No-Think (T/NT) studies

10.1.1 Summary and Key findings

T/NT-Extension and T/NT-Traits were two independent studies that used university students to examine the capacity to suppress unwanted memories in psychological traits of obsessive-compulsive disorder (OCD) and post-traumatic stress disorder (PTSD). For T/NT-Traits, a large pool of subjects was screened with Yale-Brown Obsessive Compulsive Scale (YBOCS) and PTSD CheckList - Civilian Version (PCLC) and those who scored at high (Hi) and low (Lo) extremes were recruited for the experiment. The inclusion criteria for Hi and Lo groups were decided based on z scores as well as devised cut-off values of both scales (Goodman et al., 1989; Weathers et al., 1993).

In T/NT-Extension, it was hypothesised that 12 repetitions of the No-Think manipulation would result in a suppression effect. This hypothesis was not supported. However, T/NT-Extension highlighted differences between same-cue testing and independent-cue testing with the Think manipulation. These findings prompted T/NT-Traits that probed further Hi versus Lo OCD and PTSD trait scorers in terms of No-Think memory suppression and Think performance.

For T/NT-Traits, it was hypothesised that Hi scorers would show an impaired suppression capability relative to Lo scorers in both YBOCS and PCLC groups. In this study, a significant suppression effect was found with 12 repetitions, but only when Hi and Lo scorer data were combined, yielding a larger sample size than the T/NT-Extension study. In addition, T/NT-Traits presented preliminary evidence suggestive of Lo scorers having a relatively more robust suppression capability than Hi scorers, but not objectively consistent with the *executive deficit hypothesis*. Despite the non-significant difference between suppression capabilities of Hi and Lo scorers, further exploration showed that those who scored higher in the Hi groups perhaps had some level of suppression impairment that was offset by other Hi scorers at the lower end of the Hi trait scores. These findings are suggestive of some level of individual differences in memory suppression capability between Hi and Lo scorers. However, the hypotheses were not supported and further replications by independent labs are required for confirmation.

T/NT-Traits further established that the Think manipulation resulted in opposing outcomes, with same-cue testing showing a facilitation effect and independent-cue testing showing a decrease in recall. These discrepancies were speculated to be a result of functional fixedness hampering recall in during the independent-cue testing, while same-cue rehearsal, combined with same cue recall, benefitted the same-cue testing. Two other plausible explanations, the encoding specificity principle (Tulving, 1979) and the effects of retrieval-induced forgetting (Anderson et al., 1994) were also elaborated on.

Finding a suppression effect with 12 repetitions is informative as it may lead to developing more efficient T/NT protocols in terms of experimental subject's experience, as they would find it more effortless and less arduous at the manipulation phase. However, the fact that these findings were based on the combined pool of Hi and Lo scorers (larger sample size) makes it less efficient for researchers. Therefore, for researchers who may have delimited time constraints for conducting T/NT sessions, but no limitation on available subjects, it would be expedient to use the 12 trial T/NT paradigm. By contrast, researchers who do not have time constraints for conducting individual T/NT sessions, but do have limitations on subject availability, the 16 trial T/NT paradigm would be more expedient. These conclusions are based on only two experiments within the same lab that have not been replicated yet. Future studies should address this by recruiting about $n = 48$ subjects without differentiating between Hi and Lo scorers. If such a study replicates a suppression effect with 12 repetitions, then the findings of the current study will be substantiated.

A potential strength of the T/NT paradigm used in the current project is its instructions and robust protocol. In addition, the detailed experimental instructions and the training by the MRC Cognition and Brain Sciences Unit enables successful replication. More specifically, the use of *diagnostic* questionnaire during manipulation and *post-experimental* questionnaire to avoid deception, besides ensuring sufficient sleep the night before testing, are potentially very important procedural strategies ensuring subject compliance and no fatigue – that perhaps failed previous independent replications.

However, it should be acknowledged that unless one has access to fairly robust experimental protocol and well-defined procedure, they might have more difficulty replicating the suppression effect. It is because the suppression effect is small, as T/NT-Traits show, that might be nullified due to procedural confounds.

10.1.2 Critique

These studies used a predominantly younger population, mostly female, university students who might overall have better executive control abilities and, therefore, better suppression capability, according to Levy and Anderson (2008). In the light of this, the presence of suppression capability with 12 repetitions (48 s worth of suppression per word) should not be generalised to older adults who often possess impaired executive control abilities as cited in Levy and Anderson (2008). Future studies could usefully recruit older subjects to clarify this further.

Another limitation of the T/NT-Traits study was the process of recruiting Hi versus Lo trait scorers. It was $n = 367$ subjects from whom these groups were recruited. In addition, a combination of recommended cut-off as well as z scores were used to differentiate Hi and Lo scorers. It could be argued that Hi scorers were not necessarily deficient in executive function as they were not diagnosed with either of disorders. This is further supported by the differences in No-Think recall within Hi scorers.

Therefore, this project would have benefited if more subjects with a score of 23 or higher on YBOCS and 68 or higher on PCLC were recruited. Their suppression capability might be significantly poorer than Lo scorers. In addition, these purported differences could be further displayed if clinically diagnosed OCD and PTSD subjects were recruited. Notably, Abramowitz et al. (2014) did not favour recruiting clinically diagnosed subjects (e.g., to test memory suppression in OCD and PTSD), as the results based on such a sample could be confounded due to types, effects, and duration of treatment. On the other hand, unless clinically diagnosed subject are examined directly, generalisation of T/NT-Traits on them may be considered inappropriate.

10.1.3 Future Directions

The exclusion criteria for T/NT studies were an attention-deficit hyperactivity disorder (ADHD) diagnosis and colour blindness. However, it has not been quantified as to what level of ADHD impairs a subject's participation in the T/NT experiment. With a high incidence of ADHD in general and in young adults (ADHD New Zealand, 2022), that constitute a majority of university students, it would be inappropriate to exclude all of them from participation. Future studies should quantify this by recruiting subjects who report ADHD symptoms or diagnosis. Their scores on an ADHD measure should be collected. Based on their performance in the T/NT experiment, a cut-off should be decided for future participation. This way, some subjects who could satisfactorily complete T/NT would not be unnecessarily excluded.

In terms of colour blindness, perhaps a different strategy could be used. For instance, instead of using blue, green, and red colours, different type faces such as bold, italic and underline might be used. This would help future researchers not to exclude any subjects with colour blindness.

In addition, the T/NT research should further continue to discover nuances and objective differences between subjects who score low, medium, and high on psychological scales, and those who are diagnosed with psychological disorders such as OCD, PTSD, ADHD, etc., using neutral, as well as, emotionally-valenced stimuli. The findings from No-Think memory suppression could usefully be employed to suppress and try to forget unwanted memories in some of these subjects.

10.2 The Brain Fingerprinting (BFP) studies

10.2.1 Summary and key findings

BFP-Parolees and BFP-Countermeasures were two independent studies that used parolees and university students to assess the accuracy and validity of Brain Fingerprinting (BFP). It was hypothesised that BFP would accurately classify those with concealed knowledge of real-life incidents (crime or otherwise) and those with no knowledge thereof with a 100% accuracy. Both studies demonstrated high accuracy of BFP in revealing concealed knowledge in a laboratory context with P300-MERMER epoch (300 - 1800 ms post-stimulus) and close adherence to BFP Scientific Standards. However, with a false positive and three Indeterminates in the BFP-Parolees, and a false positive and one Indeterminate in BFP-Countermeasures Experiment-1, these findings did not confirm the 100% classification accuracy reported in prior BFP research by Farwell. Therefore, the hypotheses were not supported. These studies also contribute to some of the first documented false positive and Indeterminate classifications of BFP. Notwithstanding, it is important to note that there were no false negatives.

BFP-Countermeasures Experiment-2 assessed the resistance of BFP to the modified direct-suppression and thought-substitution manipulations. It was hypothesised that neither of these countermeasures would render BFP ineffective. This hypothesis was confirmed since previously classified Information Present subjects in BFP-Countermeasures Experiment-1 were re-classified as Information Present despite the countermeasures. Therefore, the resistance of BFP to countermeasures was verified in the present studies, and can be considered a strength of the technique.

In addition, these studies also identified that BFP is not a viable test for everyone, especially persons unable to suppress excessive eye-blinking. Further investigation using forensic contexts would lend more clarity regarding the accuracy and applicability of BFP testing. Overall, it is concluded that BFP is not yet at a stage at which it can be used as a robust and completely accurate crime-detection tool. However, it is suggested that forensic brainwave research should continue in order to address the problems identified in these studies, as BFP has considerable potential to replace autonomic and other conventional crime detection techniques and provides an important addition to the armamentarium of current forensic technologies. The current state of BFP can be considered a weakness due to Indeterminates and those who cannot satisfactorily complete the test. However, this weakness could be addressed (see Future Directions below).

10.2.2 Critique

A limitation in BFP-Parolees was that, following subject withdrawals and exclusions, the number of subjects was less and there was a substantial imbalance between the 2 ground-truth Information Present subjects and the 10 ground-truth Information Absent subjects. However, it must be emphasised that, unlike previous BFP studies, the subjects in this study were real-life convicted criminals. It was challenging to find and recruit parolees with dangerous crime histories who were willing to participate in tests on their own crime incidents and be compliant with experimental protocols. Such an imbalance does not exist in BFP-Countermeasures.

Another limitation of BFP-Parolees was a low ecological validity due to the reasons mentioned above. Since the primary application target of BFP is the forensic field, it is necessary to conduct further studies that address difficulties encountered with testing parolees and setting objective measure to distinguish between subjects who can be satisfactorily tested with BFP and those who cannot. Despite these difficulties, this study should be considered an important step towards determining the efficacy, limitations, and potential of BFP in the forensic field.

A limitation in BFP-Countermeasures Experiment-2 was that each subject participated twice in the BFP test: once in Experiment-1 and an extra 10 blocks comprising Experiment-2. One could argue that this might have led to inefficacy of cognitive countermeasures. This could have also led to S24 (classified as Indeterminate in Experiment-1) being classified as IP_C in Experiment-2. To explore this further, future studies should conduct an experiment identical to Study-4 Experiment-2 without doing the Experiment-1.

Former BFP studies, including Farwell et al. (2013), promised incentive to their subjects in case they could render the BFP ineffective, or they were motivated because of facing legal consequences due to criminal offences. It could be considered a limitation that subjects in the present studies did not have such strong motivations. However, the fact that the subjects were happy to volunteer to participate shows that they were motivated to participate and follow the instructions. Provision of further motivation to subjects will be considered in future studies. Notwithstanding, in real-world forensic applications, BFP's classification needs to be independent of a subject's level of motivation; achievement of an acceptable level of behavioural accuracy should be all that is required for BFP accuracy to be valid.

It must be emphasised that the current studies were conducted with a test protocol which is critically different to that needed in real-world application of Forensic Brainwave Analysis. In the latter crime-detection setting, information would be gathered from a crime scene and the critical stimuli formulated based on that (i.e., not narrated to the testers by a subject). This also means that the information confirmation procedure would not be needed or valid in a real-life setting. Once the BFP test stimuli and questions are developed, all suspects are examined and BFP determinations of their Information Present, Information Absent, or Indeterminate statuses are made. Notwithstanding, the stories told to the testers by study subjects were corroborated with the police records (in BFP-Parolees) to ensure the accuracy of incidents. These were real-crime incidents but the procedure was kept similar with the standard BFP procedure. Real-life crime-detection testing using information directly from the crime scene or the criminal crime records could be conducted in the future once the current BFP protocol is well established and the previously-mentioned limitations are addressed. Despite reasonable logic and need for the use of information confirmation, it is possible that this procedure might reinforce original memories in IP subjects and increase their chance of IP_C determination in a biased fashion. Therefore, it is recommended that this procedure should usefully be avoided in future BFP studies. Finally, a limitation of the current BFP system is its adaptability with the current neuroscientific standards of publication as posited by Keil et al. (2014). The BFP software does not provide data on baseline correction, eye-movement correction, correction for amplifier drift, flatlining, pre-stimulus activity, etc.

10.2.3 Future Directions

Primarily, the BFP system should be improved to provide data on baseline correction, eye-movement correction, correction for amplifier drift, flatlining, pre-stimulus activity, etc. This would help BFP to stand out as a modern FBA system. In addition, an *a priori* criterion, such as >80%, should be set for the ratio of analysed trials as a factor of presented trials. Therefore, if a subjects shows >20% discarded trials (<80% accepted trials) in the first and second BFP blocks, they should be excluded. Adding this criterion would effectively detect subjects who are inappropriate for BFP testing and classify them as Indeterminate.

Once an improved system as described above is developed, the ecological validity issue of BFP-Parolees can be addressed. With the use of behavioural accuracy as well as analysed trials criteria (both requiring >80%), those who cannot participate in BFP could be determined earlier — that would save time and effort of BFP testers. Then, in carefully designed experiments, a subject pool more representative of BFP's primary application target in the forensic field (i.e., crime suspects and persons convicted but maintaining their claim of innocence) would be tested.

In addition, improvements to BFP could also be investigated in terms of setting criteria which must be met for BFP classifications to be considered valid, such as (i) behavioural accuracy in each block and (ii) averaged ERP waveform requirements (e.g., magnitude of P300-MERMER for target stimuli). Implementing these would increase number of Indeterminates but potentially achieve zero false positive and zero false negative classifications.

At this stage, it is also unclear if false negatives will continue to be zero in the field setting. Further research is needed to determine this. Further research should also be conducted on brain injury, psychological disorders, and drug use in relation with BFP to determine what types of subjects could be more prone to false negative/positive classifications. In addition, there is a need to examine reasons behind false positive classifications, to replicate the Parolee's study with a larger sample, to test the technology without the *information confirmation* step, to conduct a study under direct observation of Dr Farwell, and to consider the EEG publication standards devised by Keil et al. (2014).

To sum up, there is still a long way to go before BFP might possibly be accepted in court proceedings. This would include (i) substantial validation in the field, (ii) critical improvements to the BFP algorithms (e.g., minimum behavioural accuracy, ERP signal processing, and tests for acceptability of ERPs).

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Appendix A

Brain Fingerprinting Scientific Standards

The following procedures comprise the Scientific Standards for Brain Fingerprinting Tests. These Standards have been established in the peer-reviewed scientific literature, in four US patents and one UK patent, and in court documents where Brain Fingerprinting and Dr. Farwell's testimony on it were ruled admissible as scientific evidence in court.

1. Use equipment and methods for stimulus presentation, data acquisition, and data recording that are within the standards for the field of cognitive psychophysiology and event-related brain potential research. These standards are well documented elsewhere. For example, the standard procedures Farwell introduced as evidence in the Harrington case were accepted by the court, the scientific journals, and the other expert witnesses in the case. Use a recording epoch long enough to include the full P300-MERMER. For pictorial stimuli or realistic word stimuli, use at least a 1,800-millisecond recording epoch. (Shorter epochs may be appropriate for very simple stimuli.)

2. Use correct electrode placement. The P300 and P300-MERMER are universally known to be maximal at the midline parietal scalp site, Pz in the standard International 10-20 system.

3. Apply brain fingerprinting tests only when there is sufficient information that is known

only to the perpetrator and investigators. If possible, use a minimum of six probes and six targets.

4. Use stimuli that isolate the critical variable: the subject's knowledge or lack of knowledge of the probe stimuli as significant in the context of the investigated situation. Obtain the relevant knowledge from the criminal investigator (or for laboratory studies from the knowledge-imparting procedure such as a mock crime and/or subject training session). Divide the relevant knowledge into probe stimuli and target stimuli. Probe stimuli constitute information that has not been revealed to the subject. Target stimuli contain information that has been revealed to the subject after the crime or investigated situation.

5. If initially there are fewer targets than probes, create more targets. Ideally, this is done by seeking additional known information from the criminal investigators. Note that targets may contain information that has been publicly disclosed. Alternatively, some potential probe stimuli can be used as targets by disclosing to the subject the specific items and their significance in the context of the investigated situation.

6. For each probe and each target, fabricate several stimuli of the same type that are unrelated to the investigated situation. These become the irrelevant stimuli. Use stimuli that isolate the critical variable. For irrelevant stimuli, select items that would be equally plausible for an information-absent subject. The stimulus ratio is approximately one-sixth probes, one-sixth targets, and two-thirds irrelevants.

7. Ascertain that the probes contain information that the subject has no known way of knowing, other than participation in the investigated situation. This information is provided by the criminal investigator for field studies, and results from proper information control in laboratory studies.

8. Make certain that the subject understands the significance of the probes, and ascertain that the probes constitute only information that the subject denies knowing, as follows. Describe the significance of each probe to the subject. Show him the probe and the corresponding irrelevants, without revealing which is the probe. Ask the subject if he knows (for any non-situation-related reason) which stimulus in each group is situation-relevant

/ crime-relevant. Describe the significance of the probes and targets that will appear in each test block immediately before the block.

9. If a subject has knowledge of any probes for a reason unrelated to the investigated situation, eliminate these from the stimulus set. This provides the subject with an opportunity to disclose any knowledge of the probes that he may have for any innocent reason previously unknown to the scientist. This will prevent any non-incriminating knowledge from being included in the test.

10. Ascertain that the subject knows the targets and their significance in the context of the investigated situation. Show him a list of the targets. Describe the significance of each target to the subject.

11. Require an overt behavioral task that requires the subject to recognize and process every stimulus, specifically including the probe stimuli, and to prove behaviorally that he has done so on every trial. Detect the resulting brain responses. Do not depend on detecting brain responses to assigned tasks that the subject can covertly avoid doing while performing the necessary overt responses.

12. Instruct the subjects to press one button in response to targets, and another button in response to all other stimuli. Do not instruct the subjects to "lie" or "tell the truth" in response to stimuli. Do not assign different behavioral responses or mental tasks for probe and irrelevant stimuli.

13. In order to obtain statistically robust results for each individual case, present a sufficient number of trials of each type to obtain adequate signal-to-noise enhancement through signal averaging. Use robust signal-processing and noise-reduction techniques, including appropriate digital filters and artifact-detection algorithms. The number of trials required will vary depending on the complexity of the stimuli, and is generally more for a field case. In their seminal study, Farwell and Donchin (1991) used 144 probe trials. In the Harrington field case, a murder case wherein brain fingerprinting and Farwell's testimony in it were admitted in court as scientific evidence, Farwell used 288 probe trials (Farwell et al. 2013; Harrington v. State, 2001). In any case, use at least 100 probe trials and an equal number of targets. Present three to six unique probes in each block.

14. Use appropriate mathematical and statistical procedures to analyze the data. Do not classify the responses according to subjective judgments. Use statistical procedures properly and reasonably. At a minimum, do not determine subjects to be in a category where the statistics applied show that the determination is more likely than not to be incorrect, i.e., statistical confidence is less than 50

15. (a) Use a mathematical classification algorithm, such as bootstrapping on correlations, that isolates the critical variable by classifying the responses to the probe stimuli as being either more similar to the target responses or to the irrelevant responses. (b) In a forensic setting, conduct two analyses: one using only the P300 (to be more certain of meeting the standard of general acceptance in the scientific community), and one using the P300-MERMER (to provide the current state of the art).

16. Use a mathematical data-analysis algorithm that takes into account the variability across single trials, such as bootstrapping.

17. Set a specific, reasonable statistical criterion for an information-present determination and a separate, specific, reasonable statistical criterion for an information-absent determination. Classify results that do not meet either criterion as indeterminate. Recognize that an indeterminate outcome is not an error, neither a false positive nor a false negative. Error rate is the percentage of information-present or information-absent determinations that are false positives and false negatives respectively; accuracy is 100

18. Restrict scientific conclusions to a determination as to whether or not a subject has the specific situation-relevant knowledge embodied in the probes stored in his brain. Recognize that brain fingerprinting detects only presence or absence of information – not guilt, honesty, lying, deception, or any action or non-action. Do not offer scientific opinions on whether the subject is lying or whether he committed a crime or other act. Recognize that the question of guilt or innocence is a legal determination to be made by a judge and jury, not a scientific determination to be made by a scientist or a computer.

19. Evaluate error rate / accuracy based on actual ground truth. Ground truth is the true state of what a scientific test seeks to detect. Brain fingerprinting is a method to detect information stored in a subject's brain. Ground truth is whether the specific information

tested is in fact stored in the subject's brain. Establish ground truth with certainty through post-test interviews in laboratory experiments and in field experiments wherein subjects are cooperative. Establish ground truth insofar as possible through secondary means in real-life forensic applications with uncooperative subjects. Recognize that ground truth is the true state of what the subject in fact knows, not what the experimenter thinks the subject should know, not what the subject has done or not done, and not whether the subject is guilty, or deceptive.

20. Make scientific determinations based on brain responses. Do not attempt to make scientific determinations based on overt behavior that can be manipulated, such as reaction time.

Reference

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Appendix B

Word Pairs Used in the T/NT Task

Cue	Response	Alternate Cue	Use of Pair
ERRAND	HOUR	TIME–H	Test pair
TATTOO	UNCLE	RELATIVE–U	Test Pair
CRUMB	TOASTER	APPLIANCE–T	Test Pair
STUMBLE	CLOWN	CIRCUS–C	Test Pair
HAVEN	FALCON	BIRD–F	Test Pair
SLANDER	ROACH	INSECT–R	Test Pair
POSITION	CHAIR	FURNITURE–C	Test Pair
ORPHAN	LAMB	ANIMAL–L	Test Pair
DECAY	CARBON	ELEMENT–C	Test Pair
BRAID	DOLL	TOY–D	Test Pair
JARGON	PHYSICS	SCIENCE–P	Test Pair
ACCIDENT	SNOW	WEATHER–S	Test Pair
REFLEX	BICYCLE	VEHICLE–B	Test Pair
TRIBE	VALLEY	LAND-FORM–V	Test Pair
VICE	CIGAR	TOBACCO–C	Test Pair
VITAMIN	LEMON	FRUIT–L	Test Pair

Continued on next page

Table B.1 – continued from previous page

Cue	Response	Alternate Cue	Use of Pair
GATE	DAISY	FLOWER–D	Test Pair
PASTE	TOMATO	VEGETABLE–T	Test Pair
FAULT	SADNESS	EMOTION–S	Test Pair
PLANET	BLUE	COLOR–B	Test Pair
POLLUTION	SULFUR	CHEMICAL–S	Test Pair
CLUSTER	NECKLACE	JEWELRY–N	Test Pair
WEDGE	CHEDDAR	CHEESE–C	Test Pair
BELT	SHIRT	CLOTHING–S	Test Pair
MIXTURE	JAR	CONTAINER–J	Test Pair
KILN	HAMMER	TOOL–H	Test Pair
GREED	PENNY	MONEY–P	Test Pair
AMBITION	BALLET	DANCE–B	Test Pair
FUSS	POODLE	DOG–P	Test Pair
BROOM	HOUSE	BUILDING–H	Test Pair
RELIEF	BOURBON	ALCOHOL–B	Test Pair
SNAG	COTTON	FABRIC–C	Test Pair
ARCH	SANDAL	FOOTWEAR–S	Test Pair
CUSTOM	TOMB	BURIAL–T	Test Pair
FLAG	SWORD	WEAPON–S	Test Pair
TICKET	FLUTE	INSTRUMENT–F	Test Pair
SPINE	LOBSTER	SEAFOOD–L	Test Pair
ALARM	COBRA	SNAKE–C	Test Pair
LEVER	STEEL	METAL–S	Test Pair
APRON	NUTMEG	SPICE–N	Test Pair
THUD	FOOTBALL	SPORT–F	Test Pair
MOSS	NORTH	DIRECTION–N	Test Pair
PEG	OAK	TREE–O	Test Pair

Continued on next page

Table B.1 – continued from previous page

Cue	Response	Alternate Cue	Use of Pair
RIM	GRANITE	ROCK–G	Test Pair
GLOW	PHANTOM	SUPERNATURAL–P	Test Pair
NAIL	PICTURE	ART–P	Test Pair
MOB	ROBBERY	CRIME–R	Test Pair
PITY	GOLDFISH	FISH–G	Test Pair
AVENUE	MILE	DISTANCE–M	Filler Pair
BEACH	AFRICA	CONTINENT–A	Filler Pair
REALITY	ILLUSION	DREAM – I	Filler Pair
JAW	GUM	CANDY–G	Filler Pair
WARRIOR	HERO	CARTOON–H	Filler Pair
POLISH	DIAMOND	GEM–D	Filler Pair
BOOTH	DIAL	RINGTONE – D	Filler Pair
NEEDLE	DOCTOR	PROFESSION–D	Filler Pair
TAPE	RADIO	MEDIA–R	Filler Pair
ENERGY	AMP	—	Filler Pair
LINT	CURTAIN	—	Filler Pair
REMOVE	CANCER	—	Filler Pair
BOND	WEDDING	—	Filler Pair
LOAN	POVERTY	—	Filler Pair
TYPE	FILE	—	Filler Pair
PAPER	PACKAGE	—	Filler Pair
GARAGE	BENCHPRESS	—	Filler Pair
STRAW	WICKER	—	Filler Pair

Some word pairs were used in the initial phases, but were not used in Phase 3 for the ICT test. Therefore, their *Alternate Cue* column is empty.

Appendix C

Obsessive-Compulsive Test - Yale Brown OCD Scale YBOCS

Obsessions are frequent, unwelcome, and intrusive thoughts.

Table C.1: Obsessions

	0	1	2	3	4
1. How much time do you spend on obsessive thoughts?	None	0 - 1 hrs/day	1 - 3 hrs/day	3 - 8 hrs/day	More than 8 hrs/day
2. How much do your obsessive thoughts interfere with your personal, social, or work life?	None	Mild	Definite but manageable	Substantial interference	Severe
3. How much time do your obsessive thoughts distress you?	None	Little	Moderate but manageable	Severe	Nearly constant Disabling
4. How hard do you try to resist your obsessions?	Always try	Try much of the time	Try some of the time	Rarely try. Often yield	Never try. Completely yield
5. How much control do you have over your obsessive thoughts?	Complete control	Much control	Some control	Little control	No control

Compulsions are repetitive behaviours or mental acts that you have a strong urge to repeat that are aimed at reducing your anxiety or preventing some dreaded event.

Table C.2: Compulsions

	0	1	2	3	4
6. How much time do you spend performing compulsive behaviours?	None	0 - 1 hrs/day	1 - 3 hrs/day	3 - 8 hrs/day	More than 8 hrs/day
7. How much do your compulsive behaviours interfere with your personal, social, or work life?	None	Mild	Definite but manageable	Substantial interference	Severe
8. How anxious would you feel if you were prevented from performing your compulsive behaviours?	None	Little	Moderate but manageable	Severe	Nearly constant Disabling
9. How hard do you try to resist your compulsive behaviours?	Always try	Try much of the time	Try some of the time	Rarely try. Often yield	Never try. Completely yield
10. How much control do you have over your compulsive behaviours?	Complete control	Much control	Some control	Little control	No control

Your score: If you have both obsessions and compulsions, and your total score is; 8-15 = Mild OCD; 16-23 = Moderate OCD; 24-31= Severe OCD; 32-40 = Extreme OCD No single test is completely accurate. You should always consult your physician when making decisions about your health.

References

Goodman, W. K., Price, L. H., Rasmussen, S. A., Mazure, C., Fleischmann, R., Hills, C. L., Heninger, G. R. & Charney, D. (1989). The Yale-Brown Obsessive Compulsive Scale. I. Development, use, and reliability. *Archives of Generl Psychiatry, 46*(11): p. 1006-11. Rapp, A. M., Bergman, R. L., Piacentini, J., & McGuire, J. F. (2016). Evidence-Based Assessment of Obsessive-Compulsive Disorder. *Journal of Central Nervous System Disorders, 8*: p. 13-29. PMC4994744.

professional.

Reference: "I Want to Change My Life" by Dr. S. Melemis. www.IWantToChangeMyLife.org

Appendix D

PTSD-CheckList - Civilian Version

Below is a list of problems and complaints that people sometimes have in response to stressful life experiences. Please read each one carefully, pick the answer that indicates how much you have been bothered by that problem *in the last month*.

Numbers 1, 2, 3, 4, and 5 are displayed in front of each item.

Key: **1** = Not at all, **2** = A little bit, **3** = Moderately, **4** = Quite a bit, **5** = Extremely.

1. Repeated, disturbing *memories, thoughts, or images* of a stressful experience from the past?

2. Repeated, disturbing *dreams* of a stressful experience from the past?

3. Suddenly *acting* or *feeling* as if a stressful experience *were* happening again (as if you were reliving it)?

4. Feeling *very upset* when *something reminded* you of a stressful experience from the past?

5. Having *physical reactions* (e.g., heart pounding, trouble breathing, or sweating) when *something reminded* you of a stressful experience from the past?

6. Avoid *thinking about* or *talking about* a stressful experience from the past or avoid *having feelings* related to it?

7. Avoid *activities* or *situations* because they *remind* you of a stressful experience from the past?

8. Trouble *remembering important parts* of a stressful experience from the past?

9. Loss of *interest in things that you used to enjoy*?

10. Feeling *distant* or *cut* off from other people?

11. Feeling *emotionally numb* or being unable to have loving feelings for those close to you?

12. Feeling as if your *future* will somehow be *cut short*?

13. Trouble *falling* or *staying asleep*?

14. Feeling *irritable* or having *angry outbursts*?

15. Having *difficulty concentrating*?

16. Being *"super alert"* or watchful on guard?

17. Feeling *jumpy* or easily startled?

How is the PCL Scored?

Add up all items from each of the 17 items for a total severity score (range = 17 - 85)

- 17 - 29: This cut off shows little to no severity.
- 28 - 29: Some PTSD symptoms - If you are seeing or will be seeing a therapist, print the results of this Quiz and take to your therapist for further evaluation.
- 30 – 44: Moderate to Moderately High severity of PTSD symptoms - If you are seeing or will be seeing a therapist, print the results of this Quiz and take to your therapist for further evaluation.
- 45 - 85: High Severity of PTSD symptoms - If you are seeing or will be seeing a therapist, print the results of this Quiz and take to your therapist for further evaluation.

PCL-M for DSM-IV: (11/1/94) Weathers, Litz, Huska, & Keane National Center for PTSD-Behavioral Science Division. This is a Government document in public domain.

Appendix E

T/NT Diagnostic Questionnaire

GREEN TRIALS

For the Hint words presented in Green, how often did you try to think of the associated RESPONSE word as fast as possible?

Never		Half of the time		Always
0	1	2	3	4

RED TRIALS

1. When Hint words appeared in Red, how much time did you spend looking the Hint word, without shifting your eyes OR attention to something else?

Don't look at them		Half of the time		The entire time
0	1	2	3	4

2. For Red trials, how often did you read and understand the Hint word?

Never		Half of the time		Always
0	1	2	3	4

3. How often were you able to avoid thinking about the Response word that went with it?

Never		Half of the time		Always
0	1	2	3	4

4. How often did you replace the original Response word with another word or thought?

Never		Half of the time		Always
0	1	2	3	4

5. How often did you actively push the Response word out of mind if it did come to mind?

Never		Half of the time		Always
0	1	2	3	4

6. Did you ever *intentionally* think about the Response word "just for a second" to see if you still knew it?

Never		Half of the time		Always
0	1	2	3	4

7. How often did you think about the Response word *after* the Hint word went off the screen?

Never		Half of the time		Always
0	1	2	3	4

Appendix F

T/NT Post-experimental Questionnaire

1. Please rate the extent to which you used each of the following strategies in order to keep the response word from coming to mind when presented with Hints in Red colour.

a. I simply moved my eyes away from the HINT word so I didn't have to look at it.

Never	Rarely	Sometimes	Often	Always
0	1	2	3	4

b. Although I kept my eyes on the HINT word, I covertly shifted my attention to a different spot on the screen/elsewhere in the room, so I could avoid looking at the HINT word.

Never	Rarely	Sometimes	Often	Always
0	1	2	3	4

c. I shifted my attention to something else in my mind, such as another word, idea, sound, image, or memory. In other words, I came up with an alternative thought in order to prevent the Response word from coming to mind.

Never	Rarely	Sometimes	Often	Always
0	1	2	3	4

d. I played word games with the HINT word on the screen, repeated the HINT over and over, or simply focused on the visual properties of the word.

Never	Rarely	Sometimes	Often	Always
0	1	2	3	4

e. I simply focused on blocking/pushing out thoughts of Response word, without replacing it with any other thought.

Never	Rarely	Sometimes	Often	Always
0	1	2	3	4

f. Other, please describe your strategy below, after rating how often you employed it.

Never	Rarely	Sometimes	Often	Always
0	1	2	3	4

2. Sometimes people suspect that their memory will be tested on response words for HINT words presented in Red colour later on, even though they have been asked to not think about these RESPONSE words. Each of the following three statements is intended to measure whether you ever INTENTIONALLY made an effort to think about the responses for the HINT words presented in Red colour (so please only consider those instances in which you purposefully thought of a response, not those in which a response automatically came to mind). Please make a rating for each statement and be as honest as possible with your ratings.

	Never	Rarely	Sometimes	Frequently	Very Frequently
When I saw the HINT in red colour, I *quickly checked* to see if I remembered the response word	0	1	2	3	4
After a HINT word in red colour went off the screen I checked to see if I still remembered the response word	0	1	2	3	4
When I saw the HINT in red colour, I *quickly checked* to see if I remembered the response word	0	1	2	3	4

Last night, how many hours of sleep did you get? (estimate as accurately as possible).

0 1 2 3 4 5 6 7 8 9 10 $\leq$11

Appendix G

Additional Graphs

Figure G.1: Boxplot of YBOCS scores - Study-1

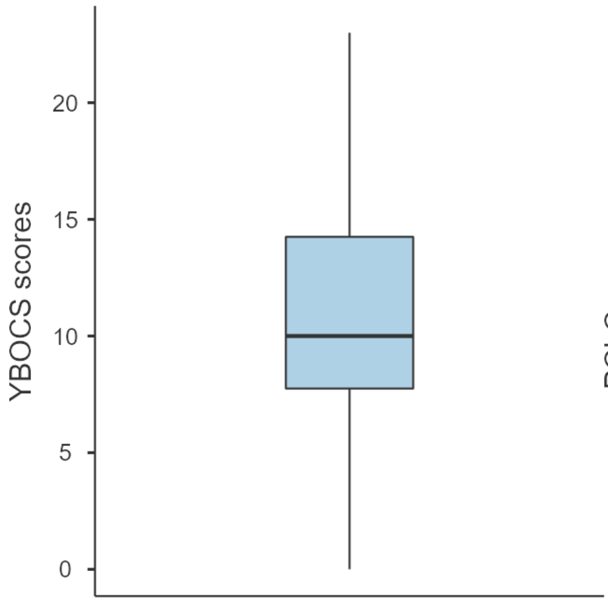
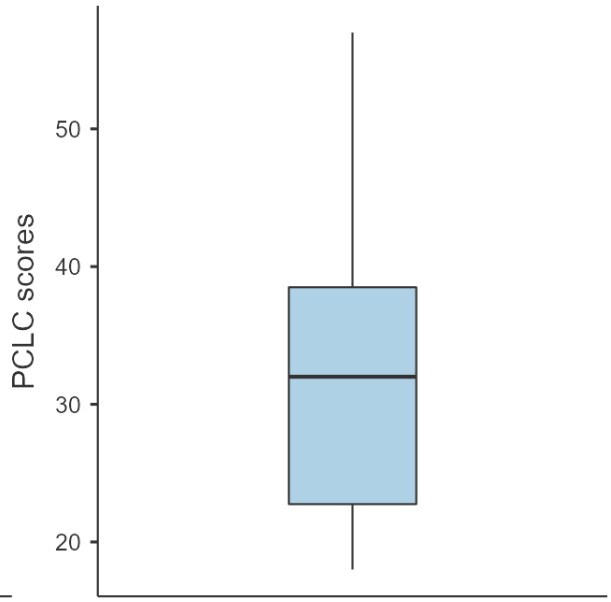


Figure G.2: Boxplot of PCLC scores - Study-1



Appendix H

Stimuli for Study-3: BFP-Parolees

Table H.1: Example of Stimuli for BFP-Parolees

Original Stimulus	Description	Irrelevant 1	Irrelevant 2
Name[a]	Name of the subject's sister	Marlene Gonzales	Tanya Lacroese
England Street	Road in which the subject lived at the time	Jackson Drive	Hillside Avenue
Name[a]	Name of the subject's girlfriend	Tilly Wilson	Mary Elwood
Petrol Station	The type of place the subject planned to rob	Supermarket	Estate Agency
Army	The organization that offered the subject's sister a job	Navy	Air Force
Park	The place where the robbery incident happened	Café	Bank
Kitchen knife	The weapon used by the subject's sister	Claw Hammer	Pepper Spray
Handbag	The main item stolen in the robbery incident	Briefcase	Money Box

Continued on next page

Table H.1 – continued from previous page

Original Stimulus	Description	Irrelevant 1	Irrelevant 2
Hit with fists	How the subject assaulted a robbery victim	Shot with gun	Struck with bat
Vomited	A physical reaction the subject's sister had after the robbery	Fainted	Cried
Wallet	The stolen item the subject put in his pocket	Wristwatch	Necklace
Marian College	The school grounds through which the subject ran after robbery	Buxton High	Stanton Primary

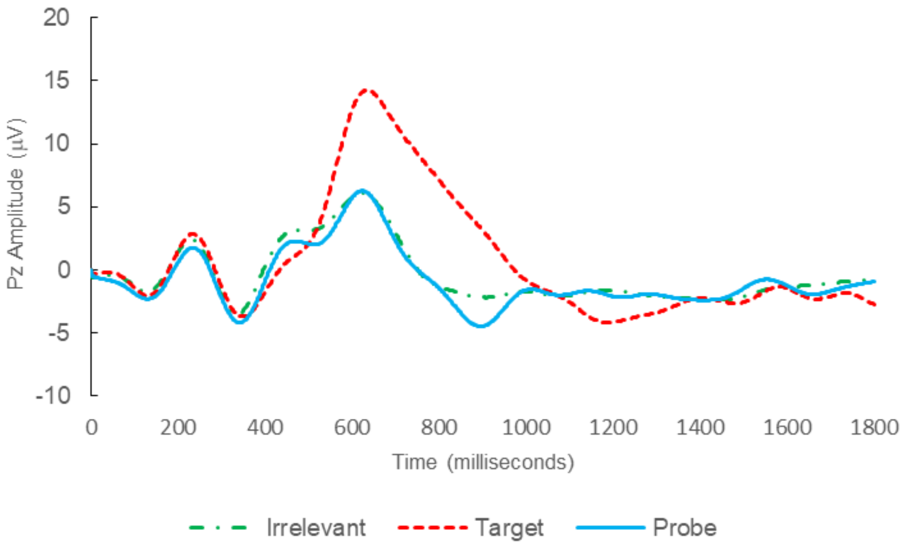
Blue text shows probes and red text shows targets.

[a] Two names of real people provided by subjects have been redacted to ensure confidentiality.

Appendix I

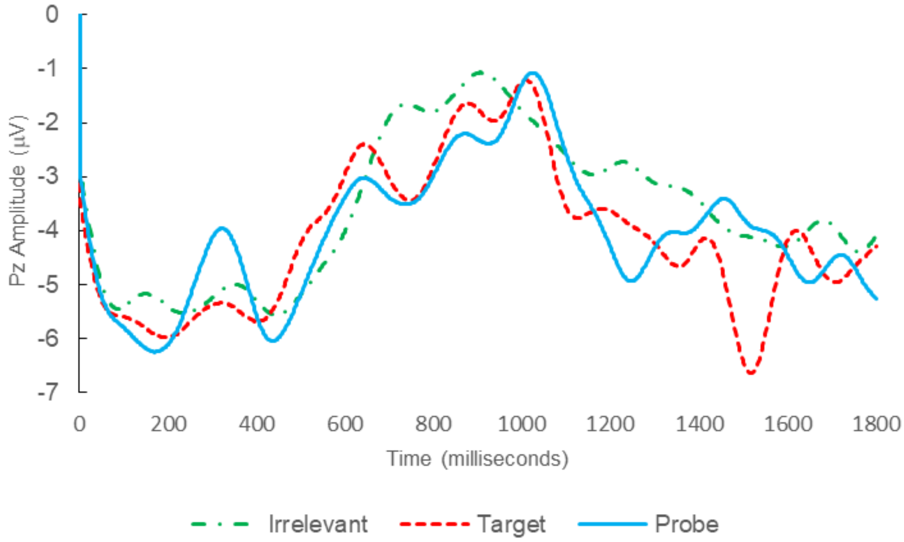
ERP Waveforms for Study-3 subjects

Figure I.1: BFP Response Waveforms of C03 in “Flatmate Assault” ($IA \rightarrow IA_C$)



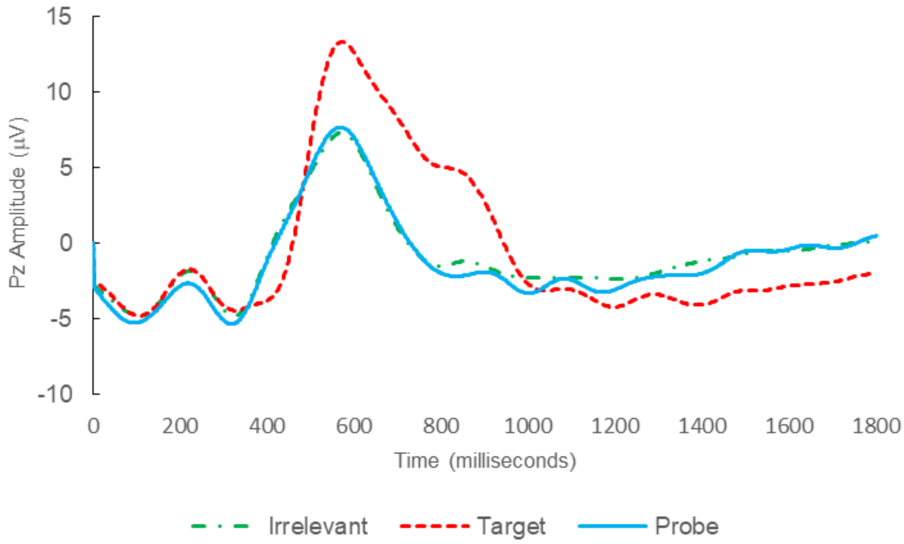
BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent. IA_C = Classified as Information-Absent.

Figure I.2: BFP Response Waveforms of C07 in "Armour Guard Heist" ($IP \rightarrow IP_C$)



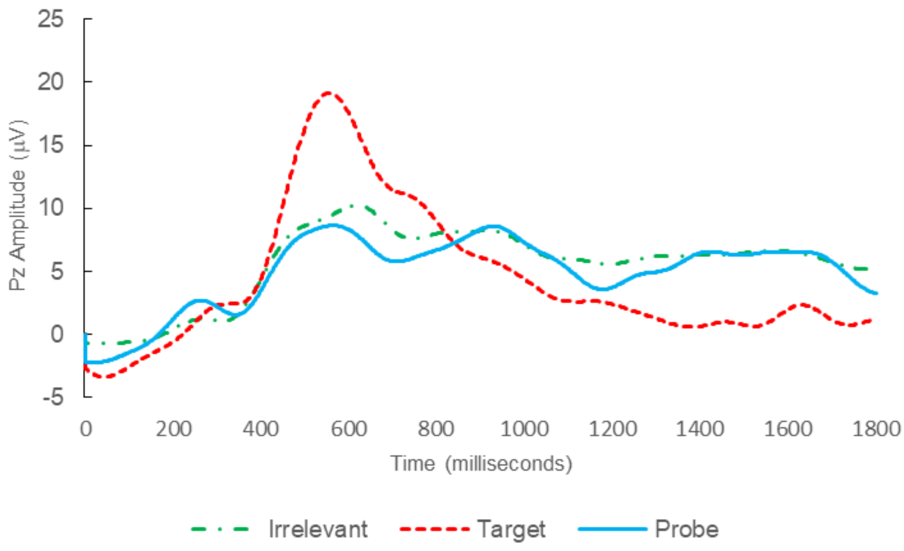
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information-Present.

Figure I.3: BFP Response Waveforms of C08 in "Armour Guard Heist" ($IA \rightarrow IA_C$)



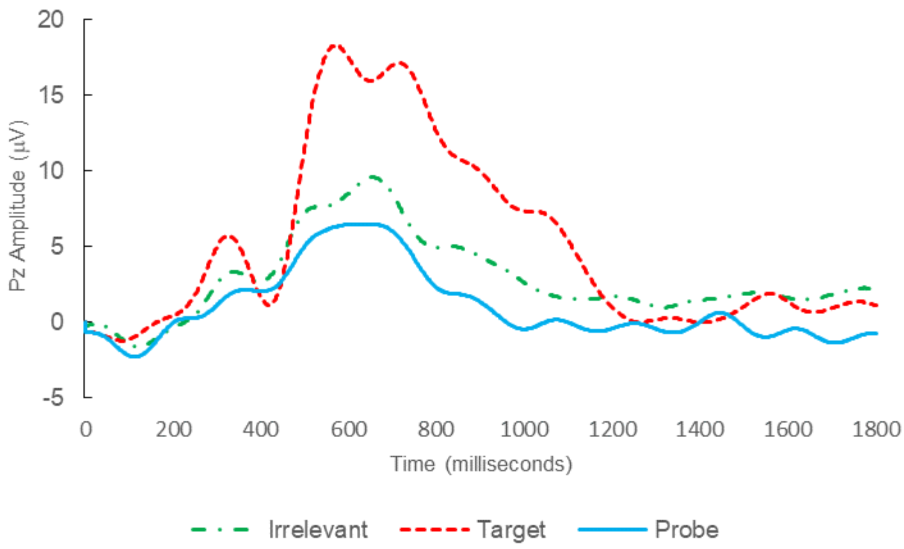
BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent. IA_C = Classified as Information-Absent.

Figure I.4: BFP Response Waveforms of C09 in “Armour Guard Heist” (IA→IA_C)



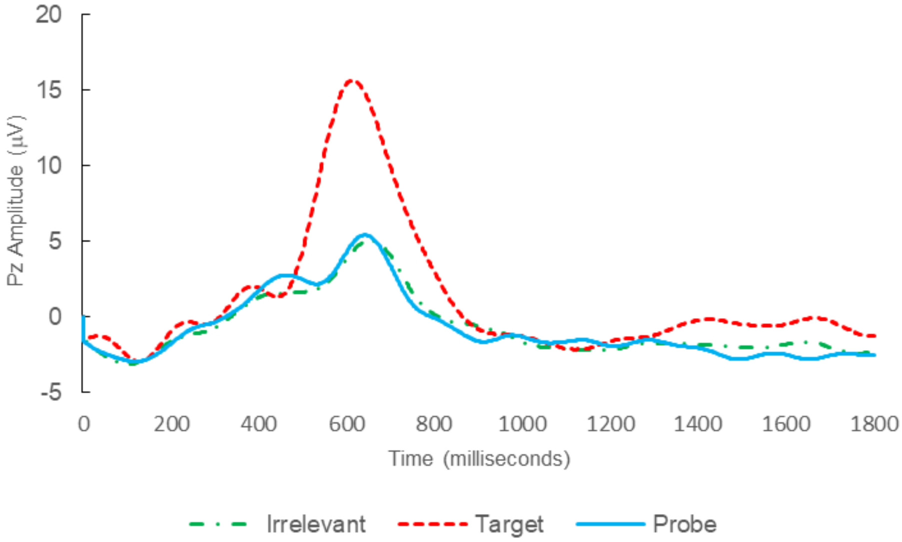
BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent. IA_C = Classified as Information-Absent.

Figure I.5: BFP Response Waveforms of C13 in “Robbery” (IA→IA_C)



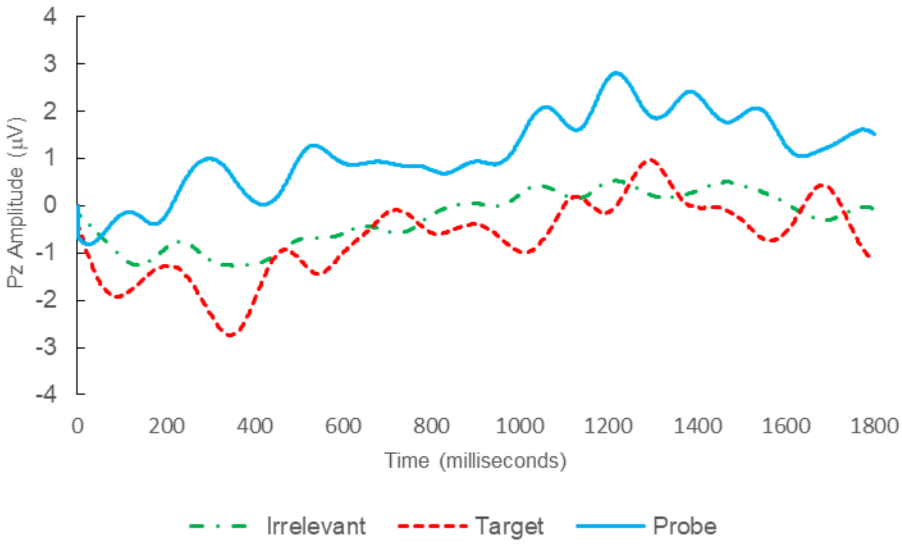
BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent. IA_C = Classified as Information-Absent.

Figure I.6: BFP Response Waveforms of C14 in “Robbery” (IA→IA_C)



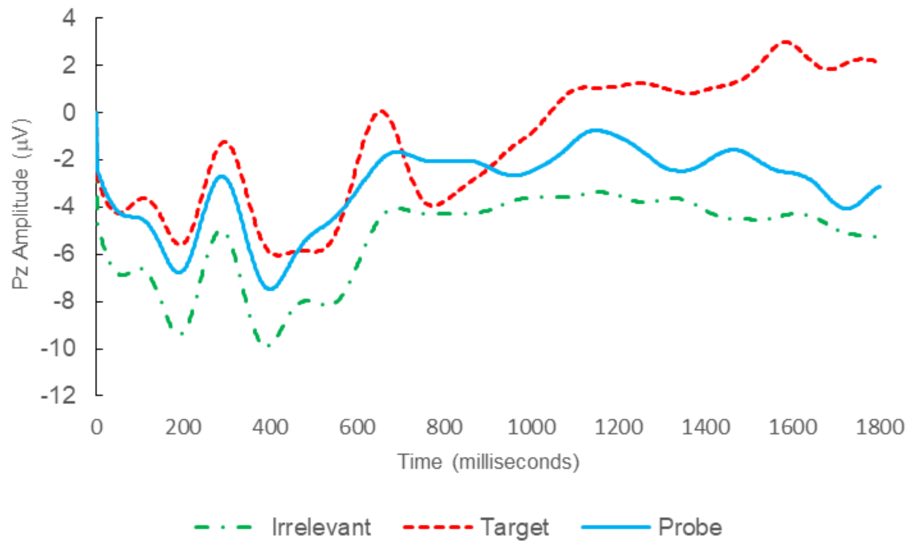
BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent. IA_C = Classified as Information-Absent.

Figure I.7: BFP Response Waveforms of C15 in “Robbery” (IA→Indeterminate)



BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent.

Figure I.8: BFP Response Waveforms of C16 in "Robbery" (IA→Indeterminate)



BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent.

Appendix J

Stimuli for Study-4: BFP-Countermeasures

Table J.1: Example of Stimuli for BFP-Countermeaures

Original Stimulus	Description	Irrelevant 1	Irrelevant 2
Name[a]	Name of a friend who was present at the time	Nadene Cooper	Marlee Morris
Name[a]	Name of a friend who was present at the time	Sophia Gillam	Charlotte Buckner
Name[a]	Name of a friend who was present at the time	Nivaan Whitley	Donnie Madden
Name[a]	Name of a friend who was present at the time	Skye Richards	Dave Bishop
Cigarette Pack	Item the subject found after they left the party	Empty Wallet	Pocket Knife
Ilam	Area where the house was	Shirley	Lincoln
Horse tranquilizer	Drug one of the friends used	Mushroom tea	Marijuana cookie

Continued on next page

Table J.1 – continued from previous page

Original Stimulus	Description	Irrelevant 1	Irrelevant 2
Into a bowl	Where the subject vomited	On the couch	Through bed sheets
Phantom shitter	The nickname given after the incident	Angry druggy	Sexual pest
Excrement on the floor	What a parent found in the night	Window was broken	Ripped up carpet
Started a fight	What the subject almost did at the party	Stole a TV	Smashed a cup
Playground	The place where the subject found something after the party	In gutter	Rooftop

Blue text shows probes and red text shows targets.

[a] Four names of real people provided by subjects have been redacted to ensure confidentiality.

Appendix K

ERP Waveforms for Study-4 subjects

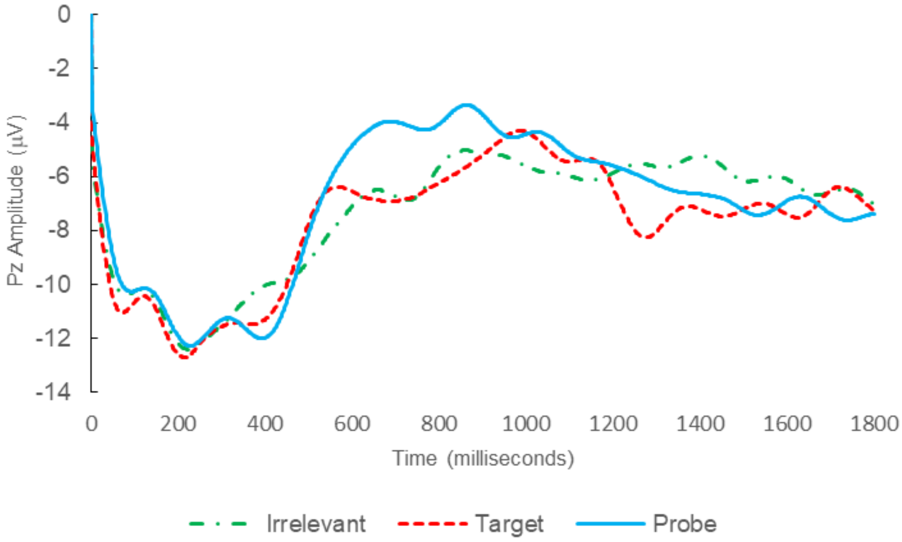
Figures below represent ERPs waveforms for the rest of Study-4 subjects. They are arranged as following.

1. For each IP subject, the ERP for Experiment-1 (BFP replication) is presented first, followed by the ERP for Experiment-2 (BFP Countermeasures). The changes or similarities between ERP responses for both experiments can be observed better with such presentation.

2. After all IP subjects are dealt with, the ERPs for IA subjects are presented.

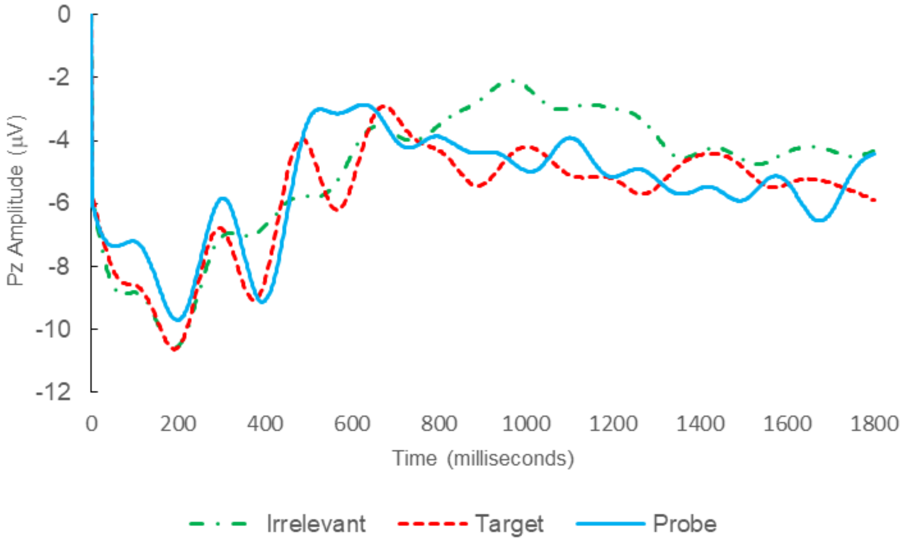
3. For convenience of direct comparison, ERPs are started on the next page, so both ERPs for each IP subject can be viewed on the same page.

Figure K.1: BFP Response Waveforms of S01 in "School Contest", Experiment-1 ($IP \rightarrow IP_C$)



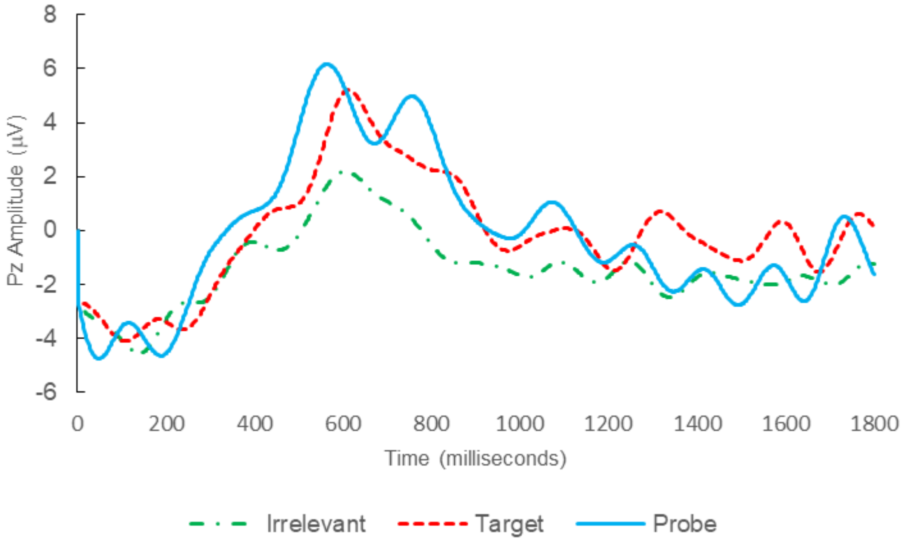
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information Present.

Figure K.2: BFP Response Waveforms of S01 in "School Contest", Experiment-2 ($IP \rightarrow IP_C \rightarrow IP_C$)



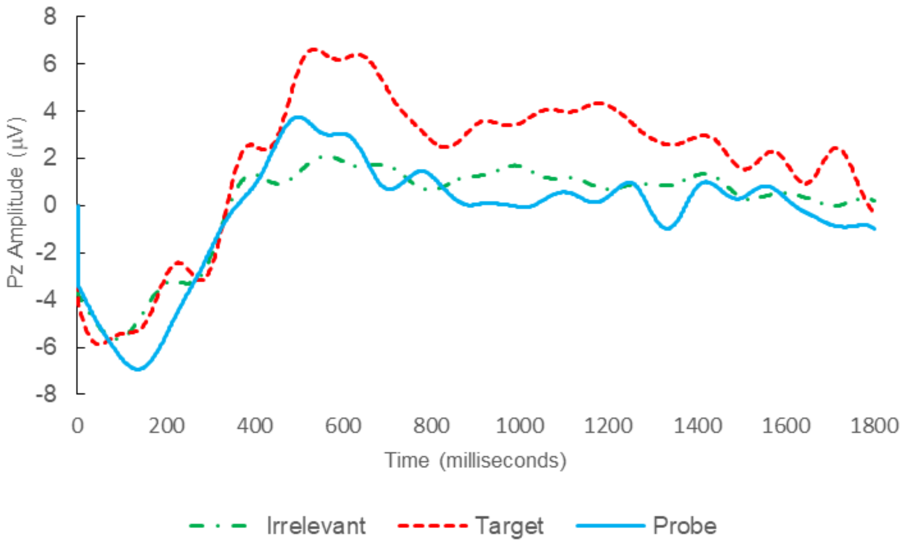
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information-Present.

Figure K.3: BFP Response Waveforms of S05 in “Insect Repellent”, Experiment-1 ($IP \rightarrow IP_C$)



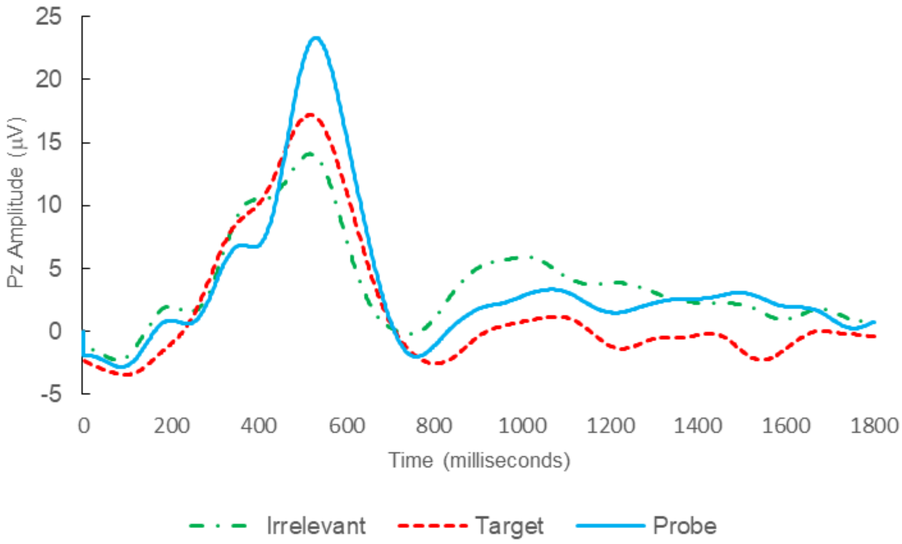
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information Present.

Figure K.4: BFP Response Waveforms of S05 in “Insect Repellent”, Experiment-2 ($IP \rightarrow IP_C \rightarrow IP_C$)



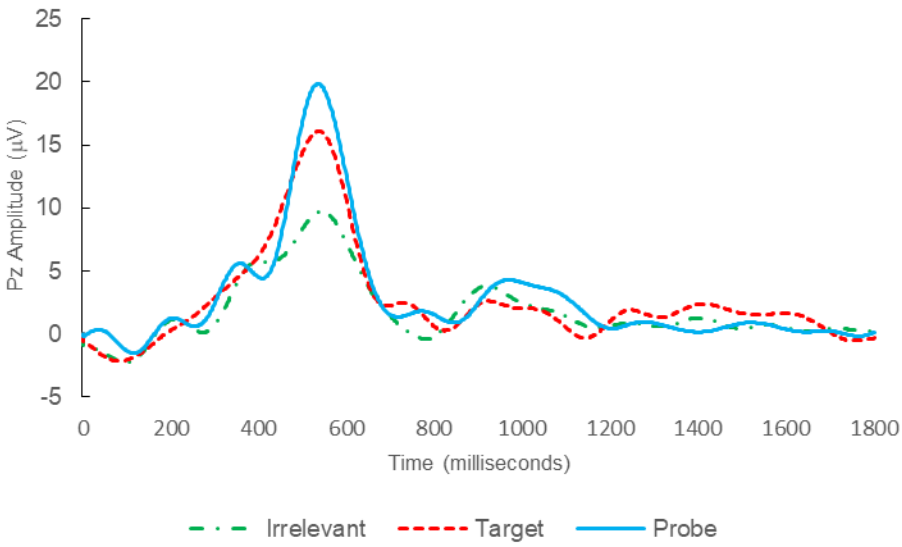
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information-Present.

Figure K.5: BFP Response Waveforms of S07 in "Sustainability Prize", Experiment-1 (IP→IP_C)



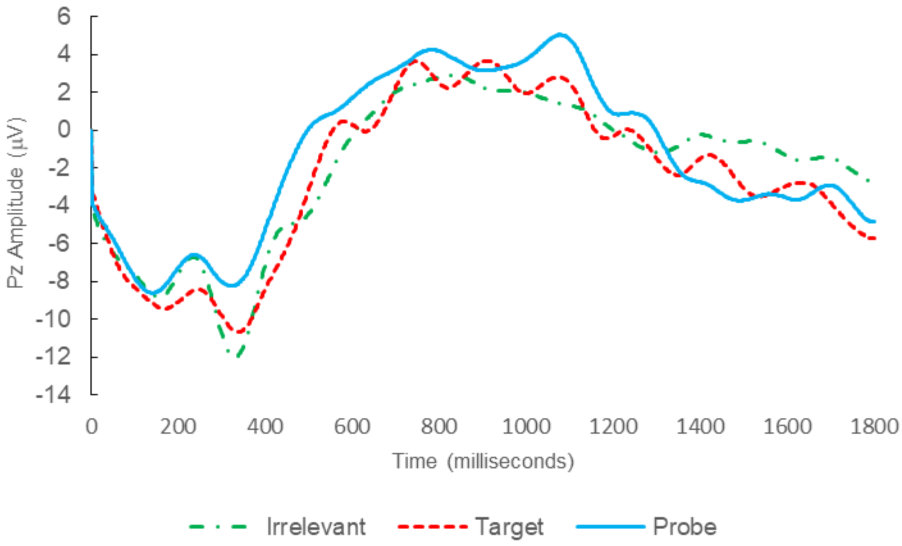
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information Present.

Figure K.6: BFP Response Waveforms of S07 in "Sustainability Prize", Experiment-2 (IP→IP_C→IP_C)



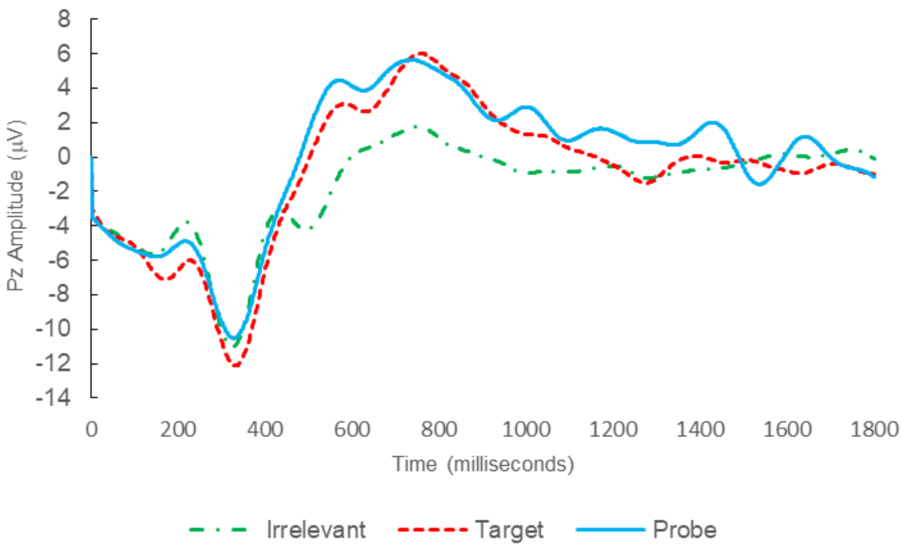
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information-Present.

Figure K.7: BFP Response Waveforms of S09 in "Police Car", Experiment-1 (IP→IP_C)



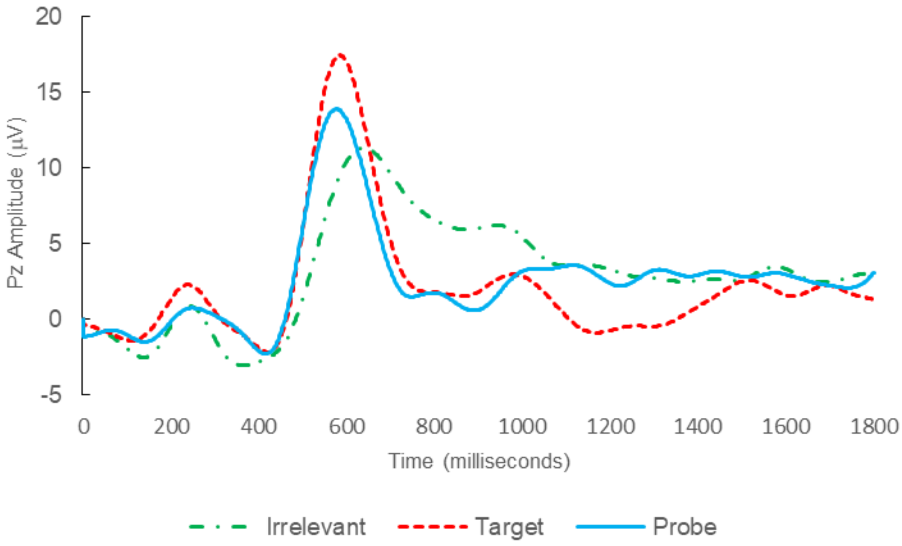
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information Present.

Figure K.8: BFP Response Waveforms of S09 in "Police Car", Experiment-2 (IP→IP_C→IP_C)



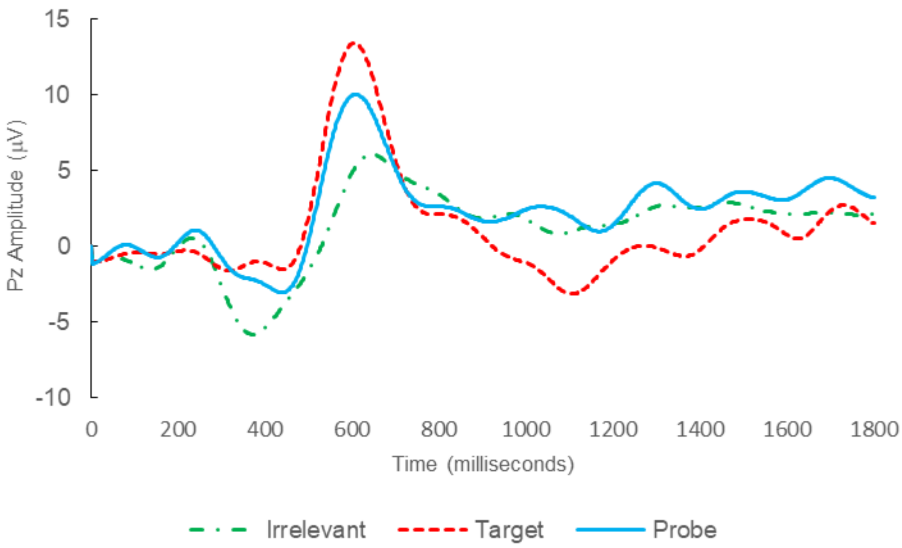
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information-Present.

Figure K.9: BFP Response Waveforms of S11 in "Bush Fire", Experiment-1 (IP→IP_C)



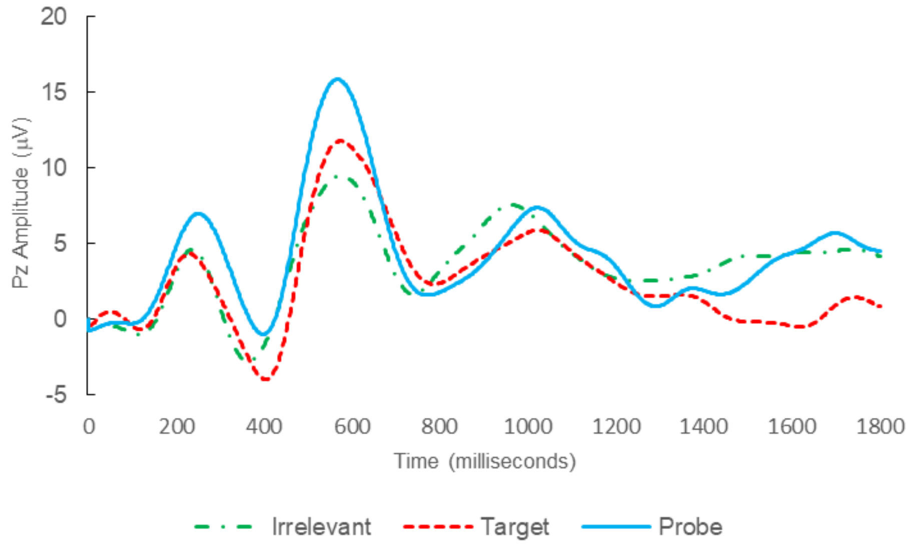
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information Present.

Figure K.10: BFP Response Waveforms of S11 in "Bush Fire", Experiment-2 (IP→IP_C→IP_C)



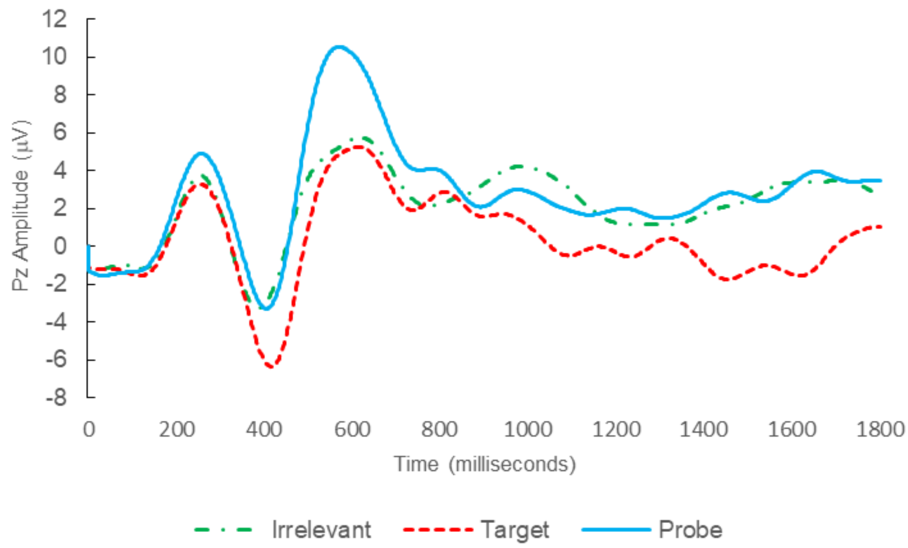
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information-Present.

Figure K.11: BFP Response Waveforms of S14 in “Sea Witch”, Experiment-1 (IP→IP_C)



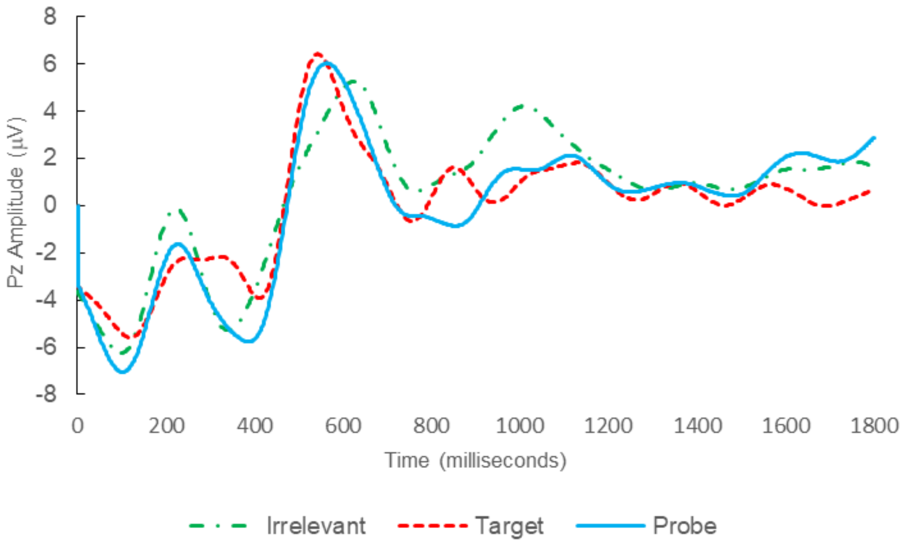
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information Present.

Figure K.12: BFP Response Waveforms of S14 in “Sea Witch”, Experiment-2 (IP→IP_C→IP_C)



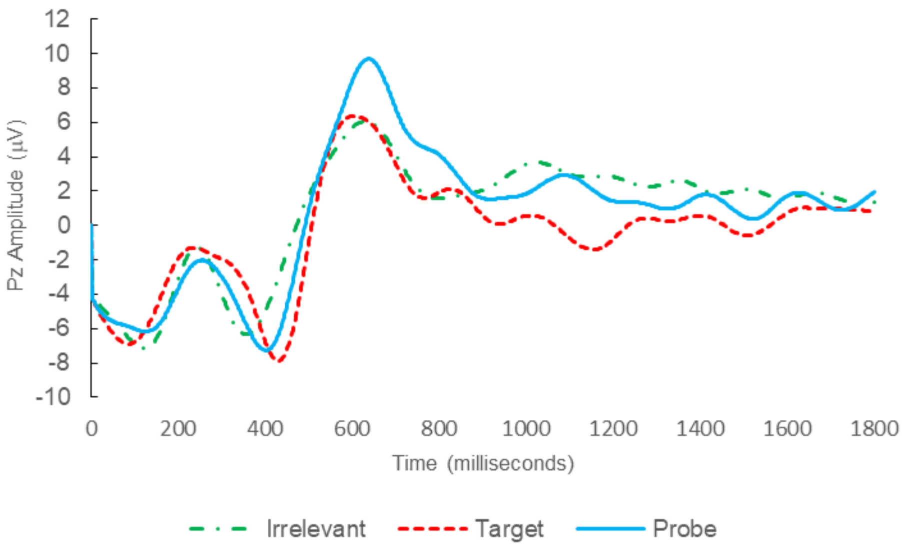
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information-Present.

Figure K.13: BFP Response Waveforms of S16 in "Trip to Queenstown", Experiment-1 (IP→IP_C)



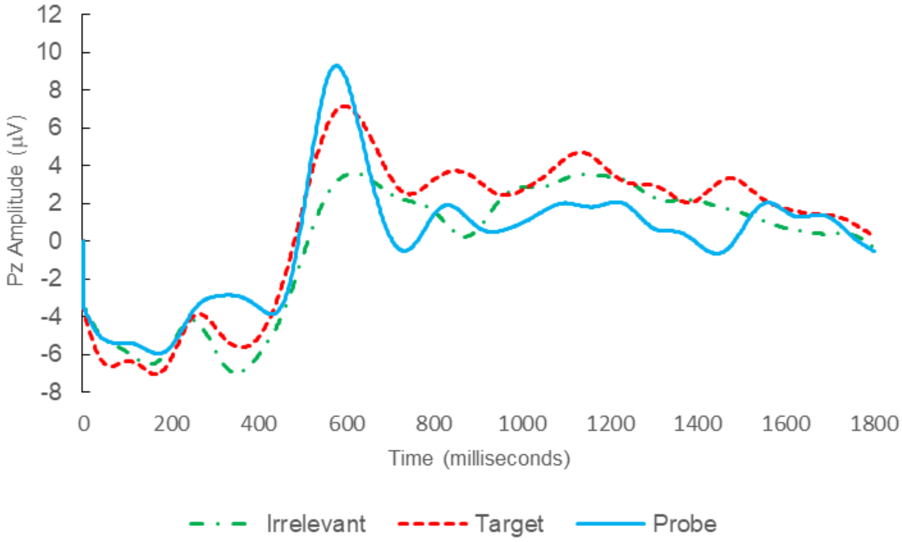
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information Present.

Figure K.14: BFP Response Waveforms of S16 in "Trip to Queenstown", Experiment-2 (IP→IP_C→IP_C)



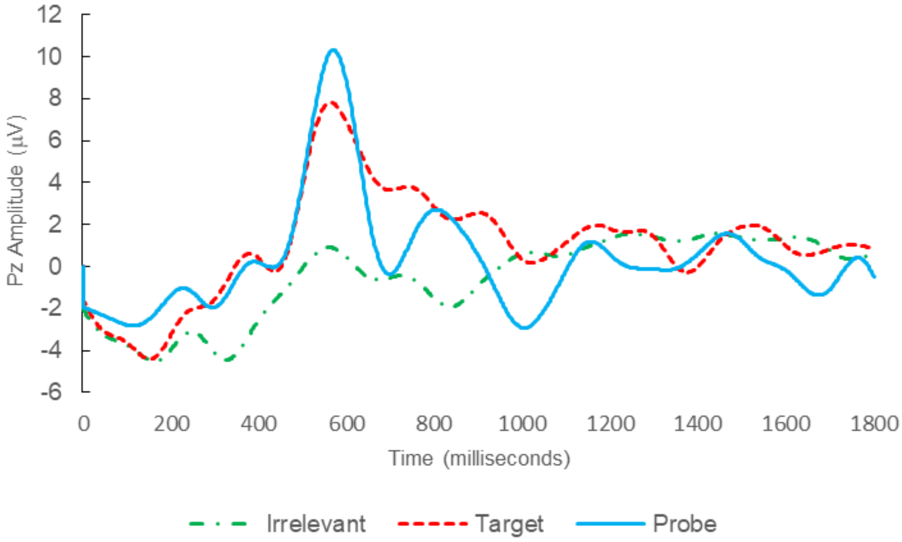
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information-Present.

Figure K.15: BFP Response Waveforms of S18 in "Street Signs", Experiment-1 (IP→IP_C)



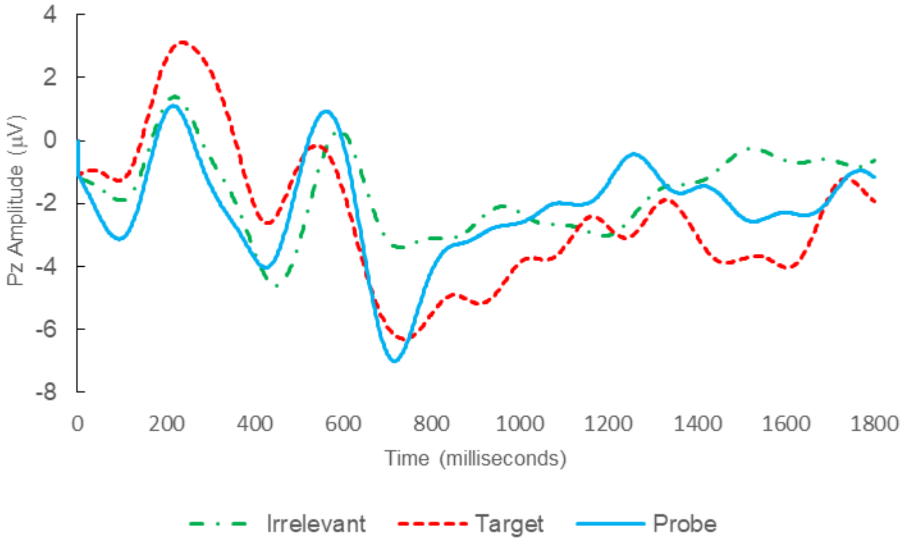
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information Present.

Figure K.16: BFP Response Waveforms of S18 in "Street Signs", Experiment-2 (IP→IP_C→IP_C)



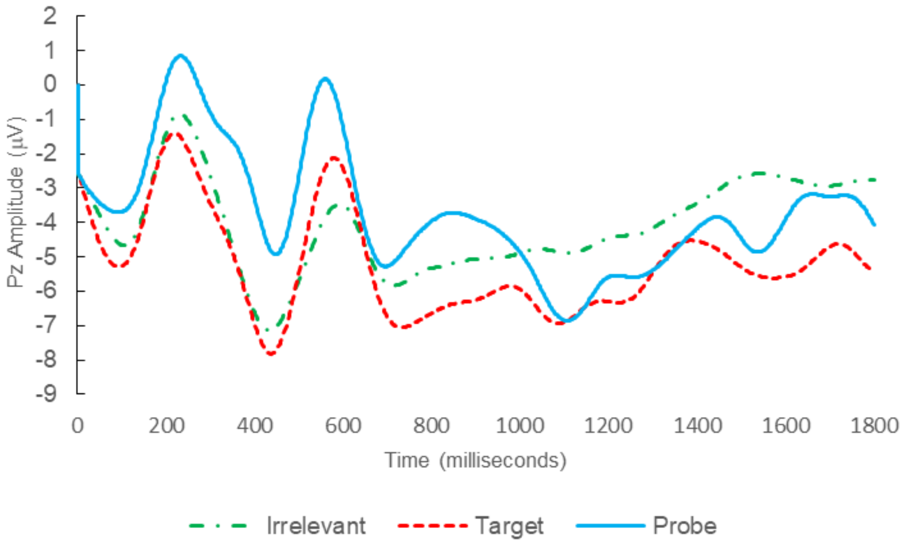
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information-Present.

Figure K.17: BFP Response Waveforms of S20 in “12 Pubs of Xmas”, Experiment-1 (IP→IP_C)



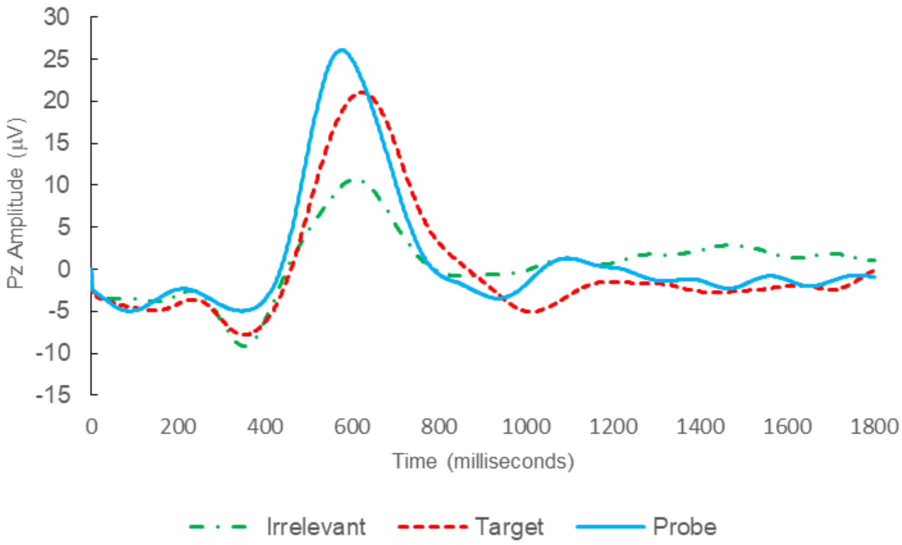
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information Present.

Figure K.18: BFP Response Waveforms of S20 in “12 Pubs of Xmas”, Experiment-2 (IP→IP_C→IP_C)



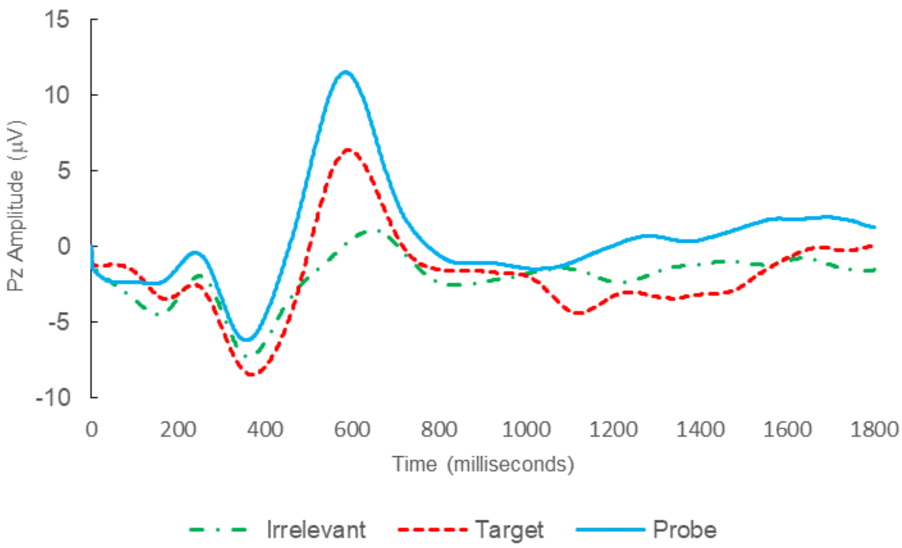
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information-Present.

Figure K.19: BFP Response Waveforms of S22 in “Motion Sickness”, Experiment-1 (IP→IP_C)



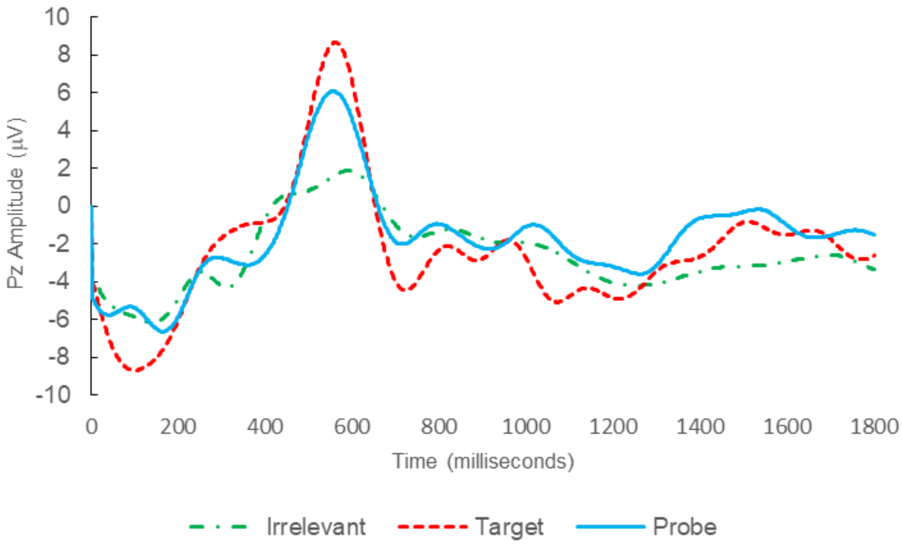
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information Present.

Figure K.20: BFP Response Waveforms of S22 in “Motion Sickness”, Experiment-2 (IP→IP_C→IP_C)



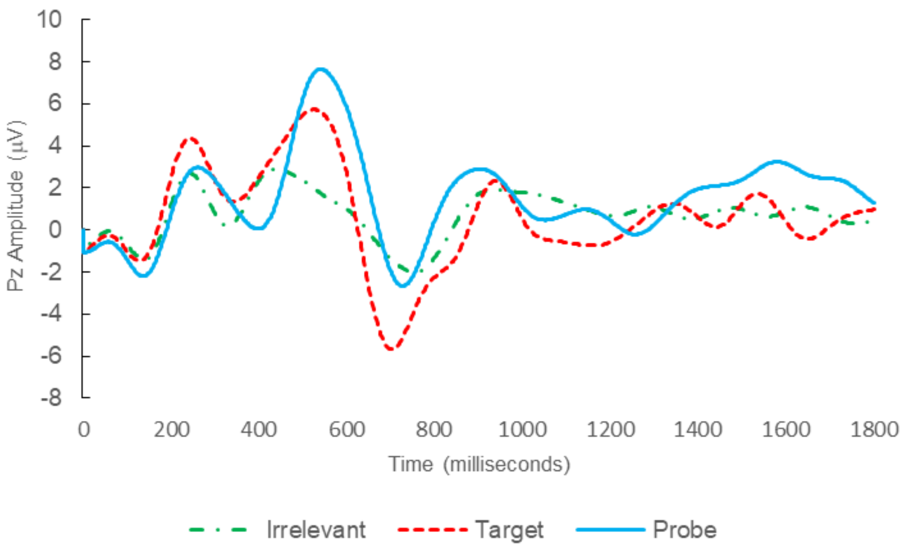
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information-Present.

Figure K.21: BFP Response Waveforms of S26 in "House Party", Experiment-1 ($IP \rightarrow IP_C$)



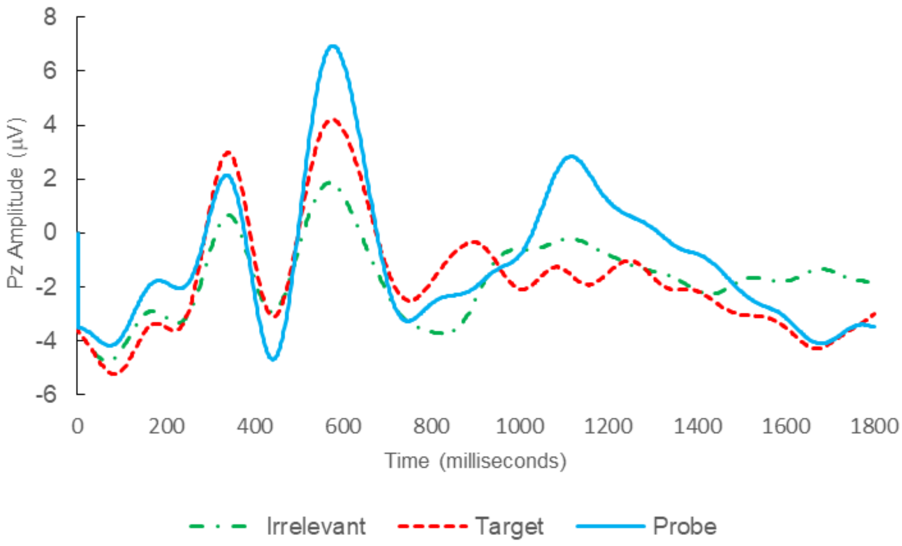
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information Present.

Figure K.22: BFP Response Waveforms of S26 in "House Party", Experiment-2 ($IP \rightarrow IP_C \rightarrow IP_C$)



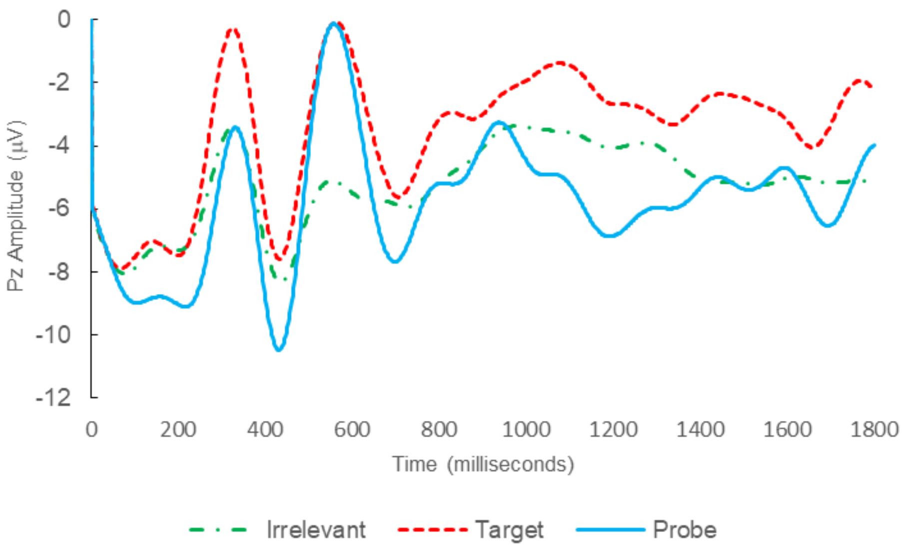
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information-Present.

Figure K.23: BFP Response Waveforms of S29 in “Bad Mosquitoes”, Experiment-1 (IP→IP_C)



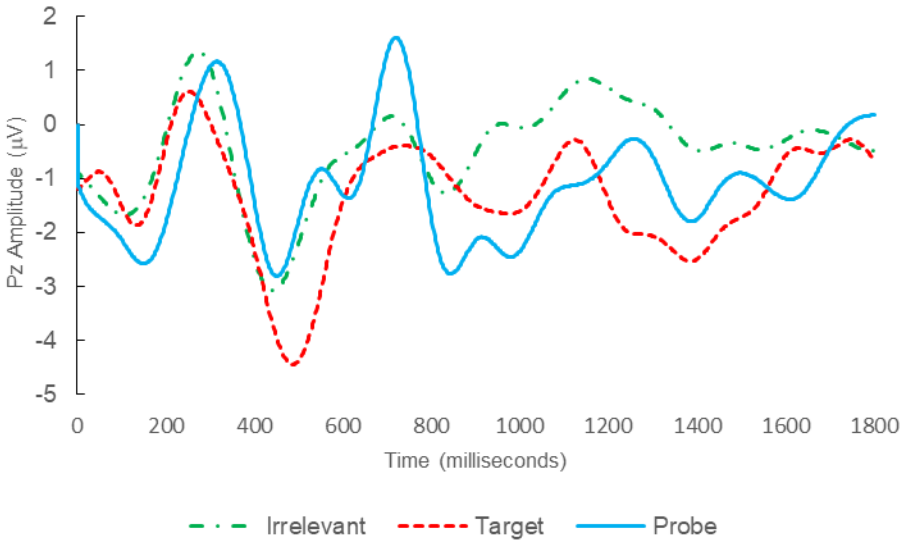
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information Present.

Figure K.24: BFP Response Waveforms of S29 in “Bad Mosquitoes”, Experiment-2 (IP→IP_C→IP_C)



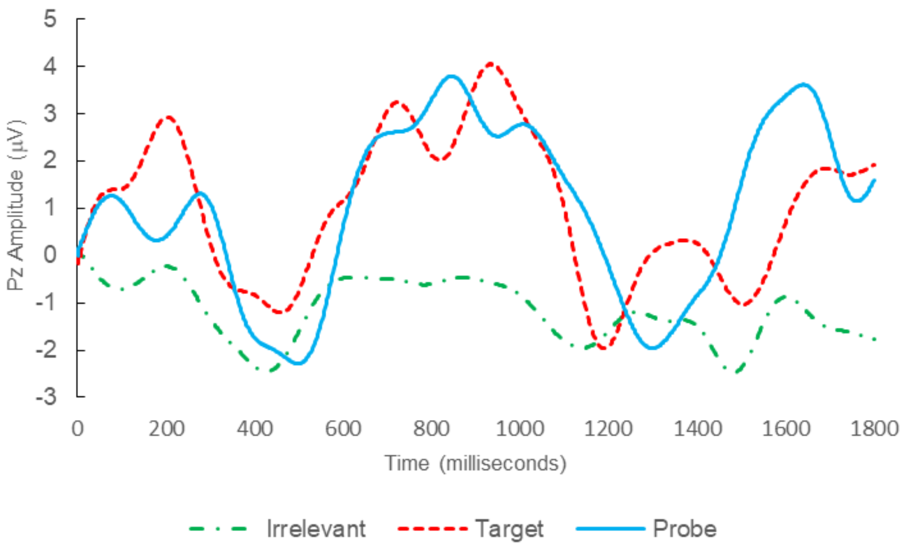
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information-Present.

Figure K.25: BFP Response Waveforms of S31 in "Representing UC", Experiment-1 (IP→IP_C)



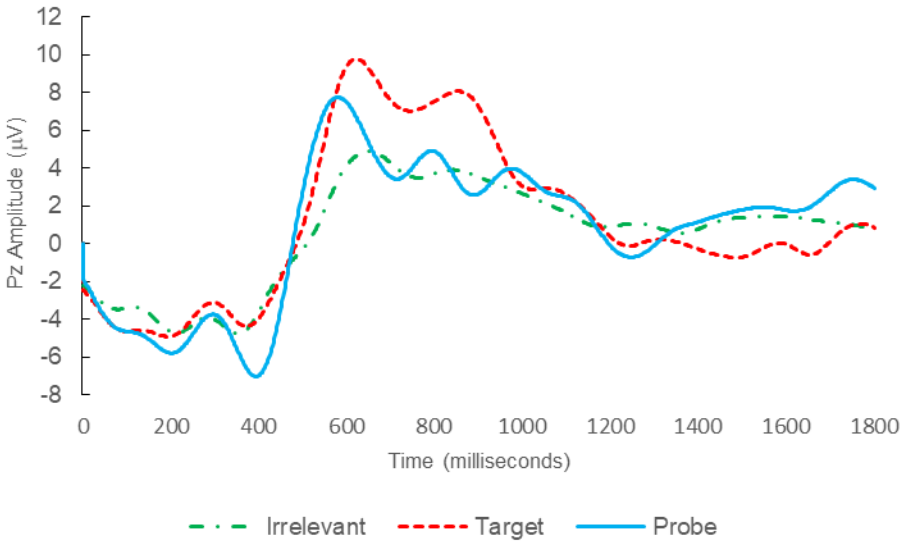
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information Present.

Figure K.26: BFP Response Waveforms of S31 in "Representing UC", Experiment-2 (IP→IP_C→IP_C)



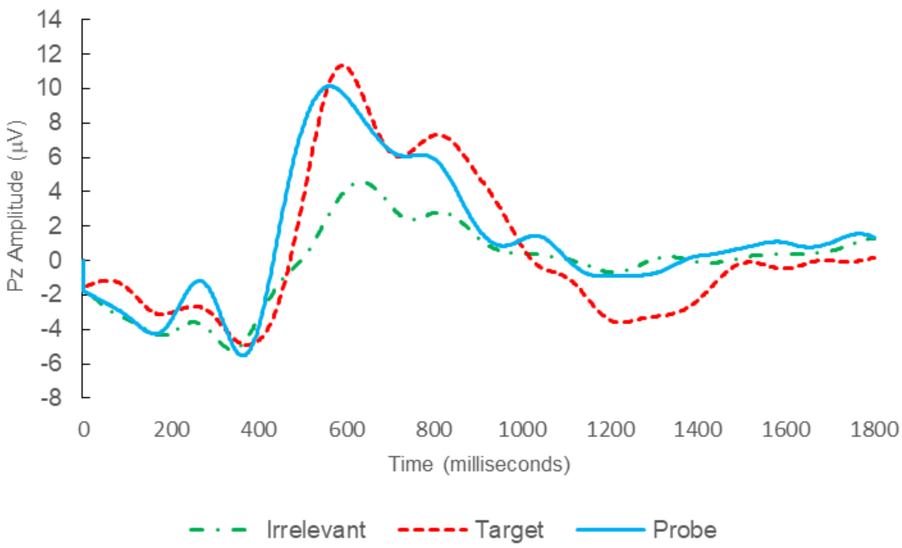
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information-Present.

Figure K.27: BFP Response Waveforms of S34 in “Trip to Vietnam”, Experiment-1 ($IP \rightarrow IP_C$)



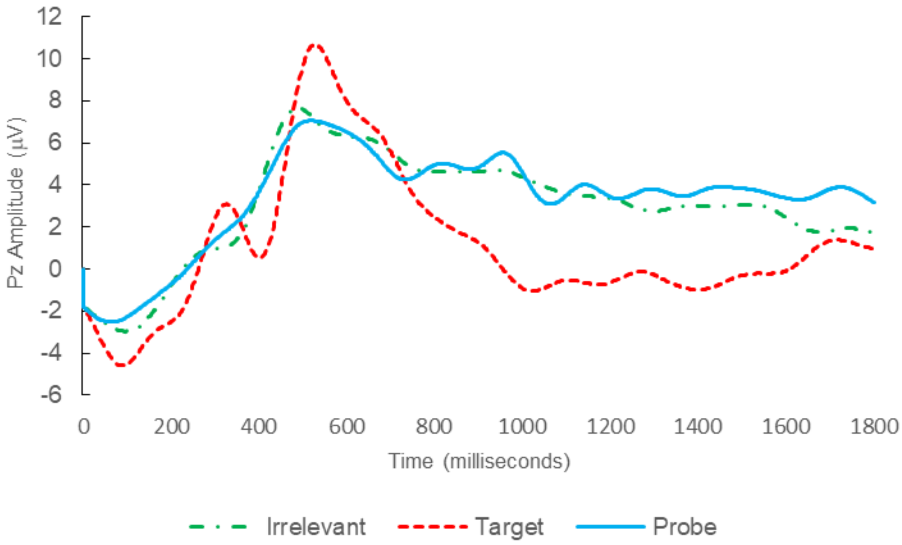
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information Present.

Figure K.28: BFP Response Waveforms of S34 in “Trip to Vietnam”, Experiment-2 ($IP \rightarrow IP_C \rightarrow IP_C$)



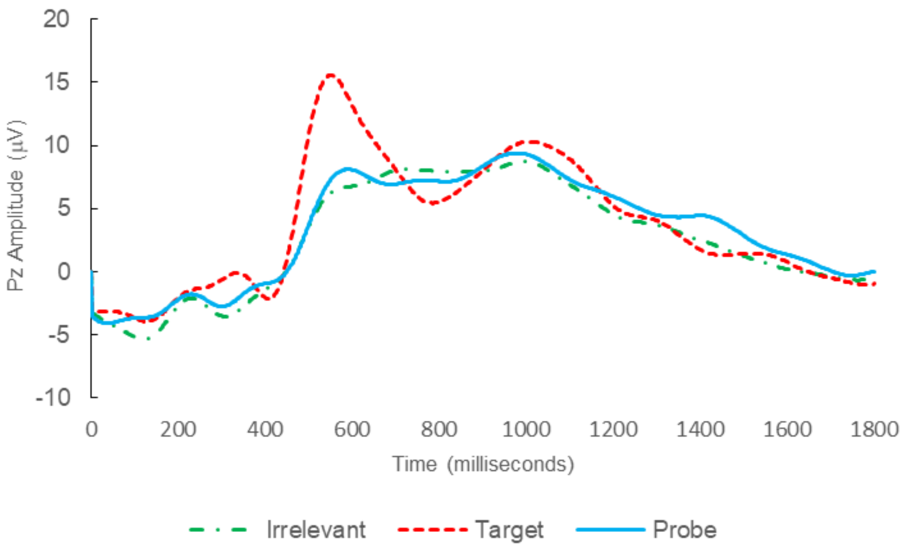
BFP = Brain Fingerprinting. IP = Ground-truth Information-Present. IP_C = Classified as Information-Present.

Figure K.29: BFP Response Waveforms of S02 in “School Contest”, Experiment-1 (IA→IA_C)



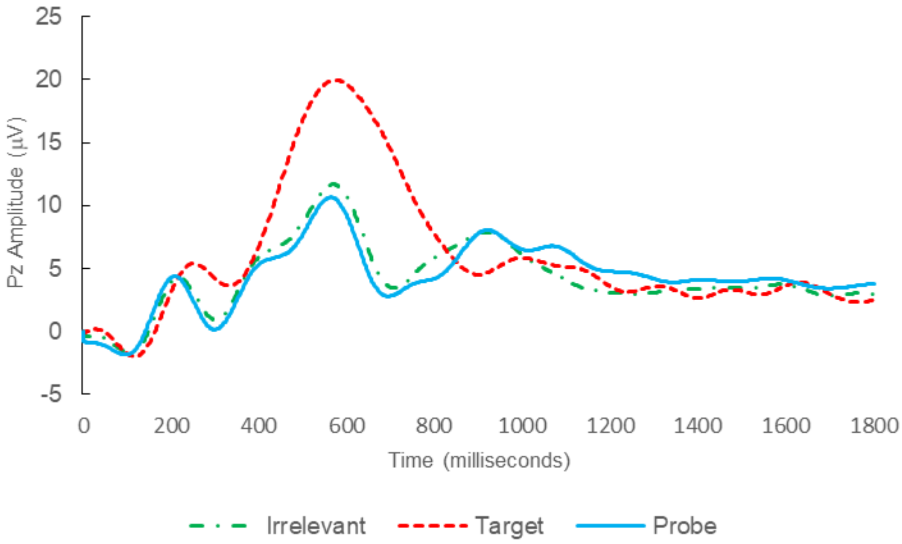
BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent. IA_C = Classified as Information Absent.

Figure K.30: BFP Response Waveforms of S06 in “Insect Repellent”, Experiment-1 (IA→IA_C)



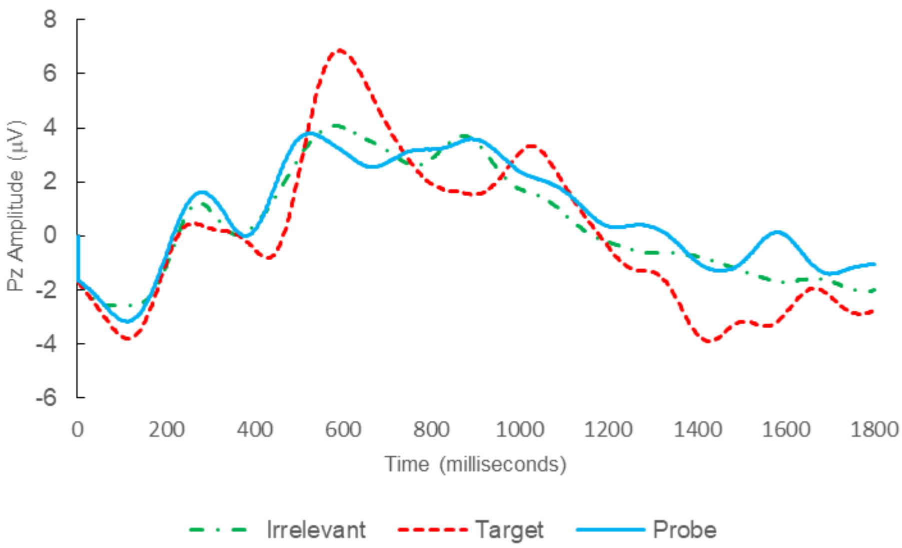
BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent. IA_C = Classified as Information Absent.

Figure K.31: BFP Response Waveforms of S08 in "Sustainability Prize", Experiment-1 (IA→IA_C)



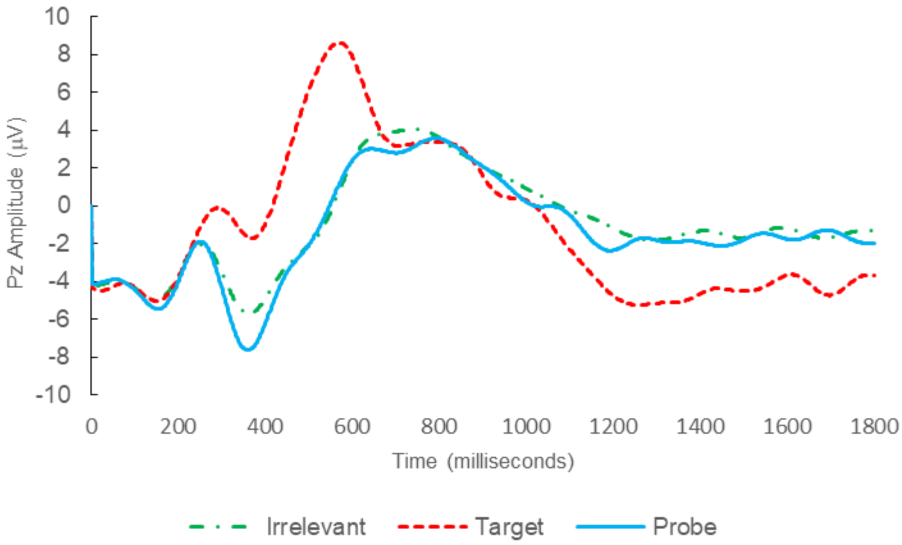
BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent. IA_C = Classified as Information Absent.

Figure K.32: BFP Response Waveforms of S10 in "Police Car", Experiment-1 (IA→IA_C)



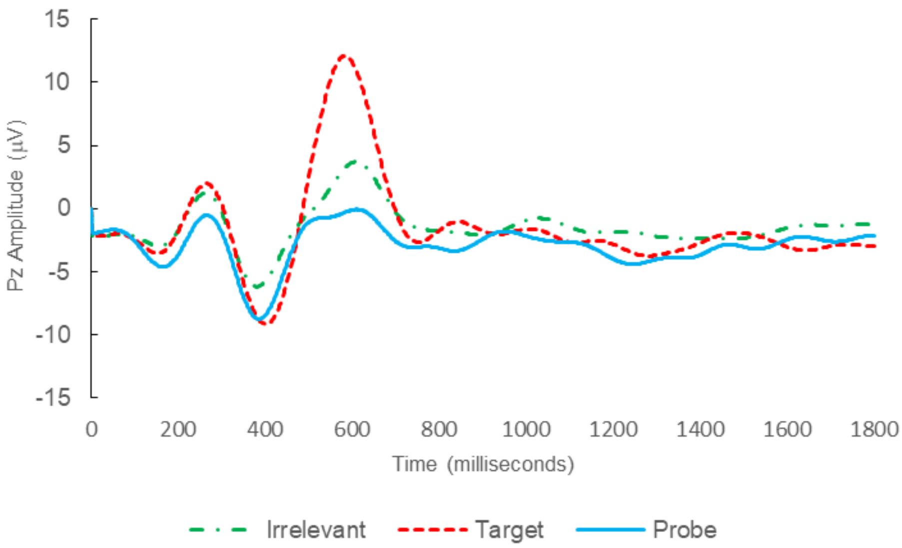
BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent. IA_C = Classified as Information Absent.

Figure K.33: BFP Response Waveforms of S13 in "Bush Fire", Experiment-1 (IA→IA_C)



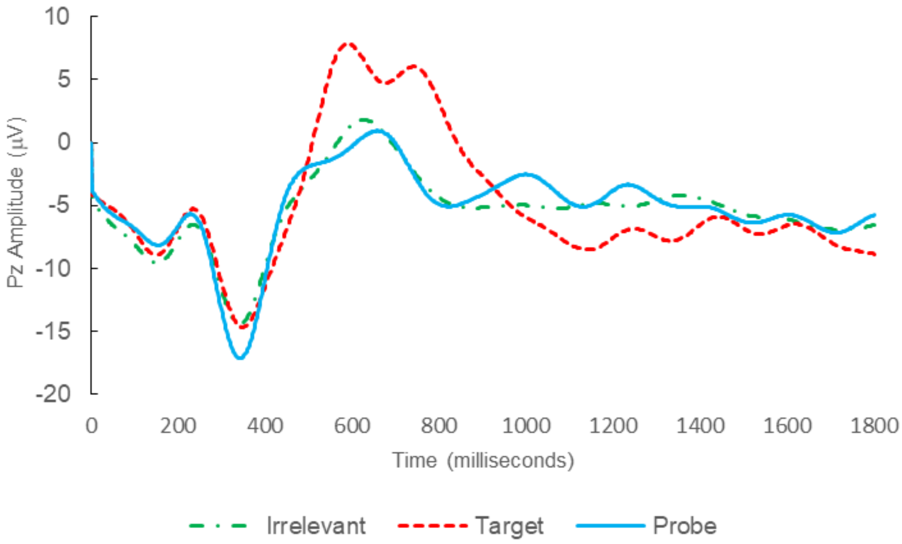
BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent. IA_C = Classified as Information Absent.

Figure K.34: BFP Response Waveforms of S15 in "Sea Witch", Experiment-1 (IA→IA_C)



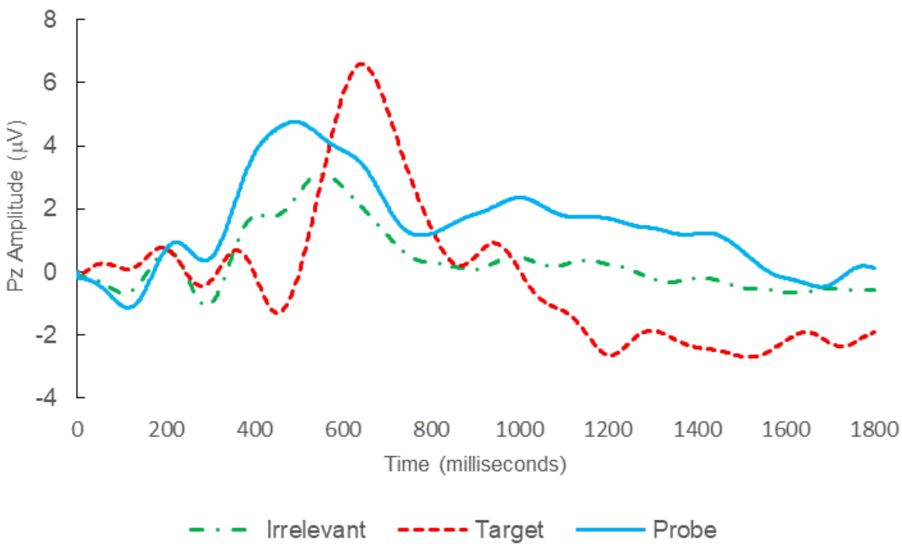
BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent. IA_C = Classified as Information Absent.

Figure K.35: BFP Response Waveforms of S17 in “Trip to Queenstown”, Experiment-1 (IA→IA_C)



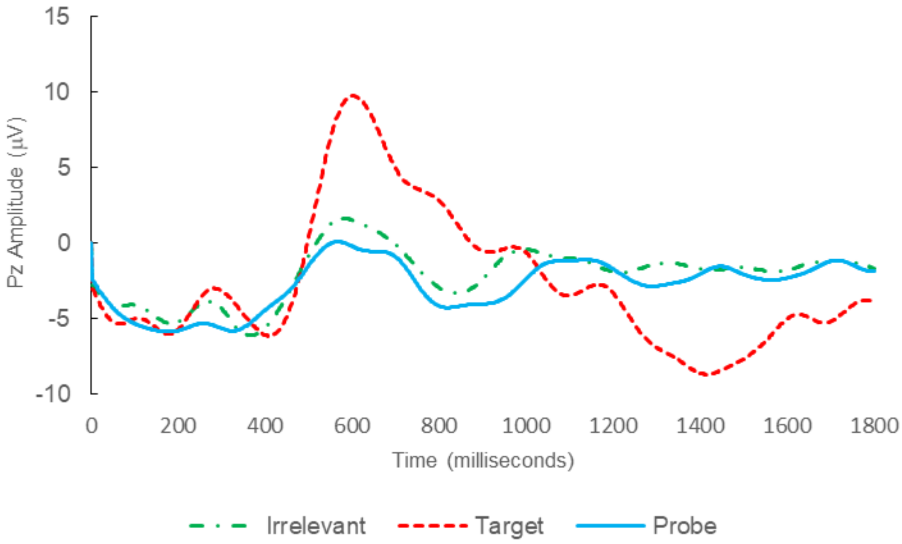
BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent. IA_C = Classified as Information Absent.

Figure K.36: BFP Response Waveforms of S19 in “Street Signs”, Experiment-1 (IA→IA_C)



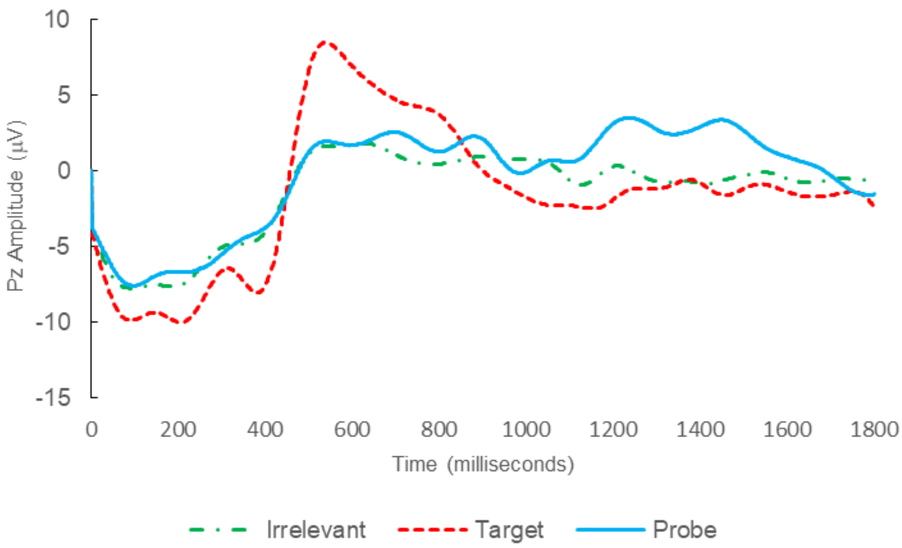
BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent. IA_C = Classified as Information Absent.

Figure K.37: BFP Response Waveforms of S21 in “Twelve Pubs of Xmas”, Experiment-1 (IA→IA_C)



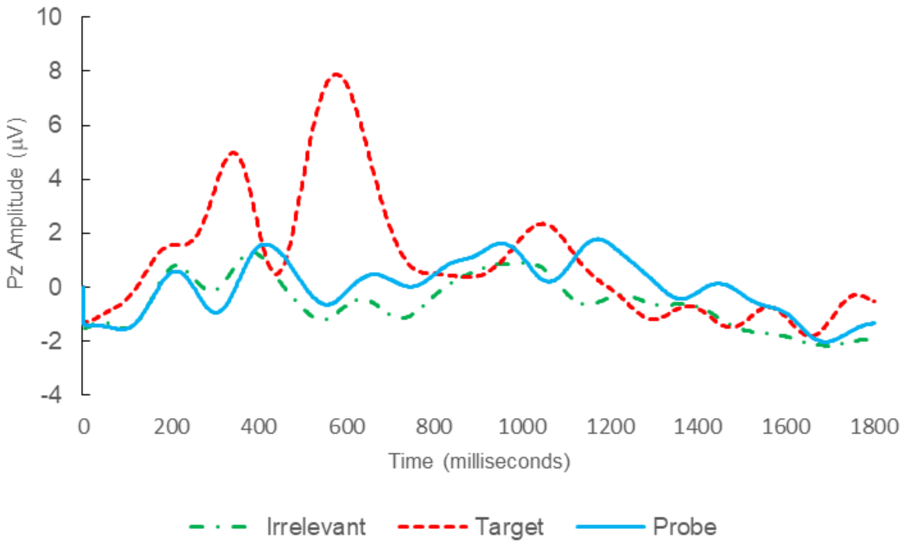
BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent. IA_C = Classified as Information Absent.

Figure K.38: BFP Response Waveforms of S23 in “Motion Sickness”, Experiment-1 (IA→IA_C)



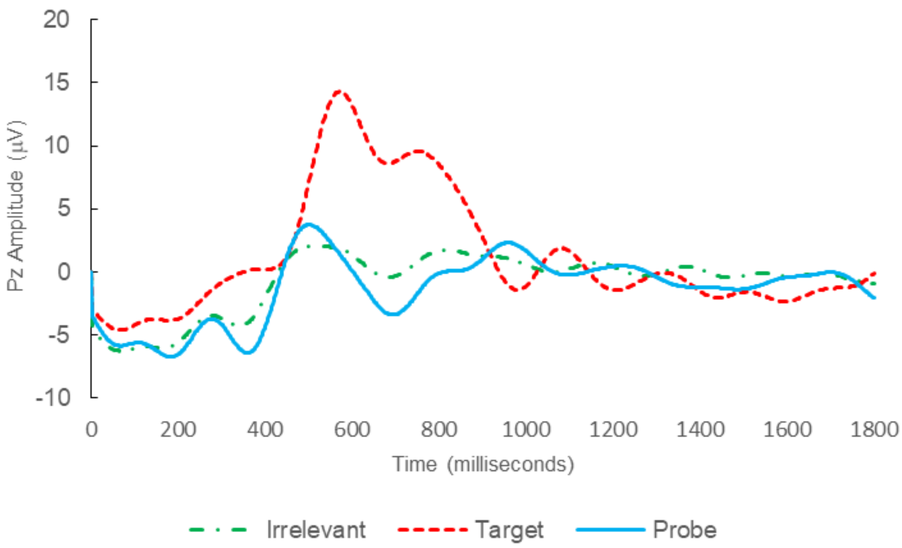
BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent. IA_C = Classified as Information Absent.

Figure K.39: BFP Response Waveforms of S25 in “Horse Riding”, Experiment-1 (IA→IA_C)



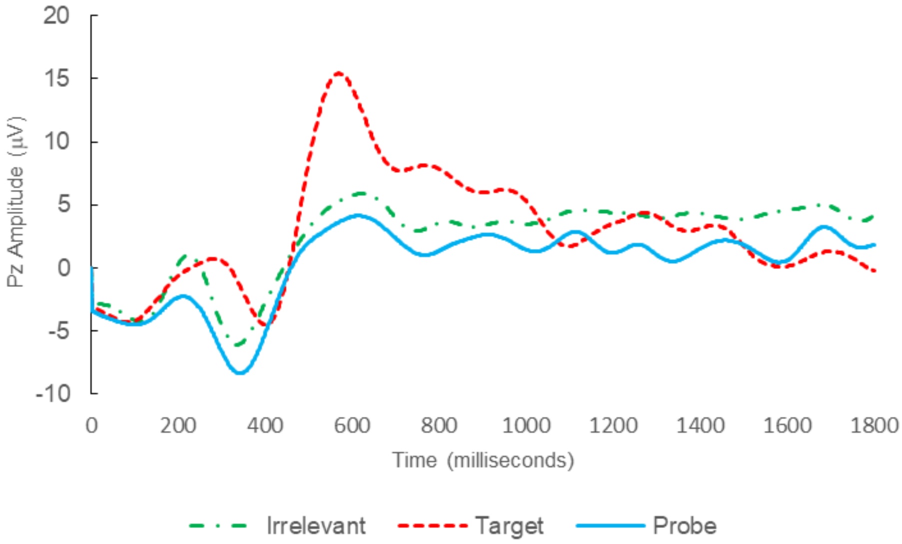
BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent. IA_C = Classified as Information Absent.

Figure K.40: BFP Response Waveforms of S33 in “Representing UC”, Experiment-1 (IA→IA_C)



BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent. IA_C = Classified as Information Absent.

Figure K.41: BFP Response Waveforms of S36 in "Trip to Vietnam", Experiment-1 (IA→IA_C)



BFP = Brain Fingerprinting. IA = Ground-truth Information-Absent. IA_C = Classified as Information Absent.