Mindfulness for Smoking-Cessation: A Behavioural and Neurophysiological Study

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Abstract

In recent years the effectiveness of skills-training, the mainstay behavioural treatment for smoking-cessation, has been questioned, providing a rationale to investigate alternative treatments.

We hypothesised that *mindfulness,* an emerging treatment for addiction, can reduce smoking by decreasing drug-related processing bias and remediating deficits in inhibitory control. Our study tested this in 37 smokers and 12 non-smokers at baseline, and at a 1–2 month follow-up after smokers used a 22-day long mindfulness-based smoking-cessation programme called *Craving to Quit* (C2Q), which was delivered via smartphone. Poor inhibitory control was defined as lower accuracy and lower amplitudes of the event-related potentials (ERPs), N2 and P3, elicited in a Go/NoGo task. Drug-related processing bias was defined as higher P3 and late positive potential (LPP) ERP amplitudes elicited for smoking images relative to neutral images, during an image slideshow task. The task also expected to show normal responding to pleasant and unpleasant images in smokers, shown by increased P3 and LPP amplitudes, compared to neutral images.

The study replicated a deficit in inhibitory control among smokers (reduced NoGo N2) but found no smoking-related processing bias at baseline. Unexpectedly, the study revealed blunted P3 amplitudes in response to all picture categories, except unpleasant, in smokers at baseline. We suggest that this may be reflective of an anhedonic state during acute withdrawal.

A large non-compliance rate led to a follow-up comparison limited to 11 smokers and 11 non-smokers. Although smokers showed significant reductions in average number of cigarettes smoked/day, they showed no change in self-reported craving. They also showed no change in processing to any of the picture categories. We suggest that limitations due to filtering hampered our ability to detect what appeared to be an increased late LPP at frontal electrodes for all categories, potentially reflecting increased awareness from mindfulness. Although smokers showed significantly lower NoGo accuracy compared to non-smokers at follow-up, they also showed increases in a neural marker of inhibitory control (NoGo P3). Further research is required to determine whether this reflects neural improvements preceding changes in behaviour, or reflects a compensatory increase in neural activity during a quit attempt.

Overall, our study suggests that mindfulness-treatment can reduce smoking when delivered via smartphone but we cannot confirm whether this is related to mindfulness, the app, being in the study or a quit attempt. Further research comparing C2Q to an alternative intervention group, is needed to further explore C2Q's mechanisms of action and whether it shows benefit over other apps.

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I am grateful for my participants, especially those who came to both sessions. I know that each session required a lot of patience.

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Abbreviations

ACC	Anterior cingulate cortex
ACT	Acceptance and commitment therapy
App	Application
BOLD	Blood oxygen level-dependent
C2Q	Craving to Quit
DA	Dopamine
E.LPP	Early LPP
EEG	Electroencephalograph
ERP	Event-related potentials
FFMQ	Five Factor Mindfulness Questionnaire
FFS	Freedom From Smoking
FDA	U.S. Food and Drug Administration
fMRI	Functional magnetic resonance imaging
FTND	Fagerstrom Test for Nicotine Dependence
IAPS	International Affective Picture Set
IFG	Inferior frontal gyrus
ISIS	International Smoking Image Series
L.LPP	Late LPP
LPP	Late positive potential (average positive amplitude over a 250–1000 ms time window between 400–2000 ms post stimulus onset)
MTSS	Motivation to Stop Scale
N2	Negative ERP peaking around 200–300 ms after stimulus onset
NRT	Nicotine-replacement therapy
NS	Non-smoker
P3	Positive ERP peaking around 300–500 ms after stimulus onset
PCA	Principal Component Analysis
PFC	Prefrontal cortex
Pre-SMA	Pre-supplementary motor area
QSU-brief	The Brief Questionnaire of Smoking Urges
QuitPal	NCI QuitPal
S	Smoker
S1	Session 1
S2	Session 2

1   Introduction

1.1   Overview of drug addiction and reward

Addiction is often described as a chronic relapsing brain disorder (Cadet, Bisagno, & Milroy, 2014; Kalivas & O'Brien, 2008) that can be conceptualised as a 3-stage cycle. In the first stage, a loss of control in regulating drug use leads to drug binging and intoxication. Following this is the second phase, drug withdrawal, which is characterised by negative affect (anhedonia). The third stage involves preoccupation and compulsions for the drug of addiction which ultimately leads to another binge episode (Wise & Koob, 2014). While addiction may begin from choice (drug experimentation), control becomes markedly disrupted as the disorder develops and individuals will seek drugs of abuse, even at the expense of serious adverse health or financial consequences (Camí & Farré, 2003; Volkow & Li, 2004).

Abnormal responding of brain reward networks to drugs of abuse is likely to play a key role in the development and maintenance of addiction. The magnitude of dopamine (DA) release in the nucleus accumbens (part of the so-called "reward system") is suggested to be at least 5–10 fold greater in response to drugs compared with natural reinforcers such as food and sex (Volkow & Li, 2004). This is also enhanced with repeated administration of drugs while repeated exposure to natural reinforcers leads to habituation of DA release (Vetulani, 2001). These supraphysiological changes to the dopaminergic mesolimbic reward system make individuals more likely to abuse drugs and to experience unpleasant drug craving with withdrawal (Vetulani, 2001; Volkow & Li, 2004).

While it is known that drugs can exacerbate DA release, the actual role of DA in initiation and maintenance of addiction is debated. Initial theories of drug addiction stemmed from early hypotheses linking DA and reward. The "anhedonia hypothesis" suggests that pleasure is directly mediated by DA and that blocking DA receptors would therefore block subjective experiences of pleasure (Wise, 1982). Following this hypothesis, other researchers suggested that negative emotional withdrawal states could be attributed to a hedonic dysregulation caused by suppressed DA neurotransmission during drug withdrawal (Koob & Le Moal, 2001). Drug taking is then reinforced by a drive to re-establish hedonic homeostasis.

Following R. A. Wise (1982), newer research has surfaced which questions the anhedonia hypothesis and its related theories of addiction. It is now believed that the involvement of DA in addiction is more related to anticipation of drug taking than the actual consumption (Berridge & Robinson, 1998; Chiara & Alan North, 1992). Support of this includes Berridge and Robinson's (1998) key finding in rats, which retained the ability to discriminate the hedonic properties of taste stimuli, even after they were given neurochemical lesions to their DA mesolimbic system. This was one of the first of many studies to suggest that DA is not necessary for hedonic processing, and that anhedonia is not necessary for increased craving and the maintenance of addiction. Other studies have shown dissociations of pleasure and drug taking in individuals addicted to cocaine and instances where DA antagonists fail to reduce amphetamine-induced pleasure. In addition, discharge of DA at the nucleus accumbens has been observed during anticipation of reward while not during the actual experience of it (Robinson & Berridge, 2000). This proposed link between DA and drug anticipation has led to the "Incentive Salience Hypothesis." Although incentive salience has been mentioned in earlier research, including Chiara & Alan North, (1992), its most well known documentation has been by Berridge and Robinson (1998). The incentive salience hypothesis separates the reward process into "wanting" and "liking" (hedonic) and asserts that they are mediated by different neural systems. Together, wanting and liking form "incentive salience," which describes the associations that change a neutral conditioned stimulus into an attractive and wanted incentive that can grab the attention. An important part of the incentive salience hypothesis is that DA systems are only necessary for attributing incentive salience to the drug of addiction and not necessary for hedonic processing as hypothesised by R. A. Wise (1982).

An alternative but complementary theory to the incentive salience hypothesis, is that proposed by Everitt & Robbins (2005). They suggested that drug taking is initially reinforced through instrumental learning of associations between actions (drug taking) and outcomes (drug effects). As addiction develops, environmental stimuli that are repeatedly paired with drug use (e.g., drug paraphernalia) can then act as triggers for consolidated drug seeking and drug taking actions. This occurs via the process of Pavlovian conditioning, which underlies the transit from controlled drug taking to uncontrollable drug habits (Everitt & Robbins, 2005).

Brewer and colleagues extended on these theories and formulated the "*addictive loop*" model for nicotine dependence (Brewer, Elwafi, & Davis, 2013). In this loop, stimulus-response associations are expanded, suggesting that both interoceptive (affect)

and exteroceptive (situation) cues can lead to increased drug craving and drug-use. In addition, these exteroceptive cues are not always explicitly drug-related. In examples by Brewer and colleagues eating a tasty meal (situation) can make an individual feel happy (affect) which can trigger a drug craving and drug use. Likewise, a boss yelling at someone (situation) can make that person feel stressed (affect) which can trigger drug craving and drug-use (Brewer et al., 2013). In addition to habits being maintained by incentive salience, they can also be maintained through operant conditioning. Through operant conditioning a positive memory formed after drug-use can reinforce an affect that was elicited by the same environmental cue that gains incentive salience, such as the memory of feeling better after drug use will increase incentive salience of the associated environmental cue, and negatively reinforce unpleasant affects associated with that cue. Likewise, positive reinforcement will occur for drug-use following a positive affect. This reinforcement then strengthens the association between drug-use and feeling better (Brewer et al., 2013).

Development of incentive salience for drugs of addiction and drug-related stimuli increases motivation for drug-use and facilitate the drug-seeking behaviour that is characteristic of addiction. Because of this, treatments for drug addiction should theoretically work by breaking down incentive salience within the addictive loop.

1.2 Nicotine addiction: a public health concern

The addictive potential of nicotine is well-documented. Although increased regulations restrict its use in public places, it is currently legal in New Zealand and most other countries around the world. As with other drugs of addiction, chronic use of nicotine is associated with perturbations to the brain reward system and increased drug-incentive salience. Its pleasurable psychoactive effects include arousal, relaxation, and improved mood, which can be attributed to its binding of nicotinic receptors, leading to the release of a number of neurotransmitters including, including monoamines, serotonin, acetylcholine, γ-aminobutyric acid (GABA), glutamate, and endorphins (Benowitz, 2008).

Up until mid-1960s there was little information regarding the impact of nicotine on health. Because of this, nicotine was regarded as fairly harmless, with about half of the American adult population smoking tobacco in 1965 (American Lung Association, 2011). Today, nicotine is recognised as the leading cause of preventable death, worldwide (Cahill, Stevens, Perera, & Lancaster, 2013). Cigarette smoking is estimated to kill half its users through respiratory diseases, cancers, and cardiovascular disease (Hoffman & Tan, 2015).

After news of tobacco's associated health risks became public in 1964, a steep decline in smoking rates followed (Henningfield, 2014). Despite this initial decline, in the last 3 years New Zealand has seen only a modest reduction of 3% with the adult daily smoking rate at around 15.5% (New Zealand Ministry of Health, 2014). This is far from New Zealand's goal of being smoke-free by 2025 (Ministry of Health NZ, 2011). In the United States over 65% of smokers want to quit annually but less than 10% achieve at least 6 months of abstinence (Centers for Disease Control, 2011). In addition, many smokers cannot easily quit in spite of these health risks (Fagerstrom, Heatherton, & Kozlowski, 1990). Havik & Maeland (1988) found that even after experiencing a heart attack, around 40% of smokers resumed smoking within 6 months. Similar results were observed in smokers following lung cancer surgery (Walker et al., 2006). It has been estimated that it takes an average of 3–4 quit attempts before an individual succeeds in quitting smoking (Raw, McNeill, & West, 1998). As well as highlighting nicotine's addictive potential, these statistics demonstrate the refractory nature of nicotine addiction and suggest a need for a new and accessible mainstay treatment for smoking-cessation. In searching for new mainstay treatment, both current pharmacological and current psychological interventions should be investigated for efficacy, accessibility and ability to be distributed cost-effectively, on a large scale. This is an important factor in achieving the goal of a smoke-free nation by 2025. In addition, the new mainstay treatment should show theoretical effectiveness in breaking down drug-incentive salience, and addiction habits, which are the proposed core of addiction.

1.3   Pharmacological interventions

Pharmacological agents for smoking-cessation currently approved by the U.S. Food and Drug Administration (FDA) include nicotine-replacement therapy (NRT), bupropion (Welbutrin, Zyban), and, most recently, varenicline (Champix). A recent meta-analysis has shown all three to be more effective than placebo with varenicline as the most effective (odds ratio of around 3.0) (Cahill et al., 2013). Bupropion and NRT were as effective as each other with an odds ratio of around 2.0; however efficacy of NRT increased to that of varenicline when 2 sources were used (e.g., gum and patches). Studies used in the above meta-analysis all included abstinence rates for at least 6 months follow-up from treatment initiation verified by 7-day point abstinence as well as levels of cotinine or expired carbon monoxide. Despite long-term efficacy, all of the above pharmacological agents have documented side effects, which may lead to users stopping treatment. Insomnia occurred in about 30–40% of patients

in trials of bupropion, along with dry mouth, nausea and, in some cases, seizures. Similar symptoms occur with NRT, as well as jaw pain and skin irritation in up to 54% of those using nicotine patches (Cahill et al., 2013). For varenicline, symptoms include nausea, insomnia and vivid dreams. Nearly 10% of participants in 2 phase-3 trials discontinued varenicline because of unpleasant side effects.

In addition to unpleasant side effects, which may lead users to stop treatment, it has been argued that pharmacological agents for smoking-cessation are not theoretically effective in breaking down nicotine addiction. Without breaking down the link between conditioned cues and smoking-related behaviours, individuals remain vulnerable to relapse which can occur even years after cessation (Kalivas & O'Brien, 2008). NRT, bupropion, and varenicline target nicotine addiction by temporarily decreasing drug compulsions and reducing unpleasant withdrawal symptoms. NRT and varenicline do this by binding to nicotinic acetylcholinergic receptors, and bupropion by inhibiting reuptake of monoaminergic neurotransmitters. Although reducing withdrawal symptoms and craving can lead to less likelihood of relapse, these benefits cease with end of treatment. Successful interventions for relapse-prevention should be able to reduce these symptoms long-term so that individuals can avoid needing to re-experience the unpleasant side effects of pharmacological treatments. While pharmacological treatments may prevent further development of new stimulus associations, they are not capable of reversing those that are already developed (Berridge & Robinson, 1998). Breaking down these associations are important in keeping smokers abstinent long-term.

1.4   Psychological interventions

The most widely used psychosocial intervention for smoking-cessation is counselling. The two main features of counselling include skills-training and therapeutic support; yet other interventions can be used in conjunction with counselling to enhance smoking-cessation. One of these additional interventions is aversive smoking, which is a process whereby individuals inhale quick and repeated puffs of cigarette smoke until they feel physically ill and incapable of inhaling more. The aim of aversive smoking is to turn a previously "pleasant" stimulus into an aversive stimulus. As well as being physically dangerous, there is insufficient evidence to support its efficacy (Hajek & Stead, 2001).

Another intervention for smoking-cessation is contingency management, which involves reinforcing short-term abstinence with monetary goals. Although contingency

management has shown some efficacy, any improvements are unlikely to sustain after contingencies are discontinued (Schlam & Baker, 2013). The latest additional intervention for smoking-cessation is exercise. Although exercise interventions have shown promise for smoking-cessation when used in conjunction with counselling (Marcus et al., 2005) more large-scale trials are needed to make robust conclusions (Ussher, Taylor, & Faulkner, 2014).

While there are several interventions that can be used in conjunction with smoking-cessation counselling, the most stable and foundational component of it is skills-training. The first part of skills-training involves teaching individuals to identify states and situations associated with increased smoking urges. Individuals are then taught cognitive and behavioural strategies for coping with these "high risk" situations. Strategies can include using cognitive reappraisal to reduce craving-induced negative moods, avoiding smoking-cues (e.g., not smoking inside and staying away from people who smoke), and distracting oneself from smoking-cues (e.g., using pleasant activities to distract oneself from cravings) (Schlam & Baker, 2013).

In addition to skills-training, another main component of counselling is therapeutic support. The importance of therapeutic support is highlighted by findings of only modest success in individuals who are taught skills-training in the form of self-help (Lancaster & Stead, 2005). Somewhat surprisingly, the efficacy of therapeutic support is not dependent on seeing individuals face-to-face. This was shown in a recent meta-analysis that suggests similar abstinence rates with both face-to-face and telephone counselling (Mottillo et al., 2009). The same review also showed little difference in success rates between individual and group counselling, indicating that therapeutic support is effective for smoking-cessation regardless of its form of delivery.

1.4.1 Smartphones

Over the last decade mobile phones have become increasingly useful around the world in providing health-related information and support, including that related to smoking-cessation (Whittaker, Borland, et al., 2012). Smartphones have promise in being a cost-effective way of delivering smoking-cessation treatment on a large scale. With increasing use of smartphones in the 21st century, this form of delivery is readily accessible to many of New Zealand smokers.

Routes for mobile-phone-based smoking-cessation interventions include text messaging and interactive applications (apps) that can be purchased from Apple or Google Play Store on smartphones. Although apps can provide an easy way to access help for

smoking-cessation, a recent content meta-analysis showed that available apps for smoking-cessation rarely adhere to any evidence-based theory of behavioural change. They include a range of components such as tracking of money savings and health benefits obtained over abstinence, calendars tracking target quit date, and instructions for cigarette cut-down (Abroms, Padmanabhan, Thaweethai, & Phillips, 2011). Although these features may be useful to a quit attempt, these features alone are not unlikely, at least theoretically, to promote behaviour change.

Two recently developed apps for smoking-cessation are based on the social cognitive theory. This theory suggests that individuals can learn behaviour and cognitive skills from observing models and this leads individuals to imitate those behaviours (Bandura, 1997). These apps have an advantage over previous apps in that they were developed from an established theory of behavioural change. One of these apps is called STUB IT and was developed by The Clinical Trials Research Unit at Auckland University, New Zealand (Whittaker, Merry, Dorey, & Maddison, 2012). The app includes texts and videos of role models designed to enhance self-efficacy for quitting. This is a useful target for smoking-cessation interventions as low self-efficacy is a risk factor for relapse (Schlam & Baker, 2013), however, a randomized controlled trial showed that STUB IT was no more effective than a control group who received regular health-related text and video messages (Whittaker et al., 2008). A similar app to STUB IT called REQ-mobile was also based on the social cognitive theory (Buller, Borland, Bettinghaus, Shane, & Zimmerman, 2014). REQ-mobile sends messages involving skills-training strategies and audio testimonials of ex-smokers (quit role models). REQ-mobile was found less effective than a simpler version of the intervention, consisting only of the texts of skills-training strategies. The researchers concluded that the audio testimonials were not useful for participants, suggesting that quit role models give little additional benefit to quit success over skills-training.

Another intervention developed by Auckland University, that involves skills-training as well as peer and therapeutic support, is called STOMP. This was a personalized 4-week text-based intervention, which pulled texts from over 1000 messages (half cessation-based, half general interest) developed by a multidisciplinary team of young adults, Maori health researchers, and experts in adolescent health, nutrition, CBT, and smoking-cessation. Text messages were chosen for each participant based on personal preferences, smoking history, barriers to cessation, etc. Personal preferences were also used to pair participants of similar interests as quit-buddies. In a large randomised controlled trial (1705 participants), researchers found that significantly more participants had quit with STOMP (28%) than in the

control group (13%) at 6-week follow-up (Rodgers et al., 2005). The above studies suggest that, as with counselling, the most useful components of mobile-phone-based interventions for smoking-cessation are skills-training plus peer and therapeutic support.

SmartQuit is a more recently developed smartphone app for smoking-cessation, which follows an alternative intervention for behaviour change called Acceptance and Commitment Therapy (ACT) (Bricker et al., 2014). ACT encourages individuals to increase their willingness to experience emotions, thoughts, and physical cravings while making committed and values-guided changes in behaviour. The key features in SmartQuit include the "I Slipped" and "Having an Urge" buttons which replace skills-training strategies for dealing with craving. Clicking on the above components provides the user with acceptance skills that can be used to cope with cravings, lapses, and the self-judgments that often accompany them. In a randomized control pilot trial, SmartQuit showed significantly larger quit rates (13%) to another app called QuitGuide (8%), based on skills-training (Bricker et al., 2014). Although these quit rates are small, the authors admit that the study was underpowered to detect differences in quit-rates and it is suggested that a full-scale efficacy trial is now needed (Bricker et al., 2014). Another reason for small quit rates could be because of the rigorous 30-day point prevalence definition used for abstinence in Bricker et al. (2014). Abstinence would have been more difficult to achieve in this study than others, which used only a 7-day point prevalence definition (Rodgers et al., 2005).

Two other apps currently being compared to each other are NCI (National Cancer Institute) QuitPal (QuitPal) and Craving to Quit (C2Q) (Penberthy, 2014). Both apps are based on evidence-based practice for smoking-cessation, including skills-training techniques and mindfulness, for QuitPal and C2Q, respectively. See section 1.6 for more on mindfulness and C2Q.

Overall, skills-training and therapeutic support appears to be the most well studied, beneficial psychological treatments available for smoking-cessation. These factors are core components of counselling, which can be delivered with equal effectiveness individually, in a group, over the telephone and more recently, via smartphones. Despite support for skills-training, recent evidence suggests that alternative interventions such as ACT may be more effective (Bricker et al., 2014) and that the efficacy of skills-training may be declining. A recent analysis of clinical trials that used skill training for smoking-cessation suggest that as smoking prevalence has declined, the remaining treatment-seeking smokers have become difficult to treat (Irvin & Brandon, 2000). In addition to this, a skills-training based smoking-cessation service in NZ called "Quitline," shows room to improve with a quit rate of only

24% (Gravitas, 2012). Because Quitline is the national government-supported service for smoking-cessation in NZ, it is important that it provides the most effective and up-to-date techniques for aiding smoking-cessation.

In addition to declining efficacy, some researchers suggest that skills-training has limited effectiveness because it fails to target the core problem of addiction (Brewer et al., 2011). As with pharmacotherapy, distraction and avoidance techniques are theoretically incapable of breaking down incentive salience attributions, but may be effective at reducing craving thus facilitating psychological interventions. Without breaking down these attributions, individuals remain vulnerable to relapse. With the goal of a smoke-free nation by 2025, New Zealand is in need of an alternative mainstay treatment for nicotine-cessation, protecting against relapse. In order to find such a treatment, neurobiological and psychological abnormalities associated with addiction should be studied. One can then hypothesise which and how alternative treatments will work.

1.5   Identifying deficits that maintain smoking addiction

Two neurobiological and psychological abnormalities that have been consistently shown in addiction are impaired inhibitory control and abnormal processing of drug-related and affective stimuli. Normalising these two processes may dismantle previous maladaptive associations and prevent against relapse.

1.5.1   Image processing bias

1.5.1.1   Behavioural measures

Individuals with addiction often exhibit an attentional bias. This describes an automatic tendency to increase attendance and processing of substance-related cues (Littel & Franken, 2011). Behavioural paradigms used to elicit attentional bias usually involve measuring a participant's performance on a simple cognitive task (e.g., sustained attention). Attentional bias is inferred when task performance is impaired during the presence of substance-related cues (e.g., image of a cigarette) compared to neutral cues (M. Field, Munafò, & Franken, 2009). Impaired performance during substance-related cues has been shown for a range of addictions including alcohol (Lusher, Chandler, & Ball, 2004), cannabis (Cousijn, Watson, Koenders, Vingerhoets, Goudriaan, & Wiers, 2013), heroin (Franken, Kroon, Wiers, & Jansen, 2000), cocaine (Hester, Dixon, & Garavan, 2006), ecstasy (Roberts & Garavan, 2013), and nicotine (Grundey et al., 2015).

1.5.1.2   Neural measures

Another way to measure drug-related attentional bias is by recording event-related potentials (ERPs) including the P3 component (also called the P300 component) and late positive potential (LPP) during passive viewing of substance-related images. The P3 is a large positive deflection peaking at approximately 300 ms after stimulus onset (Sutton, Braren, Zubin, & John, 1965). The P3 is typically recorded between 270–600 ms after stimulus onset at frontal–parietal electrodes (Asmaro, Carolan, & Liotti, 2014; Engelmann, Gewirtz, & Cuthbert, 2011; Fehr, Wiedenmann, & Herrmann, 2006; Han et al., 2014; Jang, Lee, Yang, & Lee, 2007; Juckel et al., 2012; Littel & Franken, 2007; Lubman, Allen, Peters, & Deakin, 2007; Sarlo, Übel, Leutgeb, & Schienle, 2013; van Dinteren, Arns, Jongsma, & Kessels, 2014). The P3 has been traditionally studied using oddball paradigms in which it is enhanced for infrequent target stimuli. Because of this it is believed to reflect deployment of attentional resources to target-relevant stimuli and, more recently, to motivationally salient stimuli that are also "target-relevant." In healthy individuals, the P3 is enhanced for pleasant and unpleasant stimuli relative to neutral, also for threat stimuli in people with generalized anxiety disorder (Han, Gan, Li, Li, Guo, & Yao, 2014), food stimuli in fasting individuals (Baldeweg, Ullsperger, Pietrowsky, Fehm, & Born, 1993), and substance-related stimuli in drug addiction: cannabis (Asmaro et al., 2014), alcohol (Namkoong, Lee, Lee, Lee, & An, 2004), opiates (Lubman et al., 2007), and nicotine (Littel & Franken, 2007; McDonough & Warren, 2001; Versace et al., 2011).

The LPP is another positive component related to processing of motivationally salient stimuli, which occurs from about 400 ms and lasts up to several seconds after stimulus presentation. Like the P3, the LPP is reliably enhanced following presentation of pleasant and unpleasant images compared to neutral ones (Foti, Hajcak, & Dien, 2009) and for substance-related stimuli in addicted populations (Dunning et al., 2011; Littel & Franken, 2011). Differentiation between the P3 component and the LPP can be difficult, which may be largely in part due to the overlapping time-windows that are used to define them. It is often the case that one study will use the same time window to define LPP as has been used in another study to define the P3 (Hajcak, MacNamara, & Olvet, 2010). Using temporal-spatial principal component analysis (PCA) Foti et al., (2009) suggested a separation within the LPP component and possibly a separation of the P3 from the late portion of the LPP. The initial portion of the LPP (300–600 ms) is considered to be consistent with the P3, while the later portion (> 600 ms) reflects additional processes relevant for emotional processing. In addition

to this, LPP appears to shift from parietal to more frontal sites within 1–2 s after stimulus onset (Foti et al., 2009). While the P3 and early part of LPP component appear to be similar, the P3 is a more transient potential, generally measured as peak amplitude (Littel et al., 2011). In contrast, the LPP is a more sustained potential that is measured as average amplitude within a 250–1000 ms time-window between 400–2000 ms after stimulus onset. Because of this, the P3 and LPP components cannot be thought of as identical and it is suggested that while the P3 reflects initial allocation of attentional resources to motivationally-salient stimuli, the LPP may reflect more additional and continued processing involving memory encoding and storage (Littel & Franken, 2011).

An enhanced P3 amplitude can therefore be considered to reflect an attentional/initial image processing bias while an enhanced LPP amplitude can be considered to reflect a continued image processing bias. Both of these can then be interpreted under the term, "image processing bias." Figure 1.1 shows a schematic of a typical ERP waveform elicited by an image slideshow. This was taken, and adapted from Littel & Franken (2011).

Additional information in defining the P3 and LPP can be achieved by looking at their location. ERPs do not indicate the exact location of the P3 and LPP but previous studies recording simultaneous functional magnetic resonance imaging (fMRI) and electroencephalograph (EEG) provide suggestions. Liu and co-workers found that among healthy participants viewing pleasant images, LPP was coupled with blood oxygen level-dependent (BOLD) activity in emotion-processing structures including the amygdala and prefrontal cortex (PFC) (Liu, Huang, McGinnis-Deweese, Keil, & Ding 2012). Because the LPP was defined as average amplitude between 300–600 ms, and was strongest among parietal regions, the study is likely to have inadvertently measured P3 as well. A similar study measured fMRI activity associated with LPP defined as average amplitude between 450—900 ms, which by Foti et al.'s (2009) definition, overlaps the time window of both P3 and LPP. This study found associated activity in subcortical and corticolimbic structures including the nucleus accumbens, amygdala and anterior cingulate cortex (ACC) (Sabatinelli, Keil, Frank, & Lang, 2013). In both studies, LPP was defined at only parietal or centroparietal electrodes. More information regarding LPP from EEG-fMRI could be achieved by measuring responses at later latencies and more frontal electrodes. Perhaps a better estimate of brain regions associated with LPP could be achieved by defining LPP in a later time window and at anterior electrodes. While it is difficult to determine if each potential is related to separate brain regions, findings from simultaneous fMRI-EEG recording suggest involvement of cortical and subcortical regions with both the P3 and LPP. This supports their hypothesised

involvement in emotion, attention, and cognitive processing which are enhanced for drug-related stimuli in addicted populations.
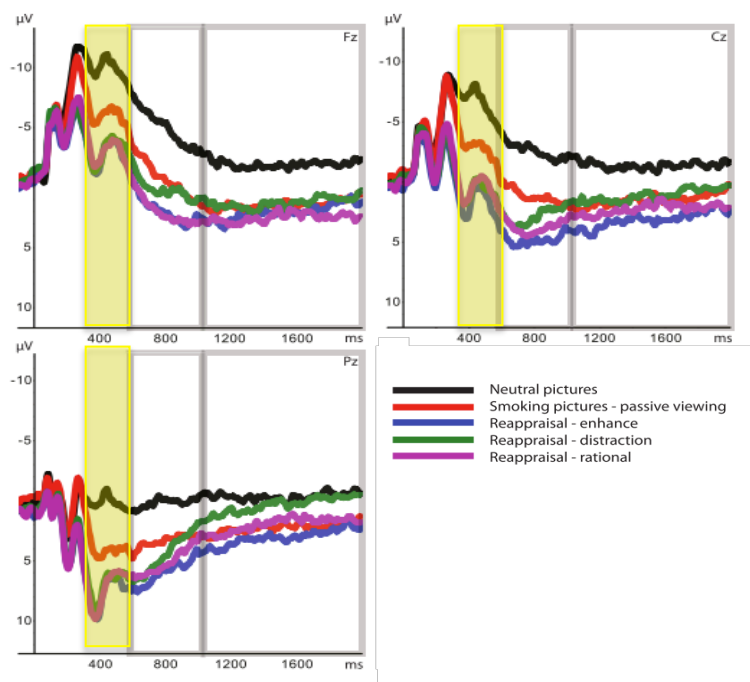
Figure 1.1. ERPs of smokers in response to neutral and smoking images (see key) at FZ, CZ, and PZ. Yellow rectangles depict the P3 time-window (300–500 ms). Left, grey-boarded rectangles depict the early LPP time window (600–1000 ms) and those on the right depict the late LPP time window (1000–2000 ms) (adapted from Littel & Franken, 2011).

1.5.1.3 Relevance

Through developing addiction, brain reward systems are suggested to become "hypersensitive" to stimuli that have been attributed with incentive salience (Berridge & Robinson, 1998). In addition to the drug, itself, incentive salience can also develop for drug-related environmental stimuli (e.g., drug paraphernalia) through Pavlovian conditioning involving repeated associations of environment and drug-use. The P3 and LPP could therefore represent useful neural markers of incentive salience for drugs and drug-related stimuli. Supporting the usefulness of measuring P3 and LPP in addiction are studies correlating drug-related image processing bias with key behavioural outcomes in addiction. Both behavioural and neural indicators of increased image processing bias to smoking cues has been related to increased self-reported craving (Littel & Franken, 2007, 2011) and increased likelihood of a short-term lapse (Janes, Pizzagalli, Richardt, Frederick, Chuzi, Pachas, Culhane, Holmes,

Fava, Evins, & Kaufman 2010; Waters, Shiffman, & Sayette, 2003) while decreased smoking-related image processing bias may relate to success in long-term abstinence. Nestor, McCabe, Jones, Clancy, & Garavan (2011) recorded fMRI activity during an image processing bias paradigm where participants had to indicate the colour of borders surrounding neutral, pleasant, or smoking images. Ex-smokers who had abstained for at least 12-months were shown to have significantly less activity in subcortical areas than current smokers during presentation of smoking images. This suggests that decreased reactivity to smoking-related images is related to successful smoking-cessation. In another study, ex-smokers, compared to current smokers, showed smaller peak P3 and smaller mean amplitude between 500–750 ms during a visual slideshow of smoking-related cues. Amplitudes of ex-smokers were as low as those observed in never-smokers (Littel & Franken, 2007). Longitudinal studies would help indicate if these neural changes are a cause or effect of smoking cessation.

In addition to bias for drug cues, responses to intrinsically pleasant cues (e.g., food and sex) may be blunted in smokers. In a study by Versace et al. (2012) smokers who showed a stronger bias to smoking cues (average amplitude between 400–700 ms post-stimulus) had a blunted response to pleasant stimuli (e.g., images of food and erotica). Individuals with a "blunted response" were also less likely to be abstinent at 12 and 24 weeks follow-up in a smoking-cessation trial. This suggests that treatment-refractory smokers are less responsive to intrinsically pleasant images than treatment-responsive smokers. This could be due to the possibility of treatment-refractory smokers being more sensitive to anhedonia during withdrawal than treatment-responsive smokers. However, it does not follow that smokers are less responsive to intrinsically pleasant images than non-smokers. In comparison to non-smokers, smokers showed significantly larger average amplitudes between 400–600 ms post-stimulus in response to erotic images (Minnix et al., 2013). No significant differences were observed for neutral, unpleasant and low-arousal pleasant images. This suggests that smokers are more sensitive to highly arousing pleasant images than non-smokers. This however, is the only study to our knowledge that has compared smokers to non-smokers on pleasant and negative image categories. Therefore more research is needed to consolidate the findings of Minnix et al. (2013).

A recent study showed evidence of modulating drug-image processing bias with behavioural manipulation. Littel & Franken (2011) showed decreased early LPP (600–1000 ms) in response to smoking images for individuals who either imagined alternative interpretations of smoking images or actively focused on alternative stimuli in the smoking images. This study provided promise for the ability of behavioural interventions to modulate

drug-image processing bias. Interventions that resolve abnormalities of P3 and LPP during presentation of smoking-related and affective images could show efficacy for smoking-cessation.

1.5.2 Inhibitory control

1.5.2.1 Measures

In addition to abnormal processing of affective and drug-related stimuli, smokers have also shown deficits in markers of early inhibitory control. Inhibitory control can be defined as the ability to inhibit automatic but task-inappropriate behaviour (Powell, Dawkins, West, Powell, & Pickering, 2010) and can be measured by behavioural accuracy in a range of cognitive tasks. One of these tasks is called the "Go/NoGo" task in which individuals are required to press the spacebar in response to frequently occurring target stimuli ("Go") and refrain from pressing spacebar during infrequent displays of non-target stimuli ("NoGo"). In addition to behavioural accuracy, two other measures of inhibitory control are ERPs called N2 and P3.

N2 is a negative waveform occurring anteriorly approximately 200–300 ms following presentation of non-target stimuli. It has been consistently related to performance on the Go/NoGo task (Falkenstein, Hoormann, & Hohnsbein, 1999) and is suggested to be a more sensitive measure of inhibitory control than task accuracy (Buzzell, Fedota, Roberts, & McDonald, 2014). Initially it was believed that N2 reflected "response inhibition" which defines the neural process of inhibiting a motor response (Jodo & Kayama, 1992). Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof (2003) challenged this definition by showing enhanced N2 for low frequency target stimuli as well as low-frequency non-target stimuli, dissociating N2 from inhibition of motor activity. Instead of response inhibition, Nieuwenhuis et al., (2003) suggested that N2 indicates a monitoring of response conflict (conflict-monitoring), which occurs when two opposing response tendencies are activated (e.g., Go vs. NoGo). In a recent review of ERP and fMRI measures of inhibitory control, Luijten et al. (2014) concluded that N2 is indicative of early cognitive processes important for inhibitory control rather than actual inhibition of the motor system. Consistent with previous studies, we will assume that reduced NoGo N2 amplitudes indicate impaired conflict-monitoring, representing an early process important for efficient inhibitory control.

The anatomical location of N2 was investigated by Gonzalez-Rosa et al. (2013) who measured ERPs inside an MRI scanner in healthy participants performing a modified version

of the Go/NoGo task. Results showed BOLD activations within the rostral anterior cingulate cortex (ACC) and pre-supplementary motor area (pre-SMA) during the NoGo N2 time frame, which suggests that the ACC and pre-SMA are generators of the N2. Luijten et al. (2014) suggested that the ACC and inferior frontal gyrus (IFG) are generators of the N2. The ACC and pre-SMA have been consistently related to measures of inhibitory control (Luijten et al., 2014) and have even been specifically related to conflict monitoring (Maier & di Pellegrino, 2012; Nachev, Wydell, O'Neill, Husain, & Kennard, 2007). Therefore the above studies add to the reliability of N2's involvement in early cognitive control.

A second ERP shown to be related to inhibitory control in the Go/NoGo task is the NoGo P3, which is a positive component, peaking between 300–500 ms after stimulus onset at central electrode sites (Luijten, Littel, & Franken, 2011). While in oddball paradigms increased P3 reflects responding to more "target-relevant" stimuli, in this task it supposedly reflects the late stage of inhibitory control. Studies show larger P3 amplitudes in tasks where individuals need to refrain from an overt motor response compared to refraining from a covert response (e.g., counting) (Smith, Jamadar, Provost, & Michie, 2013). This suggests that, unlike N2, P3 in the Go/NoGo task is related to actual inhibition of the motor cortex (Smith et al., 2013). Throughout the thesis we will refer to positive ERP activity within 300–500 ms after stimulus presentation as the P3. In the context of the image slideshow task this will reflect attentional processing, while in the Go/NoGo task it will reflect early motor inhibitory control.

Figure 1.2 shows a schematic of a typical waveform elicited in a Go/NoGo task, adapted from Buzzell et al (2014).
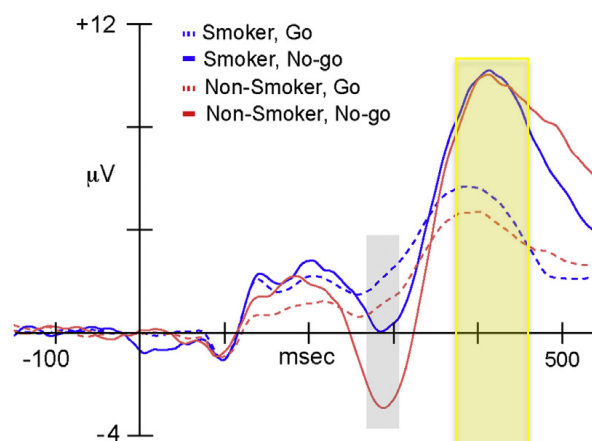

Figure 1.2. Figure of grand averaged ERPs for frontocentral cluster of electrodes in response to Go and NoGo stimuli in a Go/NoGo task. Grey rectangle indicates the N2, while yellow rectangle indicates the P3 (adapted from Buzzell et al., 2014).

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1.5.2.2 Relevance

Smokers have shown reduced NoGo N2 amplitudes (Luijten et al., 2011; Buzzell et al., 2014), and reduced NoGo P3 amplitudes and increased NoGo P3 latencies (Yin et al., 2015), and decreased accuracy (Luijten et al., 2011; Yin et al., 2015) in the Go/NoGo task relative to controls. Luijten et al. (2011) showed that reduced NoGo N2 amplitude difference was not restricted to smoking-related images, which suggests that smokers have a generalized deficit in inhibitory control processes. While Buzzell et al. (2014) found reduced NoGo N2 amplitudes in smokers; they observed no impairment in behavioural performance on the Go/NoGo task in smokers compared to controls. Because their sample of smokers had low nicotine dependence, they suggest that more significant behavioural differences may have occurred in a sample of moderately nicotine-dependent smokers.

Reduced amplitudes of both NoGo N2 and P3 have also been observed in other impulsive populations including internet addiction disorder (Dong, Lu, Zhou, & Zhao, 2010), borderline personality disorder (Ruchsow et al., 2008) and violent offenders (Chen, Tien, Juan, Tzeng, & Hung, 2005). This suggests that low inhibitory control is related to higher levels of impulsivity. Because higher levels of impulsivity has shown to be related to faster relapsing in smokers (Doran, Spring, McChargue, Pergadia, & Richmond, 2004), NoGo N2 and P3 amplitudes may also have the potential to predict speed to, and likelihood of a relapse. In support of this, ex-smokers have shown better performance in the Go/NoGo task and higher levels of prefrontal cortical activity during NoGo trials than current-smokers (Nestor et al., 2011). Because these areas included the ACC and frontal gyri, which are the suggested neural generators of N2, it can be hypothesised that increased NoGo N2 and perhaps P3 would also correlate with successful abstinence.

The above studies show that image processing bias and inhibitory control are two psychological and neurobiological factors that consistently show abnormalities among those with nicotine addiction. Furthermore, they have been related to changes in relapse, quit rates, long-term abstinence, and craving. Because of this, it is logical to assume that an intervention that could resolve these psychological and neurobiological abnormalities would also produce successful smoking-cessation. A relatively new intervention that has already shown success in quit rates and sustained abstinence is *mindfulness* (Brewer et al., 2011). Although not yet confirmed, research into mindfulness suggests that it may enhance quit rates through resolving abnormalities in inhibitory control and in attentional and affective processing of smoking-related stimuli.

1.6 Mindfulness: An eligible candidate for a new mainstay treatment for nicotine addiction

1.6.1.1 Origins

Mindfulness is the Western translation for the Pali term "Sati" which originated from Theravada Buddhism (early Buddhism). In Theravada Buddhism, Sati is the 7th step of the Noble eightfold Path to ending suffering and describes a deliberate awareness, where one keeps one's mind alert to phenomena that affect the mind and body (Sedlmeier et al., 2012). Since being adopted in Western psychotherapy, the qualities of mindfulness have expanded to include not only awareness, but also non-judgement, acceptance, and compassion (Siegel, Germer, & Olendzki, 2008). Those practising mindfulness learn to focus on moment-to-moment sensations, perceptions, emotions, and cognitions while avoiding rumination of the past and future (Garland & Howard, 2013). This reduces suffering and improves emotional regulation (Siegel et al., 2008). The process of becoming more mindful is cultivated through *formal meditation* where one focuses one's awareness (e.g., on the physical sensations of the breath) in the present moment and in a nonjudgmental way. Formal practice improves ability of individuals to practise mindfulness "informally." Mindful walking is an example of informal practice, during which one focuses on awareness of their most predominant sense within each moment-to-moment experience (e.g., pressure on feet, birds tweeting, leaves blowing).

1.6.1.2 Application

Mindfulness as a therapy has been tailored to different mental illnesses showing clinical success for chronic pain (la Cour, & Peterson, 2015), depression (Strauss, Cavanagh, Oliver, & Pettman, 2014), and, recently, addiction (Brewer et al., 2011). The application of mindfulness to aiding smoking-cessation is a relatively new and promising area of research. In a randomized control trial, mindfulness produced a significantly higher rate of 7-day point prevalence abstinence (31%) at 17-week follow-up than the Freedom From Smoking (FFS) (6%) intervention, a well-known skills-training counselling intervention developed by the American Lung Association (Brewer et al., 2011; Elwafi, Witkiewitz, Mallik, Iv, & Brewer, 2013).

Through mindfulness, smokers learn to observe and accept their cravings without acting on them. They are taught this through the use of analogies and metaphors such as "urge surfing." This technique suggests that the listeners imagine their own cravings as waves.

They are encouraged to "ride" the waves through their natural intensity and fluctuations instead of resisting or giving into them (Marlatt & Gordon, 1985). This is similar to the acceptance strategy used in the SmartQuit app discussed above, which showed higher efficacy than an app based on skills-training (QuitGuide) (Bricker et al., 2014).

In a smoking-cue exposure exercise by Bowen & Marlatt (2009), smokers were instructed through a set of steps, which resulted in drawing a lighter towards a cigarette in the mouth without igniting it. Within this exposure exercise, participants were given suggestions of how to cope with arising cravings. They were told either to use their "usual techniques" (control) or to non-judgmentally observe their thoughts and sensations and "surf" their cravings (mindfulness). At 24-hour and 7-day follow-up, those in the mindfulness condition showed a higher reduction in number of cigarettes smoked/day compared to the control condition. Interestingly, there was no difference in recorded urges, suggesting that mindfulness, at least initially, does not reduce level of urges but rather the responses to those urges. Elwafi et al.'s (2013) study expanded on this finding by showing that a 4-week mindfulness intervention decoupled the positive correlation commonly observed between craving and smoking. It has been suggested that breaking this link may be a critical target in long-term success of smoking cessation (Brewer, et al., 2013). As a result, these findings have contributed to the development of a smartphone application called *Craving to Quit* (https://cravingtoquit.com). This is a 22-day programme that incorporates mindfulness techniques and is currently being tested in 2 separate studies, against daily experience-sampling (of craving and smoking status) (Garrison et al., 2015), and another app called *QuitPal* (http://smokefree.gov/apps-QuitPal), which is based on skills-training (University of Virginia, 2014). Experience-sampling is a method of collecting data at multiple time points across an extended testing period (e.g., > 1 week) and is useful for tracking progress during of after an intervention.

Mindfulness is unlike skills-training strategies, which attempt to reduce unhelpful habits by cue avoidance, increasing positive affect, diverting attention, and substituting behaviours. Diverting attention may be unsuccessful because it requires cognitive resources, which can be depleted with increased negative affect (Brewer et al., 2011). Substituting behaviours and avoiding cues may be less successful because they do not directly dismantle the addictive loop and simply leave it dormant to be reactivated at another time (Brewer et al., 2013). Mindfulness is suggested to be a more promising intervention than skills-training for preventing relapse as it directly dismantles the addictive loop, in part by breaking down unhelpful associations between affect and craving (Brewer et al., 2011). Those who practise

mindfulness learn to sit with and accept their cravings while not reacting to them. This avoids reinforcing unhelpful associations such as "I feel better when I smoke" and is likely why mindfulness is able to decouple the relationship between craving and smoking (Brewer et al., 2013), and break down the persistent association between drug cues and responses.

1.6.1.3 Neural mechanisms

Only one study has linked mindfulness-associated smoking reduction with potential neurobiological mechanisms. In this study by Tang, Tang, & Posner (2013), smokers were randomly assigned to a 2-week meditation programme involving mindfulness or a control condition with relaxation training. Those in the mindfulness condition showed increased resting state activity in the PFC and ACC post-intervention compared to pre-intervention. In addition they showed significantly reduced smoking and craving. These effects were specific to the mindfulness condition. Because increased activity was observed in brain areas associated with self-control (ACC, PFC), Tang et al. (2013) suggest this is a mechanism through which mindfulness reduces smoking.

Other studies have provided evidence of mindfulness increasing neural markers of early inhibitory control in non-smoking populations. Experienced meditators, compared to controls, showed increased cortical thickness of the dorsal ACC (Grant, Courtemanche, Duerden, Duncan, & Rainville, 2010) and even brief mindfulness training (11 hours separated over a month) was shown to increase fractional anisotropy on MRI (method for analysing integrity of white matter fibre tracts) in the corona radiata of healthy undergraduate students (Tang, Lu, Geng, Stein, Yang, & Posner, 2010). The corona radiata is an important white-matter tract that connects the ACC to the striatum and other structures and is considered a key node of the self-regulation network (Tang et al., 2010). This network is broadly defined as the ability to control one's thoughts, feelings, and behaviours (Posner, Rothbart, Sheese, & Tang, 2007). In another study by Hölzel et al. (2007), experienced-mediators showed increased rostral ACC activity during mindful breathing. Hölzel et al. (2007) suggest that this reflects an improved ability for attention and emotion regulation. Because the rostral ACC has been specifically related to N2 activity (Gonzalez-Rosa et al., 2013) and to conflict-monitoring (Maier & di Pellegrino, 2012), mindfulness may also increase N2 amplitudes in Go/NoGo tasks. If mindfulness can improve inhibitory control and emotion regulation in smokers, this could potentially lead to better control over a smoker's automatic tendency to smoke in response to craving, i.e., smokers become able to accept cravings without acting on them. It is possible that this mechanism was occurring in a study by Elwafi et al. (2013), mentioned

above. Their finding of a decoupling between craving and smoking could be explained by an increased inhibitory control developed through mindfulness practise. Also in support of this mechanism, Berkman, Falk, & Lieberman (2011) have shown that increased inhibitory control is related to an increased ability to inhibit automatic responding to cravings. Baseline fMRI activity during a Go/NoGo task was measured in participants attempting to quit smoking through professionally-led cessation programmes such as Freedom From Smoking. Experience-sampling for 3 weeks, 8 times daily was employed to measure "everyday self-control". Increased activation in the basal ganglia, pre-supplementary motor area (pre-SMA), and IFG (inferior frontal gyrus) at baseline was correlated with an attenuated association between craving and smoking (Berkman et al., 2011). Because this decoupling is similar to that seen in Elwafi et al. (2013), there is rationale to hypothesise that mindfulness attenuates the association of craving and smoking through improving neural markers of early inhibitory control. Tang et al. (2013) did not find this decoupling, which may be because they used inappropriate measures of craving. "How much are you craving a cigarette right now?" used by Berkman et al. (2011) could evoke a different answer to a rating of the "severity of craving" (used in Tang et al. 2013). Tang et al. (2013) appear to measure attitude towards craving rather than craving itself. Using appropriate measures of craving could show that mindfulness decouples craving and smoking through increasing neural markers of early inhibitory control such as the NoGo N2 amplitude.

Another, although less researched mechanism through which mindfulness might reduce smoking is by altering processing bias to smoking-related and affective cues. One study showed that an 8-week mindfulness-based programme reduced attentional bias to pain stimuli (e.g., picture of a broken leg) in chronic pain sufferers (Garland et al., 2013). Other studies have measured the relationship between attentional bias and dispositional mindfulness using the Five-Factor Mindfulness Questionnaire (FFMQ). This is a 39-item scale that measures 5 constructs related to mindfulness including non-reactivity to inner experience, non-judging of inner experience, observation of sensations and perceptions, acting with awareness, and describing and discriminating emotional experiences. Garland, Boettiger, Gaylord, Chanon, & Howard (2012) measured the association between higher trait-mindfulness and behavioural attentional bias to alcohol stimuli in recovering alcoholics. Although they were unable to show behavioural alcohol-attentional bias, higher trait-mindfulness showed an association with greater recovery of heart-rate variability to alcohol stimuli. While this finding suggests mindfulness can promote faster physiological recovery to

drug stimuli, it does not show how mindfulness affects initial reactivity or attentional bias to drug stimuli.

Another study using EEG showed associations between high trait-mindfulness and lower LPP amplitudes to intrinsically pleasant and unpleasant images in healthy subjects (Brown, Goodman, & Inzlicht, 2013). In contrast to Brown et al. (2013), a more recent study by Garland, Froeliger, & Howard (2015) suggests that mindfulness increases LPP amplitude to intrinsically pleasant stimuli. This was shown in a group of participants with chronic pain and opiate misuse who underwent two ERP sessions, separated by an 8-week mindfulness-based intervention. At the end of the intervention, participants who received the mindfulness-based intervention had increased LPP amplitude (400–1000 ms) compared to baseline in response to rewarding stimuli while no increases of LPP were observed in response to neutral stimuli. Furthermore, these increases were not seen in the control group that received therapeutic and group support. It is suggested that mindfulness interventions may remediate reward-processing deficits in addiction, such that individuals become more attentive to natural rewards (e.g., food).

Therefore, mindfulness-based interventions may also remediate reward-processing deficits in smokers through increasing P3 and LPP amplitudes to pleasant stimuli and perhaps reducing those in response to unpleasant stimuli, as suggested by Garland et al. (2013). Although results from Brown et al. (2013) would suggest a different responding to pleasant stimuli, this could be because his study compared responding to high arousal images (mutilation and erotica) as opposed to lower arousal images (garbage and flowers) used in Garland et al. (2015). The lower LPP amplitudes for non-mindful participants seen by Garland et al. (2015) may reflect lower levels of "awareness" while higher LPP amplitudes for non-mindful participants in Brown et al. (2013) could reflect lower levels of "non-reactivity."

While mindfulness might lead to increased P3 and LPP responding to pleasant images, responding to smoking-related stimuli is less clear. Although Elwafi et al. (2013) found a decoupling of craving and smoking during the first 4-weeks of mindfulness treatment, a positive correlation re-emerged at 6-weeks, which then increased at 3 and 4 months. This suggests that while inhibitory control is important in the early stages of mindfulness-based smoking cessation, craving may be more important for long-term abstinence. It seems that being more aware of cravings, encouraged in mindfulness, would at least initially make those cravings stronger. In the same way this may lead to initial increases in processing bias to

smoking cues. This may then drop with repeated practice indicating increased tolerance and decreased reactivity to smoking cues.

Overall, there is evidence of mindfulness interventions improving smoking-cessation outcomes over the current mainstay treatment of skills-training. There is also a promising case for mindfulness to improve inhibitory control and restore abnormal processing to drug-related and affective stimuli. These mechanisms may reflect the ability of mindfulness to break down incentive salience attributions, which could lead to better smoking-cessation outcomes and less likelihood of relapse.

2   Aims and hypotheses

Mindfulness offers an appealing behavioural alternative to the skills-training techniques taught in counselling. Previous research leads us to suggest that mindfulness can reduce smoking through increasing inhibitory control and decreasing smoking-related processing bias. Mindfulness may also increase processing of affective (pleasant and unpleasant) and neutral stimuli. Mindfulness has shown promising efficacy for smoking-cessation when delivered in the form of group therapy, and this intervention has recently been formulated into a smartphone-based app called *Craving to Quit*. The current study aimed to test the effectiveness of *Craving to Quit*. If effective, the app would be a cost-effective way to distribute support for smoking-cessation on a national level. In addition we aimed to explore the mechanisms behind mindfulness, which could support the theoretical effectiveness of mindfulness and/or guide development of future addiction-related treatments.

2.1   The original proposal

Originally the study aimed to compare the effects of a mindfulness-based smoking-cessation app, *Craving to Quit,* with one based on skills-training: *QuitPal*. We aimed to compare them by measuring behavioural and EEG variables at 2 sessions, 4 weeks apart. We had originally aimed to match the 2 interventions on all factors other than mindfulness (see Appendix A for comparison of key processes involved in apps). This was so that we could make stronger inferences about the effect of mindfulness on smoking-cessation and the mechanisms involved. Unfortunately, despite many efforts, recruitment was poor. We chose to drop the *QuitPal* group to retain more numbers in the *Craving to Quit* group, which consequently limited the scope of our study. In addition we loosened the inclusion criteria, in order to include less dependent and older smokers.

We also had problems with compliance in the smoker group meaning that some key measures of the study had to be dropped. These included experience-sampling, weekly, and monthly follow-up questionnaires.

The hypotheses described below and following methods section is a reflection of what the final study was able to achieve.

2.2 The current study

We aimed to replicate several findings including:

1.   A smoking-related image processing bias in smokers relative to non-smokers, indicated by higher P3 and LPP amplitudes for smoking images in smokers at baseline (Littel & Franken, 2007; McDonough & Warren, 2001; Minnix et al., 2013).

2.   Lower inhibitory control in smokers relative to non-smokers, indicated by lower Go/NoGo accuracy (Luijten et al., 2011; Yin et al., 2015), NoGo N2 (Buzzell et al., 2014; Luijten et al., 2011; Yin et al., 2015) and NoGo P3 amplitudes at baseline.

3.   No difference in smokers and non-smokers for low-arousal pleasant, unpleasant, and neutral stimuli (Minnix et al., 2013).

4.   The ability of a mindfulness-based intervention to reduce smoking status (number of cigarettes smoked/day) (Bowen & Marlatt, 2009; Brewer et al., 2011).

Aims 1 and 2 are important because they contribute to the interpretations for Hypotheses 1, 3 and 4, below. Likewise, Aim 3 would help with the interpretation of results from Hypothesis 4, i.e., does the intervention alter variables that were normal or abnormal to start with. Finally, Aim 4 is important because several of our hypotheses are related to discovering the mechanisms of this process.

We had 7 specific, and novel hypotheses relating to these replication aims:

2.2.1 Hypothesis 1: Behavioural markers of inhibitory control

Question and significance

There are currently no studies that have investigated effects of a mindfulness-based intervention on behaviour associated with an inhibitory control task in smokers. We aim to test this because the results will increase our understanding of the mechanisms involved in mindfulness-based interventions for smoking cessation. This will be tested by measuring accuracy in the Go/NoGo task before and after use of *Craving to Quit* in smokers.

Hypothesis and rationale

We hypothesise that a mindfulness-based intervention would increase behavioural markers of improved inhibitory control in smokers. This is because previous studies have

shown that a mindfulness-based intervention can increase MRI neural markers of inhibitory control (see section 1.6).

2.2.2 Hypothesis 2: ERP markers of inhibitory control

Question and significance

There are currently no studies that have investigated effects of a mindfulness-based intervention on ERPs associated with an inhibitory control task in smokers. We aim to test this because the results will increase our understanding of the mechanisms involved in mindfulness-based interventions for smoking-cessation. This will be tested by measuring ERPs and behaviour elicited by the Go/NoGo task before and after use of *Craving to Quit* in smokers.

Hypothesis and rationale

We hypothesise that a mindfulness-based intervention would increase ERP markers of improved inhibitory control (NoGo N2 and P3) in smokers. This is because previous studies have shown that mindfulness can increase MRI neural markers of inhibitory control (see section 1.6).

2.2.3 Hypothesis 3: ERP markers of increased image processing of pleasant, unpleasant, and neutral stimuli.

Question and significance

There are currently no studies that have investigated effects of a mindfulness-based intervention on ERPs associated with neutral, pleasant, and unpleasant image processing in smokers. We aim to test this because the results will increase our understanding of the mechanisms involved in mindfulness-based interventions for smoking cessation. This will be tested by measuring P3 and LPP elicited by neutral, pleasant and unpleasant images before and after use of *Craving to Quit* in smokers. If *Craving to Quit* increases image processing, the results of Aim 3 could indicate whether increases were from a normal or abnormal baseline.

Hypothesis and rationale

We hypothesise that a mindfulness-based intervention would increase ERP markers of image processing in response to neutral, pleasant and unpleasant images at follow-up, indicating a generalised increase in image processing in smokers. This is because the

acceptance fostered in mindfulness may increase processing of stimuli. A mindfulness intervention has also been shown to increase processing of intrinsically pleasant stimuli in opiate addiction (Garland et al., 2015).

2.2.4 Hypothesis 4: ERP markers of processing bias to smoking-related images

Question and significance

No current study has investigated the effects of a mindfulness-based intervention on ERPs associated with smoking-related image processing in smokers. We aim to test this because the results will increase our understanding of the mechanisms involved in mindfulness-based interventions for smoking cessation. This will be tested by measuring P3 and LPP elicited by the smoking-related images before and after use of *Craving to Quit* in smokers.

Hypothesis and rationale

We hypothesise that a mindfulness-based intervention would decrease ERPs associated with smoking-related image processing bias in smokers. This is because higher mindfulness has been associated with less drug-related processing bias in alcoholism (Garland et al, 2012). In addition, we suggest that mindfulness can remediate reward-processing deficits (see section 1.6), which may involve normalising image processing bias of drug-related stimuli.

2.2.5 Hypothesis 5: *Craving to Quit* will increase *mindfulness* at follow-up.

Question and significance

There are currently no studies that have investigated effects of a mindfulness-based intervention on *mindfulness* in smokers. We aim to test this because the results will increase our understanding of the mechanisms involved in mindfulness-based interventions for smoking cessation. This will be tested by measuring the five facets of the Five-Factor Mindfulness Questionnaire (FFMQ) (Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006) before and after use of *Craving to Quit* in smokers.

Hypothesis and rationale

We hypothesise that a mindfulness-based intervention would increase mindfulness at follow-up. This is because mindfulness-based interventions teach individuals to be more *mindful*.

2.2.6 Hypothesis 6: *Craving to Quit* will reduce smoking

Question and significance

There is nothing in the literature to indicate whether or not a mindfulness-based smoking-cessation app can reduce smoking status. We aimed to test this because if a smartphone app shows effectiveness for smoking-cessation it will provide an easily accessible and cost-effective way to target smoking-cessation at a large scale. This will be tested by comparing smoking status of smoker participants before and after use of *Craving to Quit*.

Hypothesis and rationale

We hypothesise that the *Craving to Quit* app would reduce smoking status in smokers who were motivated to quit. This is because Brewer et al. (2011) showed that a mindfulness-based smoking cessation intervention was effective in reducing smoking, when delivered in the form of group therapy.

2.2.7 Hypothesis 7: Decoupling of craving and smoking

Question and significance

Although Elwafi et al (2013) have shown that a mindfulness-based intervention delivered via group therapy can decouple the link between smoking and craving, there is nothing in the literature to indicate whether or not the same pattern can occur when the intervention is adapted to a smartphone app. We aim to test this because it will add support for the proposed decoupling mechanism of mindfulness and support the application of a mindfulness-based intervention to smartphone app. Measuring correlations between smoking status and craving in smoker participants who had used *Craving to Quit* will test this.

Hypothesis and rationale

We hypothesise that there would be no correlation between craving and smoking status at 1–2 month follow-up of smokers. This is because Elwafi et al. (2013) showed that a mindfulness-based smoking-cessation intervention, delivered in a group, could decouple the link between craving and smoking.

3 Methods

3.1 Participants

3.1.1 Power analysis

We estimated the number of participants needed to observe a small effect size (25%) with 90% power at baseline, using the standard deviation and mean taken from findings of P3 elicited by non-smokers at PZ (Littel & Franken, 2007). We estimated this by using the formula, $n = 1 + 2C(s/d)^2$ (US National Research Council, 2003), where C was 10.51, representing 90% power for a significance level of $p = 0.05$, s is the estimated standard deviation of the variable that we intended to measure (P3), and d was the 25% difference from the estimated mean that we wished to detect. Using this formula it was estimated that we would need 8 participants per group ($n = 1 + (2 \times 10.51) (6.37/11.1)^2$) to show differences between smokers and non-smokers in response to smoking images.

When we began the study, there was no previous literature available to indicate how many participants would be needed to show a change in ERPs or Go/NoGo accuracy within groups. Previous studies showing change in smoking status did not provide means or standard deviations to use in an estimated power analysis. These studies examined abstinence rather than number of cigarettes smoked per day. Because of this, we decided to aim for 16 participants per group to show differences at follow-up. This was twice as many as indicated by the power analysis for detecting differences at baseline.

3.1.2 Participant screening

The study aimed to recruit 16 smokers and 16 non-smokers between ages 18 and 65 years to participate in a study assessing the effectiveness of smartphone-based behavioural interventions for smoking. To account for potential drop-outs, we initially recruited 18 non-smokers (mean age = 25.17, SD = 7.15, 44.4% male, 55.6% female) and 37 smokers (mean age = 32.46, SD = 12.01, 48.6% male, 51.4% female). The majority of participants were to be recruited from the Canterbury of University campus using advertisements distributed physically and via departmental emails. Because this yielded a low number of people engaging in the survey, we also attempted to recruit from Lincoln University, Christchurch Polytechnic Institute of Technology, Otago Medical School, Christchurch Public and Princess

Margaret Hospitals, Hagley Radiology, various workplaces, local GPs, SmokeFree Canterbury, occupational health nurses at various large construction companies, and various Facebook groups including "Christchurch Buy, Sell and Trade." See Appendix B for advertisement. The majority of recruited non-smoker controls were from the University of Canterbury, while the majority of those in the smoker group were recruited from "Buy, Sell and Trade" groups on Facebook.

Participants were excluded if they have had a serious or unstable medical condition within the last 6 months, were currently taking psychoactive medication (e.g., neuroleptics, anxiolytics, and antidepressants) or answered "Yes" to either themselves, family, or close friends considering them to being "a heavy user of any recreational drug other than nicotine (e.g., alcohol, marijuana, ecstasy)." Additional exclusion criteria for smokers included current involvement in any smoking-cessation activities (Versace et al., 2011), including nicotine-replacement therapy, and a score of less than 3 out of 7 on the Motivation To Stop Scale (MTSS).

Inclusion criteria for smokers was smoking ten or more cigarettes a day, a Fagerstrom Test for Nicotine Dependence (FTND) value of at least 3 (low) nicotine dependence, having less than 3-months abstinence within the last year, wishing to cease smoking, and having an iPhone Model 4 or later or a smartphone with Android Model 2.3.3 or later. Smoker participants who smoked less than 10 cigarettes a day were included if they had a FTND score of 4 or more. Inclusion criteria for non-smokers were having smoked less than 10 cigarettes during their lifetime (Luijten et al., 2011) or having smoked none within the past 20 years. The latter criterion was added because we observed from initial screening results that participants over 30 were unlikely to have smoked less than 10 cigarettes within their lifetime, even if they considered themselves "non-smokers."

The screening was done via a confidential online survey that was made using an online research software called "Qualtrics" (www.qualtrics.com). Contact details were asked at the end of the survey for those who were eligible. Eligible participants were then sent an information sheet and encouraged to book their first test session. Recruitment of participants was approved by the University of Canterbury Human Ethics Committee (see Appendix C). Over 600 people started the survey, but many people were either did not finish, were not eligible, not interested, or interested but did not turn up to their first booked session. The main reason for exclusion of potential smoker participants was that they had lower scores of the FTND, or reported smoking a lower number of cigarettes/day than the minimum requirements. The main reason for exclusion of potential non-smoker participants was that

they had smoked more than 10 cigarettes within their lifetime or had smoked within the last 20 years.

3.2 Tasks

3.2.1 Go/NoGo task

To measure inhibitory control, a Go/NoGo task was developed on E-Prime 2.0 software using the letters 'M' and 'W' as both Go and NoGo stimuli. The task involved 4 blocks of 128 trials with 75% Go and 25% NoGo trials. Two versions of the task were developed. One version used the letter 'M' as the Go stimulus for the first 2 blocks, the other used 'W.' At half-way (block 3) the Go and NoGo stimuli were reversed (i.e., the Go stimulus became the NoGo stimulus and vice versa).

Each block began with a white fixation cross, displayed for 250 ms. This was followed by the letter stimulus (either 'M' or 'W') presented for 500 ms or terminated on key press. Trials finished with a 500-ms black screen. This was the same timing procedure used as by Dong, Lu, Zhou, & Zhao (2010) and was chosen over longer inter-trial intervals in order to obtain more trials to average for our ERPs.

Participants were instructed to press the spacebar key each time they saw the Go stimulus, and NOT to press it when they saw a NoGo stimulus. Participants were told to respond using either the middle or index finger of their dominant hand. They were instructed both written and verbally to respond as quickly and as accurately as possible.

Participants were given a practice block of 30 trials. During the practice block, feedback was given for correct hits and rejections as well as misses and false alarms. The feedback was presented as white italicised text on the 500 ms black screen that followed each stimulus.

Between each of the 4 experimental blocks was a 1-min break, in which "Break. Please relax in your chair" was presented in white text on a black screen for 30 s followed by a 30-s countdown, also in text. Halfway through the experiment, participants were presented with an instruction screen explaining the change in Go and NoGo stimuli. The screen was terminated on key press and was followed by a break screen.

All stimuli and text were presented in 18 pt. white Courier New font on a black screen. Participants were seated approximately 0.5–1.0 m away from the screen. The task took around 15–20 min.

3.2.2   Image slideshow

To measure attentional and emotional image processing bias an "image slideshow" was developed similar to that of Versace et al. (2011), using E-Prime 2.0 software. The image slideshow involved 4 categories (neutral, unpleasant, smoking and pleasant) of 36 different images. Each image was presented twice giving a total of 288 images. Images were selected from the International Affective Picture Set (IAPS) (Lang, Bradley, & Cuthbert, 2005) and the International Smoking Images Series (ISIS) (Gilbert & Rabinovich, 1999), and were sorted into categories by using separate normed ratings for valence and arousal from the IAPS and ISIS groups. These average ratings are as follows (valence and arousal, respectively): neutral: 4.98, 2.86; pleasant: 7.39, 5.26; unpleasant: 2.68; 5.31; smoking: 5.36, 3.78. Note that these norms were created using different groups of participants. The provided norms for the smoking images are from smoker-participants only.

Pleasant, unpleasant, and neutral categories all had a 1:1 ratio of images involving people and images not involving people (e.g., objects, scenery). The same could not be done for the smoking set because the majority of images with available normed ratings involved people.

The slideshow was separated into 8 blocks of 36 trials. Each trial involved a 2500 ms display of a white fixation cross in the centre of a black background, followed by a 2000 ms image display. For each block a pseudo-random trial list was created. The list was of 36 trials involving 9 trials for each of the 4 image categories. No more than two trials of the same category were presented consecutively. During the slideshow the trial lists (blocks) were shown in random order. For each trial in the list a random image of that category was shown. No image was presented more than twice during the whole slideshow.

Five trials out of each trial list were "noise" trials. These trials had a longer fixation-cross display of 6050 ms. During these trials a 50-ms burst of white noise would play through earphones. The noise would occur at 1 of 4 random times within the first 550 ms of the fixation-cross display. The noise trials would occur pseudo-randomly at every 4th, 5th, or 8th image. The purpose of the noise was to keep participants focused. The longer fixation-cross display was to give enough time for participants' EEG to return to baseline in case the noise introduced EEG artefact.

Participants were instructed both written and verbally to relax and watch the image slideshow while trying to remain as still as possible.

Between each block, participants were given 30-s breaks involving a 10-s countdown displayed in white font on a black computer screen. All text was presented in 18 pt. white Courier New font.

At the beginning of the experiment, participants listened to five examples of the white noise. These occurred during pseudo-random intervals of 25–44 s. These intervals mirrored the intervals that occurred in the blocks.

The total task took about 30 min.

3.3 Interventions

Smoking participants would use their personal smartphones for the following intervention.

3.3.1 Craving to Quit (C2Q)

Within the *Craving to Quit* application (Figure 3.1) is a 22-day programme for quitting smoking. The programme involves a gradual cut-down of smoking over 3-weeks until the "quit day" at Day-21. Users are sent app notifications each day for suggested number of cigarettes to smoke. This is based on the average number of cigarettes smoked/day that users enter into the app at the start of the programme. This average is then tapered by 1/21 for each day of the programme. For each day until the designated quit day, the app has a list of "Today's activities" and "Today's goal" including short videos and audio recordings that introduce new mindfulness techniques. Figure 3.2 shows an example this in Day 3 of the programme. The videos and recordings firstly explain the rationale behind each exercise, and then guide the participant through practising it. These videos often explain exercises using metaphors or analogies. For example, the 'RAIN' (Recognise, Accept, Investigate, Note) exercise teaches participants to ride out cravings through likening their cravings to waves and likening mindfulness to a surfboard that is used to ride the waves. The RAIN exercise is in the form of an audio recording, and is encouraged to be used every time the user has a craving to smoke. This replaces distraction and avoidance techniques, which are encouraged in skills-training. The app has an "Exercises" feature where users can access a list of exercises including meditation practices and motivational videos. Over the course of the programme each exercise becomes assessable once it has been introduced in "Today's activities." Each meditation exercise takes between 6 and 10 min to complete. The app also has a "Night

Reflection" feature (Figure 3.2) where users can reflect on the day's goals and complete a meditation practice (e.g. Body Scan and Loving Kindness).

At the beginning of the app, users enter a quitting pact, which can be visited at any time throughout the programme. This includes a record of when the user began their quitting pact, their planned quit date, the amount of money they will save each month (based on current smoking rate and average price of cigarettes), and 3 personalised goals for quitting. On Day-6, users record their triggers for smoking into their quitting pact, and on Day-20 they decide on a "mantra," which is also entered into the quitting pact. A mantra is a saying that users can repeat to themselves whenever they have a craving to smoke, e.g., the mantra "not even one," reminds the user that they should not smoke even one cigarette. Day-22 shows a video explaining how users can stay "on track" after quitting on Day-21. In addition to the programme, the app sends several reminders throughout the day to "Check-In." This is a feature that involves asking users their current craving and number of cigarettes they have smoked since the last reminder. Their craving can be measured using the "Want-O-Meter" feature, and cigarettes smoked can be measured used the "Tracker."

Within the app, users can access the "Community" feature (Figure 3.2), which takes them to an online *Craving to Quit* forum. Here, users can create a personal profile and connect with others also using the C2Q app. Users can interact with each other via private or public messages and can also ask questions to psychiatrist Dr Judson Brewer through the "Ask the Doc" feature. Within the *Craving to Quit* forum, users can post public journal entries for which other users and Dr Judson Brewer can comment on and provide feedback.

Other features of the app include: "Reminder Settings," where users can change the frequency of "Check-In" notifications, "Activity Feed," in which users can look at their recent activity on the app (e.g., videos watched), and "My Morning Stats" which shows users their progress of cigarettes smoked/day and money saved since the beginning of the programme.
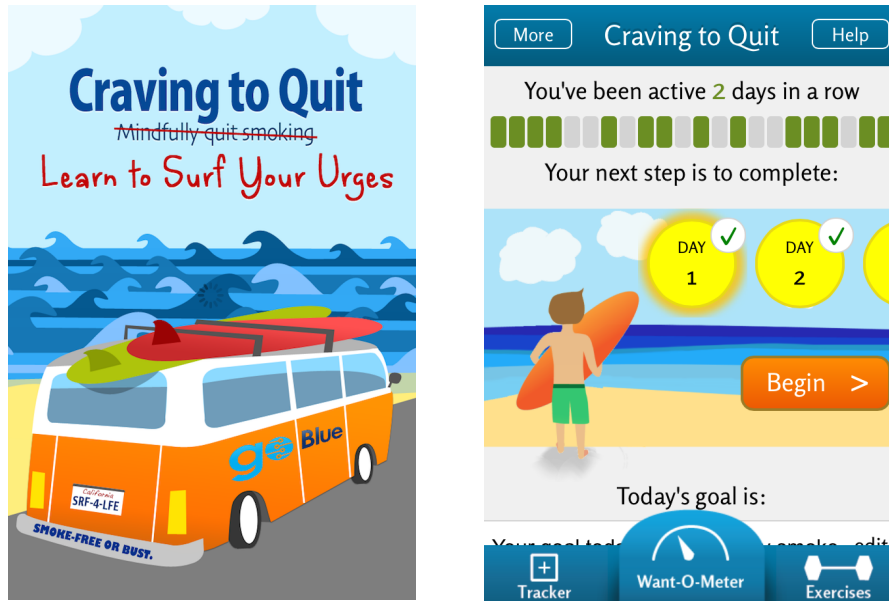
Figure 3.1. Craving to Quit title screen (left) and main screen (right) showing Days 1 and 2 of the 22-day programme.
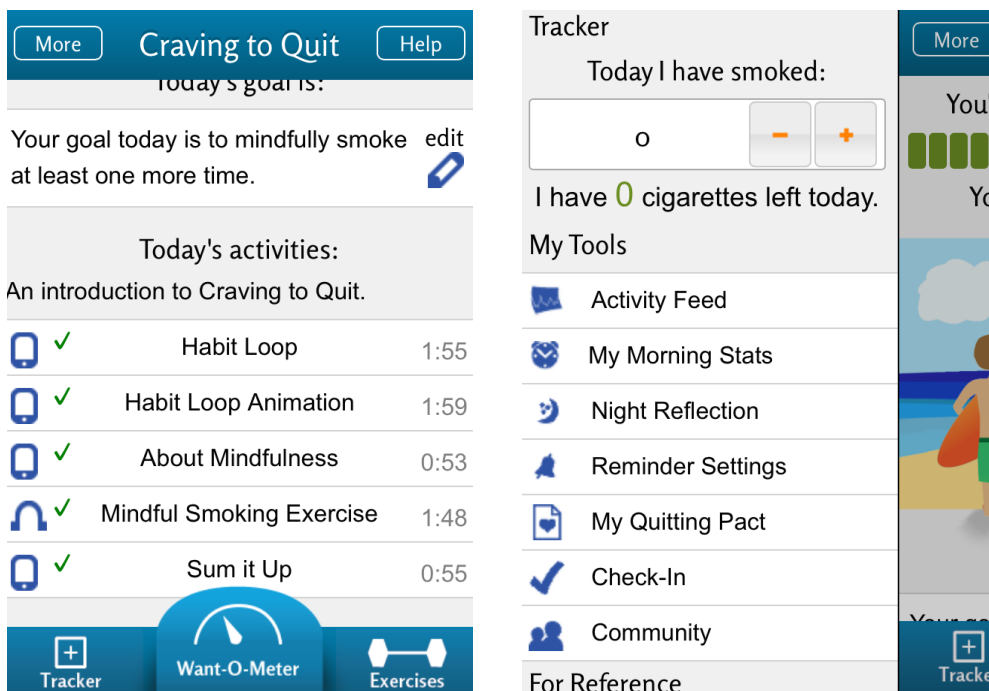

Figure 3.2. Activities and goals for Day 3 of the programme showing several app features: Want-O-Meter, Tracker, Exercises (left), Activity Feed, My Morning Stats, Night Reflection, Reminder Settings, Quitting Pact, Check-In, and Community (right).

3.3.2   No Intervention

Non-smoker participants received no intervention and were instructed to "continue life as normal" until their second session (see Appendix F for control handout).

3.4   Procedure

Participants were first screened using the online Qualtrics survey, and sent an information sheet (Appendix D) if they were eligible for the study. Individual morning appointment times (starting between 7.30 a.m. and 10.30 a.m.) for Session 1 were booked for people who had passed the screening survey and agreed to participate in the study. Before the Session 1, participants were assigned to an intervention group. This was *Craving to Quit* for smokers and No Intervention for non-smokers. All participants were sent instructions on how to prepare for their visit (Appendix E). Smokers were asked to abstain from smoking for 8 hr before the experiment. This is to reduce acute effects of nicotine on ERP amplitudes and to make sure all participants were equivalent for levels of nicotine.

Participants were talked through the structure of the session on arrival and shown the EEG cap. This included explanation of all the preparation in setting up the cap, gel, and external electrodes. After participants signed the consent form the EEG cap was set up.

Following set up of the cap, the experimenter explained the first task, the Go/NoGo task, and was present during the practice trials. After the Go/NoGo experimental trials, participants had a short break while the experimenter loaded the image slideshow task. During the experimental trials of both tasks, the experimenter was in an adjacent room. After this task the participants moved on to the image slideshow, then completed the FFMQ questionnaire online and were pencilled in for their second session.

Smoker participants also completed the QSU-brief online before completing the FFMQ. Both questionnaires were converted to an online form using Qualtrics. After the online questionnaires the experimenter helped participants set up a personal username and password for the C2Q app. Participants were given detailed instructions of how to use the C2Q app (see Appendix F for C2Q and Control handouts). To motivate participants to continue use of the C2Q app, weekly phone calls and texts were sent to check in with how participants were going. We were able to track participant use of the app and those who stopped using it were sent a "Getting back on track" email (see Appendix G). Tracking

allowed us to see when follow-up sessions needed to be rescheduled. We aimed to receive participants for Session 2 once they had completed at least 70% of the programme.

All participants completed the same tasks at Session 2 as in Session 1 and were given a $20.00 petrol, supermarket, or Westfield voucher for their time, and a debriefing sheet, which explained the purpose of the project (see Appendix H). Session 2 was between 3 weeks and 2 months from Session 1. As with Session 1, smokers were asked to abstain from nicotine for 8 hours before the experiment. The procedure is summarized in Table 3.1.

Table 3.1. Procedure summary showing tested variables and estimated time involved for each main phase of the experiment (bold).

	Tested variables	Estimated time involved
Screening	FTND	5–10 min
	MTSS	
Session 1	Image P3, LPP	1.5–2.5 hr
	Go/NoGo N2, P3, accuracy, reaction time	
	FFMQ	
	QSU-brief	
	Smoking status	
Intervention	No intervention	1–2 month
	C2Q	
Session 2	Image P3, LPP	1.5–2.5 hr
	Go/NoGo N2, P3, accuracy, reaction time	
	FFMQ	
	QSU-brief	
	Smoking status	

In the handouts designed for the original study (see section 2.1) participants were also asked to record their smoking status and craving each day from Session 1 up until Session 2

(experience-sampling) via text messaging and to complete 4 x weekly follow-up questionnaires. We planned to use experience sampling to investigate correlations between craving and smoking throughout use of the app. This was changed because of low compliance and instead participants were given a sheet of paper to record smoking status and craving and were asked to complete only a 1 x monthly follow-up questionnaire. Even after these changes, the measures still yielded a low response, which led us to drop both the experience-sampling and follow-up questionnaires completely. As mentioned in section 2.1, the key comparison group receiving *QuitPal* was also dropped from the design. See Appendix I for the methods summary and handout for *QuitPal*, and the daily texts that were designed to go with this intervention.

3.5 Measures

3.5.1 Fagerstrom Test for Nicotine Dependence (FTND)

The FTND is a 6-item self-reported questionnaire (Heatherton, Kozlowski, Frecker, & Fagerstrom, 1991). The points for each answer are added to give a total score between 0–10 of nicotine dependence. The categories of nicotine dependence ranged from very low (0–2), low (3–4), medium (5), high (6–7), and very high (8–10) (Fagerstrom et al., 1990).

3.5.2 Behaviour on the Go/NoGo Task

The reaction time for correct Go trials and commission errors were calculated, as well as the percentage of correct hits and rejections for Go and NoGo trials, respectively (Smith et al., 2013).

3.5.3 Craving: QSU-brief

The Brief Questionnaire of Smoking Urges (QSU-Brief) (Cox, Tiffany, & Christen, 2001; Tiffany & Drobes, 1991) was used to measure self-reported nicotine craving for at Sessions 1 and 2. The QSU-brief is a 10-item questionnaire measured on a scale of 1 (strongly disagree) to 7 (strongly agree). Total craving was recorded as a score between 10 and 70.

3.5.4 Smoking Status

Baseline smoking status (average number of cigarettes smoked/day) was measured from each participant's registration on *Craving to Quit*. Follow-up smoking status was

measured by a question tagged onto the end of the QSU-brief questionnaire in Session 2: "On average, how many cigarettes per day have you smoked during the last week."

3.5.5   Motivation to Stop Scale (MTSS)

The MTSS was used to measure each smoker-participant's motivation levels for quitting smoking. This is a one-item scale, which asks "Which of the following describes you?" The possible responses to choose from include: (1) "I don't want to stop smoking"; (2) "I think I should stop smoking but don't really want to"; (3) "I want to stop smoking but haven't thought about when"; (4) "I REALLY want to stop smoking but I don't know when I will"; (5) "I want to stop smoking and hope to soon"; (6) "I REALLY want to stop smoking and intend to in the next 3 months"; and (7) "I REALLY want to stop smoking and intend to in the next month." The following interpretations are listed for each response: 1- absence of any belief, desire, or intention; 2- belief only; 3- moderate desire but no intention; 4- strong desire but no intention; 5- moderate desire and intention; 6- strong desire and medium-term intention; and 7- strong desire and short-term intention (Kotz, Brown, & West, 2013).

3.5.6   Mindfulness

Mindfulness was measured using the Five-Factor Mindfulness Questionnaire (FFMQ) (Baer et al., 2006) which assesses several factors including observing, describing, acting with awareness, non-judging of inner experience, and non-reactivity to inner experience.

3.5.7   EEG Recording and Data Reduction

The EEG was recorded using a Neuroscan SynAmps^{2TM} Model 8050 EEG amplifier (Compumedics Neuroscan, USA). Recordings were made at 64 scalp sites with Ag/AgCl electrodes mounted in an elastic cap, (Neuroscan Quik-Cap, Compumedics USA). In addition, 4 electrodes were placed outside of the cap, one above and one below the eye to record vertical eye movement, and 2 placed on the left and right mastoids. Online continuous EEG was initially recorded using a bandpass of 1.0–40.0 Hz but later changed to a bandpass of DC–200.0 Hz. During recording, EEG was referenced to an electrode between CZ and CPZ using Neuroscan Acquire 4.4 (Neuroscan Compumedics, USA) at a sampling rate of 1000 Hz.

Offline data was filtered using Neuroscan EDIT 4.4 (Neuroscan Compumedics, USA) with a FIR analogue filter and bandpass of 1.0–30.0Hz using a 48 dB/octave cut-off. Other ERP studies generally use a lower high-pass filter of 0.1 Hz but because approximately a third

of participants were recorded online with a high-pass of 1.0 Hz, we filtered all at 1.0 Hz to ensure ERPs were comparable.

All channels were visually inspected before re-referencing. Channels that appeared to have come off during the recording or had impedances over 100 kΩ were interpolated using 2–4 nearby channels. This was done through the Linear Montage Editor, as suggested by Neuroscan Compumedics. Three different references were tested, including the original (between CZ, CPZ), the average of left and right mastoids, and the average reference of all electrodes. The average reference gave the cleanest EEG recordings and largest ERP peaks, so was chosen as the final reference. After interpolation and re-referencing, ocular artefact was corrected for. Continuous EEG was segmented into 1000 ms epochs for the Go/NoGo recordings, and 2000 ms epochs for the image slideshow recordings. Epochs were baseline-corrected for 200 ms preceding stimulus onset for both task recordings. Epochs with an EEG amplitude above 75 or below -75 µV were excluded from averaging. The final epochs for each participant were then averaged to give an ERP for each scalp site. In the Go/NoGo task, N2 was defined as the most negative amplitude between 220 and 310 ms at FZ, F1, F2, FCZ, and CZ, while P3 was defined as the most positive value between 300 and 500ms at FCZ, CZ, C1, C2, and CPZ. In the image slideshow, P3 was defined as the maximum voltage between 300 and 500ms at FZ, F1, F2, FCZ, CZ, and CPZ. The early LPP (E.LPP) was defined as average amplitude between 600–1000 ms at FZ, F1, F2, FCZ, CZ, and CPZ. Late LPP (L.LPP) was defined as average amplitude between 1000–1500 ms at FZ, F1, F2, FCZ, CZ, and CPZ, and as average amplitude between 1500–2000 ms at PZ, P1, and P2. The reasons choosing these time windows are discussed in section 5.1.

3.6   Statistical analyses

All EEG and Go/NoGo behavioural data were tested for normality by examining scores of kurtosis and skewness. The majority of data had scores of kurtosis and skewness that were within the recommended range for normality for each sample size and had non-significant heterogeneity, determined by the Levene's test. We also tested sphericity of data using Mauchley's test. For most analyses sphericity was not violated. Because of this we decided to compute Analyses of Variance (ANOVA) to investigate interactions for EEG data and Go/NoGo behavioural data at both baseline and follow-up. We used a multiple comparison approach for data analysis. Although the majority of means comparisons were planned and hypothesis-driven, in some instances comparisons were made after inspection of

the data. For this reason, and for all dependent variables, family error rate was controlled for with the Student Newman-Keuls correction method for multiple contrasts. The sampling error was that of the high-order effect from a precursor ANOVA and was used as denominator for the q statistic, correcting for unequal sample sizes, as appropriate (Howell, 2010; Ryan, 1959; Wilcox, 1987). Because the sampling error and degrees of freedom were obtained from precursor ANOVA, we report the partial eta-squared values ($\eta p2$) for effect size. We analysed up to 9 electrodes for each EEG variable (image slideshow P3, E.LPP, L.LPP, N2, and Go/NoGo P3), and found that nearby electrodes often showed similar effects, but with different degrees of significance. Only results for electrodes in which statistical differences were found by way of multiple comparisons are reported. However, non-significant differences are interpreted accordingly in the Discussion section. ANOVA was used to analyse follow-up data for smoking status. Where sphericity was violated, values for the corrected Greenhouse–Geisser estimate are reported. For results of EEG and behavioural Go/NoGo data, values of partial eta-squared ($\eta p2$) are reported from the ANOVA interaction, representing small ($\eta p2 = 0.01$), medium ($\eta p2 = 0.06$), and large ($\eta p2 = 0.14$) effects (Cohen, 1988). Cohen's d effect size are reported for ANOVA result of smoking status, with $d = 0.2$, $d = 0.5$, and $d = 0.8$, indicating small, medium and large effects, respectively (Cohen, 1988).

Mann-Whitney tests were used to test baseline FFMQ data, and Wilcoxon signed-rank tests for craving and FFMQ data at follow-up. Effect size, r, was used for Mann-Whitney and Wilcoxon signed-rank tests, as suggested by A. Field, (2013).

Pearson correlations coefficients, r, were used to test decoupling of smoking status and craving at baseline and follow-up using one-tailed tests for correlation. For baseline and follow-up, $r = 0.1$, $r = 0.3$, and $r = 0.5$, were used to indicated small, medium, and large effects, respectively (A. Field, 2013).

4 Results

4.1 Participants: Descriptive Statistics

4.1.1 Baseline

As indicated, we recruited a total of 55 participants (18 non-smokers and 37 smokers) between the ages of 18 and 63, who were tested at baseline. Three non-smoker participants had to be removed from the study because of noisy EEG data, in which the reference electrode came off. The EEG and behavioural data from the Go/NoGo task of an additional two non-smokers had to be removed, as participants did not understand the task and pressed spacebar for all stimuli. EEG data for the image slideshow is missing for two other non-smoker participants because the experimenter did not press record. This meant that the final baseline non-smoker group for the image slideshow was different to that of the Go/NoGo task and both were different to the final FFMQ non-smoker group. Ages were significantly different between smoker and non-smoker groups for image slideshow [$F_{(1,49)}$ = 5.21, p = 0.026], and FFMQ [$F_{(1,50)}$ = 4.39, p = 0.041], comparisons with non-smokers being younger on average. So that any differences in comparisons could not be attributed to age, two of the youngest non-smoker participants were removed from the study altogether.

Due to the aforementioned incidences, all baseline analyses included 37 smokers while the number of non-smokers included at baseline differed for each analysis; FFMQ (n =13), Go/NoGo variables (n = 11) and image slideshow variables (n = 12). In all baseline analyses, the mean age of the smoker group was not significantly different to that of the non-smoker group (Table 4.1). For all baseline analyses there was no difference in gender (Table 4.2). On average, smokers tested at baseline had moderate nicotine dependence (M = 5.35, SD = 1.53) and a moderate desire to quit, with intention (M = 5.14, SD = 1.13).

Table 4.1: ANOVA results show that smokers and non-smokers do not differ in age at baseline.

Baseline Analysis	NS age M (SD)	S age M (SD)	F	df	p
FFMQ	26.54 (7.83)	32.46 (12.01)	2.73	1,48	0.105
Image slideshow	25.67 (7.49)	32.46 (12.01)	3.38	1,47	0.072
Go/NoGo	27.00 (8.47)	32.46 (12.01)	1.97	1,46	0.167

Table 4.2: ANOVA results show that smokers and non-smokers did not differ in gender at baseline.

Baseline Analysis	NS male:female	S male:female	F	df	p
FFMQ	7:6	18:19	0.10	1,48	0.753
Image slideshow	5:7	18:19	0.01	1,47	0.937
Go/NoGo	5:6	18:19	0.11	1,46	0.536

4.1.2 Follow-up

Out of the 37 smokers who completed Session 1, only 13 completed at least 70% of the app (16 days) within 2 months of starting it. Fifteen participants completed 3 or less days of the app, and 9 of these did not complete any days of the app. The remaining 9 participants used it for 6–14 days.

Eleven of the smokers who completed at least 70% of the app returned for the second visit and all were included in follow-up analyses. All non-smokers returned for the second session, although one non-smoker could not be included in the follow-up analysis of the image slideshow because the experimenter forgot to record it. Table 4.3 shows that the smokers were not significantly different from non-smokers in age for FFMQ, image slideshow, and Go/NoGo analysis. Groups were also not significantly different in gender (Table 4.4) or for time elapsed between sessions (Table 4.5).

Table 4.3: ANOVA results show that smokers and non-smokers did not differ in age at follow-up.

Follow-up Analysis	NS age M (SD)	S age M (SD)	F	df	p
FFMQ	26.54 (7.83)	29.09 (8.83)	0.56	1,22	0.461
Image slideshow	23.83 (4.07)	29.09 (8.83)	3.24	1,20	0.087
Go/NoGo	27.00 (8.47)	29.09 (8.83)	0.32	1,20	0.577

Table 4.4: ANOVA results show that smokers and non-smokers did not differ in gender at follow-up.

Follow-up Analysis	NS male:female	S male:female	F	df	p
FFMQ	7:6	7:4	0.22	1,22	0.646
Image slideshow	5:6	7:4	0.17	1,20	0.937
Go/NoGo	5:6	7:4	0.17	1,20	0.738

Table 4.5: ANOVA results show that smoker and non-smokers did not differ for time between sessions.

	Time between sessions (days)				
Follow-up Analysis	NS M (SD)	S M (SD)	F	df	p
FFMQ	34.38 (14.19)	40.64 (12.25)	1.31	1,22	0.265
Image slideshow	32.81 (13.37)	40.64 (12.25)	2.04	1,20	0.168
Go/NoGo	33.09 (12.69)	40.64 (12.25)	2.01	1,20	0.171

4.1.3 Reasons for non-compliance

Over 60% of the smokers used less than 70% of the C2Q programme (i.e., less than 16 days) during the course of the study. Because of this, a multi-choice follow-up questionnaire for non-compliant participants, was created to examine which features put them off using the app. Non-compliant participants generally fell into one of 2 camps: Those who completed 3 or less days (n = 15), or those completed 4–14 (n = 9) days of the app. Because of this, the

following questions were constructed: Q1: "Some participants completed less than 3 days of the *Craving to Quit* programme. If this was you, why did you not use if for longer?" and Q2: "Some other participants used the Craving to Quit programme for up to 2 weeks then stopped. If this was you, why did you stop?" Unfortunately we made a mistake, in that Q1 should have been "3 days or less" instead of "less than 3 days."

Text messaging feedback from some participants indicated that the app was helpful, but only during the first week of use. These same participants did not go on to complete the app. A third question was constructed to investigate why participants used some of the app then stopped: Q3: "Even those who completed the programme often missed 1 or several days. How did you feel when you missed a day of the programme?"

Questions 1, 2, and 3 were e-mailed to 24 non-compliant participants in the form of a link to a single online Qualtrics questionnaire. Each question was multi-choice. Of those who were emailed links, 12 completed it. Most responded to both Q1 and Q2, i.e., did not choose one of the 2 camps described above. This is likely because some options for reasons of not using the app were under Q2 but not Q1, and vice versa. Because of this, results of Q1 and Q2 were combined with Table 6 showing "reasons for why participants did not use the app for longer." Table 4.6 shows the frequencies of responses to each multi-choice answer in Q1 and Q2. The most common reason for not using the app for longer was that the exercises were too long and "Other reasons." There was the option for participants to enter text for "Other reasons." Of those who did, responses included: "made me think about smoking more," technical problems, the app was "hard to use and took a lot of time" and was not practical to use with people around. No one answered that they forgot to use the app, or that they were not seeing any benefits.

Table 4.7 shows the frequencies of responses to each multi-choice answer in Q3. The most frequent response for how participants felt when they missed a day of the programme was "like there was no point continuing because I had already failed."

Table 4.6: Reasons of why participants did not use the app for longer (Q1 and Q2 combined). The most common reason was because "The exercises took too long" and "Other reasons."

Reasons	Frequency
I forgot	0
I didn't have enough time	2
I am not a mindfulness person so a mindfulness-based programme won't work for me	1
I changed my mind about quitting	2
The app had technical problems	2
Stressful or important events came up	3
I wasn't seeing any benefits	0
The app made me want to smoke	0
The notifications were annoying	3
I felt bad if I missed a couple of days and was told that I should be smoking less than I was	3
The exercises took too long	4
It was not practical to use the rain exercise during the day	3
I didn't like the idea of mindfulness/ I got bored or irritated doing the mindfulness exercises	2
Other reasons	4

Table 4.7: How participants felt when they missed a day of the app. The most frequent answer was feeling like they had "failed."

Reasons	Frequency
Fine. I didn't mind picking up where I had left off if I had miss a day or several	2
Fine. I had already decided to stop using the app	3
I felt guilty	3
Disappointed in myself	3
I felt like there was no point continuing because I had already "failed" the programme	6
I wanted to restart the programme and my quit attempt	3
Other reasons	2

4.2 EEG filtering observations: choosing appropriate ERP time windows

4.2.1 Image slideshow task

Upon visual inspection of ERPs elicited by the image slideshow task, the early LPP and late LPP appeared earlier and smaller at PZ compared to frontal and central sites, and the P3 peak was almost unrecognizable at PZ. This pattern had not been documented in previous literature and may be because of the higher high-pass filter used in the current study (1.0 Hz) compared to previous studies (0.1 Hz).

To further investigate this frontal-parietal inconsistency, 0.1 Hz and 1.0 Hz high-pass filters were compared using data from the 13 participants who came to both sessions, and whose EEG had been recorded online with a DC–200 Hz band-pass. Visual inspection of ERPs showed reduced parietal positivity but increased frontal positivity during 1 s after picture onset, for the higher higher-pass filter (1.0 Hz). This pattern inversed during 1–2 s post-picture onset, showing increased parietal positivity and decreased frontal positivity with the 1.0 Hz high-pass filter (Figures 4.1 & 4.2).

We were unable to reliably measure P3 amplitude at PZ. Hence, it was decided to only analyse P3 at frontal, frontal central, and centroparietal electrodes. At parietal electrodes, a

large positive peak was observed at between 500—750 ms post stimulus-onset. This peak may have been a late P3 but exceeds the upper limit of time-windows used in other studies (600 ms), that tested a similar paradigm (Asmaro et al., 2014; Engelmann et al., 2011; Jang et al., 2007; Littel & Franken, 2007; Sarlo et al., 2013; Yücel & Lubman, 2007). There is only 1 study to our knowledge that has measured P3 within latencies up to 800 ms post-stimulus onset (Wang et al., 2015), within a similar paradigm to the current study. Because of this, we were unsure of whether *late P3* was a valid interpretation of the observed parietal peak, and we decided to not measure it. Originally we had planned to measure early and late LPP as average amplitude between 600–1000 ms, and 1000–2000 ms post-stimulus onset, respectively, and at frontal, frontocentral, centroparietal, and parietal electrodes. These definitions were the same as those used in Littel et al. (2011). In the current study, early and late LPPs appeared to occur at earlier latencies for parietal than frontal electrodes. Because of this our originally planned definitions were altered. Although it would have been preferable to have the same time-window definitions for parietal electrodes as for the other electrodes, separate time windows were used to ensure that adjacent negative components were not being measured that could reflect a different mental process. Because time-window definitions of early and late LPP vary in the literature, it was decided that this would be an acceptable compromise. At frontal, frontocentral, and centroparietal electrodes, the early LPP was defined as average amplitude between 600–1000 ms Littel & Franken (2011). The late LPP at PZ, P1, and P2 was defined as average amplitude over 1000–1500 ms after stimulus-onset, while at frontal, frontocentral, and centroparietal sites it was defined as over 1500–2000 ms.

4.2.2 Go/NoGo task

Upon visual inspection of ERPs elicited by the Go/NoGo task, differences between filtering (0.1 Hz vs. 1.0 Hz) had the most dramatic effects on later positive components occurring after 600 ms from stimulus onset (Figures 4.3 & 4.4). We did not intend to measure any later components so this was not a problem for the ERPs we intended to measure. It was observed that N2 could be reliably defined for our range of participants as peak negative amplitude between 220 and 310 ms after stimulus-onset, and P3, as peak positive amplitude between 300 and 500 ms after stimulus-onset. These are similar to time-window definitions that have been used in previous studies (Buzzell et al., 2014; Luijten et al., 2011).
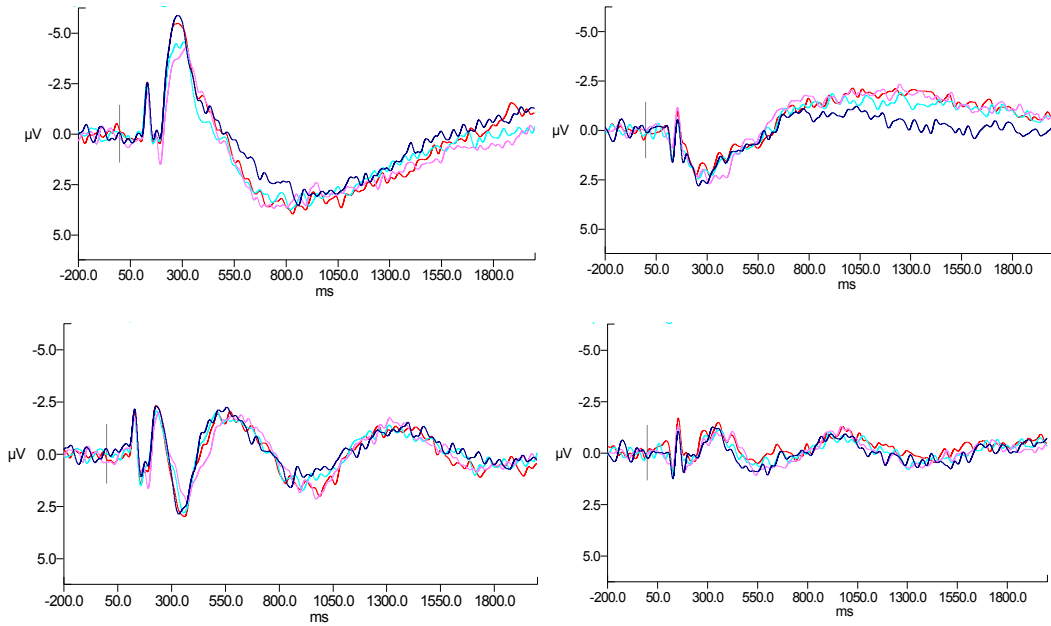
Figure 4.1. Grand averaged ERPs for 4 NS at baseline, elicited from the image slideshow task, 0.1–30.0 Hz (top) and 1.0–30 Hz (bottom) for FZ (left) and PZ (right). Picture categories: neutral (navy), pleasant (light blue), smoking (pink), unpleasant (red). Vertical grey line marks stimulus onset (i.e., 0 ms).
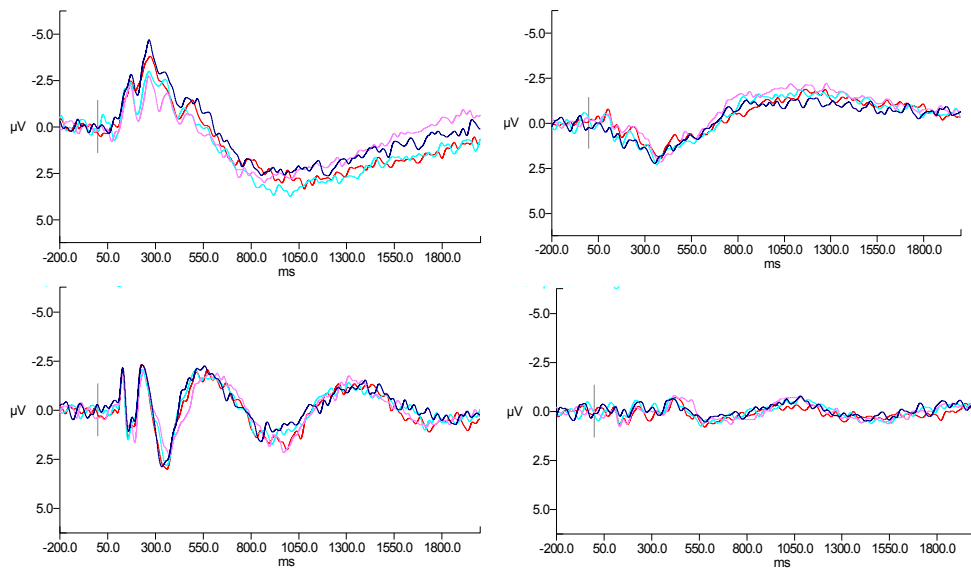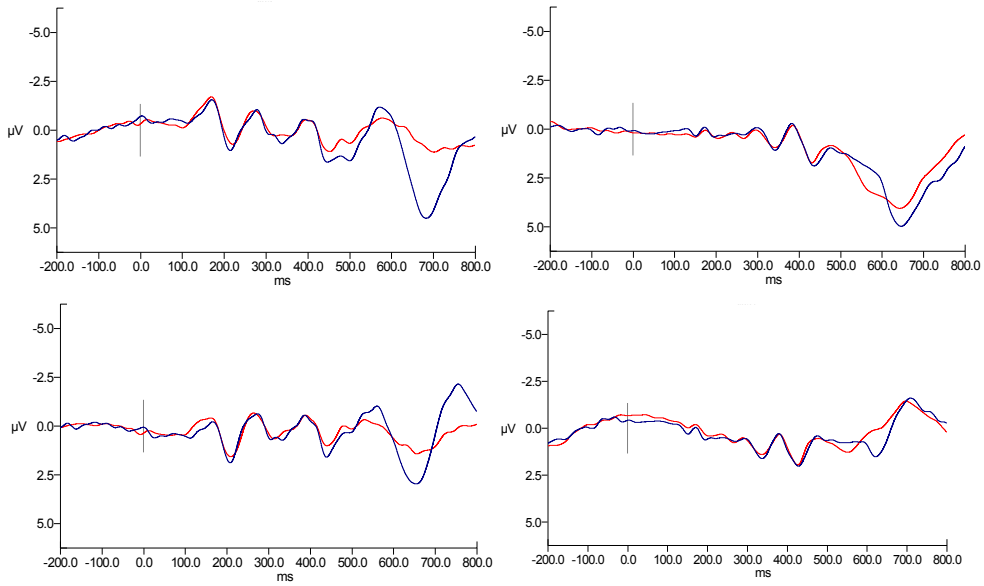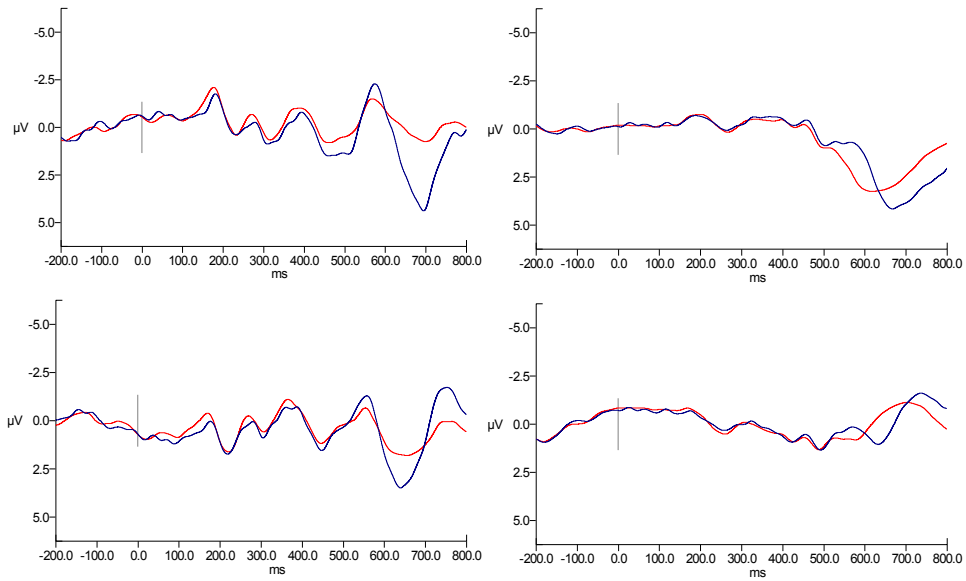

Figure 4.2. Grand averaged ERPs for 9 S at baseline, elicited from the image slideshow task, 0.1–30.0 Hz (top) and 1.0–30 Hz (bottom) for FZ (left) and PZ (right). Picture categories: neutral (navy), pleasant (light blue), smoking (pink), unpleasant (red). Vertical grey line marks stimulus onset (i.e., 0 ms).

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Figure 4.3. Grand averaged ERPs for 5 NS at baseline, elicited from the Go/NoGo task, 0.1–30.0 Hz (top) and 1.0–30 Hz (bottom) FZ (left) and CPZ (right). Categories: NoGo (navy), Go (red). Vertical grey line marks stimulus onset (i.e., 0 ms).

Figure 4.4. Grand averaged ERPs for 9 S at baseline, elicited from the Go/NoGo task, 0.1–30.0 Hz (top) and 1.0–30 Hz (bottom) for FZ (left) and CPZ (right). Categories: NoGo (navy), Go (red). Vertical grey line marks stimulus onset (i.e., 0 ms).

4.2.3 Filtering differences between smokers and non-smokers: Interpreting the ERP results

By the time online filtering had been changed from 1.0–40.0 Hz to DC–200.0 Hz most of non-smoker data had been recorded. This meant that most of non-smoker data was recorded online with a band pass of 1–40 Hz, while most of smoker data was recorded online with a bandpass of DC–200 Hz. Although it seemed that offline filtering made these equivalent, advice from Compumedics suggested that the data might not be entirely comparable. Because of this we compared group averages for each task (Go/NoGo and image slideshow) for participants that were to be included in the final analyses (12 NS and 37 S, including a mixture of EEG recorded with online filter of 1.0–40.0 Hz and DC–200.0 Hz) with groups averages of some recordings that were filtered online using only a DC–200 Hz bandpass (5 NS and 9 S). Visual inspection was made to see if differences between groups remained when groups had identical online and offline filtering. This revealed that amplitudes differences between groups remained, but difference in latencies of LPP components seen in the main comparison, disappeared when filtering was identical (Figures 4.5 & 4.6). This suggested that any latency differences between groups might be due to the difference online-filtering parameters but this did not affect us, as we did not plan to measure latencies. Because amplitude group differences remained when filtering was identical, we were confident that such results were a true reflection of group differences. While measurement of latency was not planned, these differences were still important in determining how to define ERP time windows, especially the LPPs. After careful examination of individual ERPs, it was decided that the time-windows defined above were the most appropriate in our study.

See Appendix J for ERP figures (7.2–35) elicited at each analysed electrode for image slideshow and Go/NoGo tasks at baseline and follow-up.
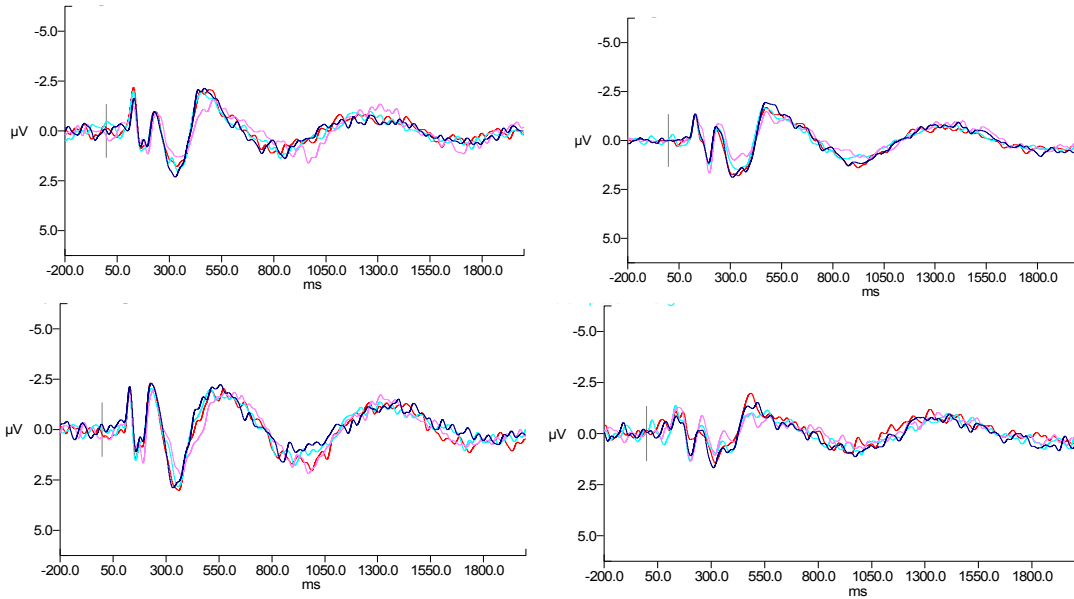
Figure 4.5. Grand averaged ERPs at FZ, 1.0–30 Hz, at baseline. Amplitude group differences including both 0.1 and 1.0 Hz online filtering, 12 NS (top left) and 37 S (top right) remain when 1.0 Hz online filtering is removed, 4 NS and 9 S (bottom). Picture categories: neutral (navy), pleasant (light blue), smoking (pink), unpleasant (red). Vertical grey line marks
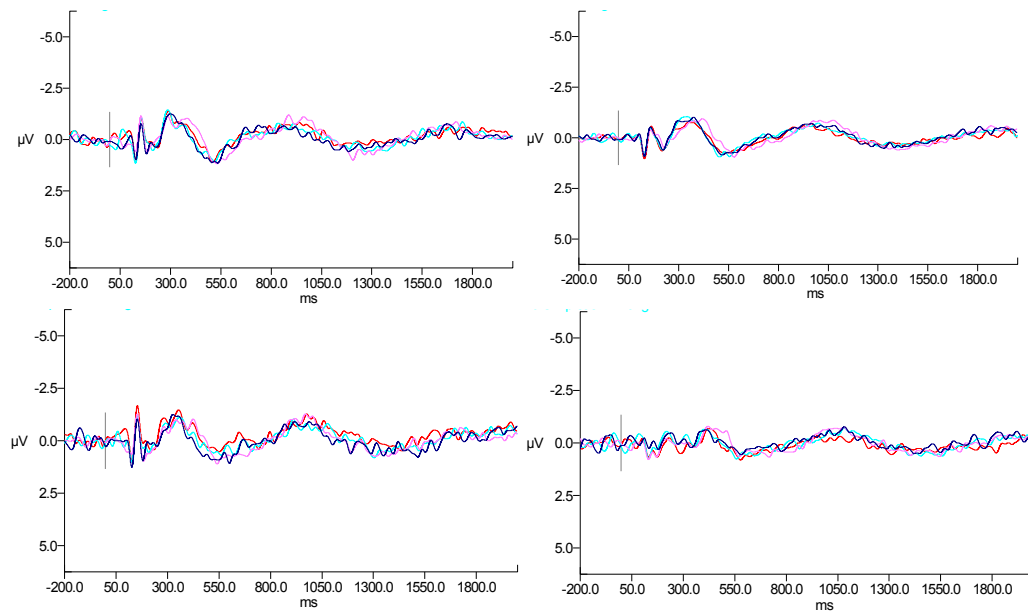

Figure 4.6. Grand averaged ERPs at PZ, 1.0–30 Hz, at baseline. Amplitude group differences including both 0.1 and 1.0 Hz online filtering, 12 NS (top left) and 37 S (top right) remain when 1.0 Hz online filtering is removed, 4 NS and 9 S (bottom). Picture categories: neutral (navy), pleasant (light blue), smoking (pink), unpleasant (red). Vertical grey line marks stimulus onset (i.e., 0 ms).

4.3 Baseline analyses

4.3.1 Attentional and emotional image processing bias: Image slideshow task

4.3.1.1 P3

Multiple comparisons tests showed significant differences at F1, $\eta p2 = 0.065$, showing decreased P3 for smoking images relative to neutral images in smokers, $q_{N-K} = 4.48$, $p = 0.010$, but not for non-smokers $q_{N-K} = 3.58$, $p = 0.156$, Figure 4.7. Other categories did not elicit significantly different amplitudes to the neutral category for either group. Neutral and smoking images appeared to elicit larger amplitudes for non-smokers compared to smokers, however neither was significant.
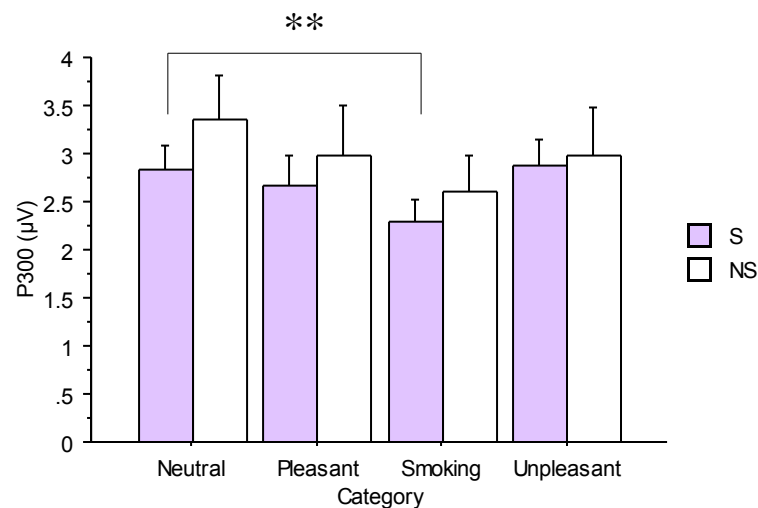
Figure 4.7. P3 amplitude at F1. Amplitude was lower in response to smoking images compared to neutral images for smokers only. Values represent means and ±SEM. ** = p < 0.01.

Other significant effects were observed at CZ, $\eta p2 = 0.045$. Smokers showed lower P3 compared to non-smokers for neutral, $q_{N-K} = 3.85$, $p = 0.038$, pleasant, $q_{N-K} = 6.77$, $p < 0.001$, and smoking images, $q_{N-K} = 5.60$, $p = 0.002$, but no difference for unpleasant images, $q_{N-K} = 1.96$, $p = 0.169$, Figure 4.8. There were no differences between neutral and other categories observed within each group.
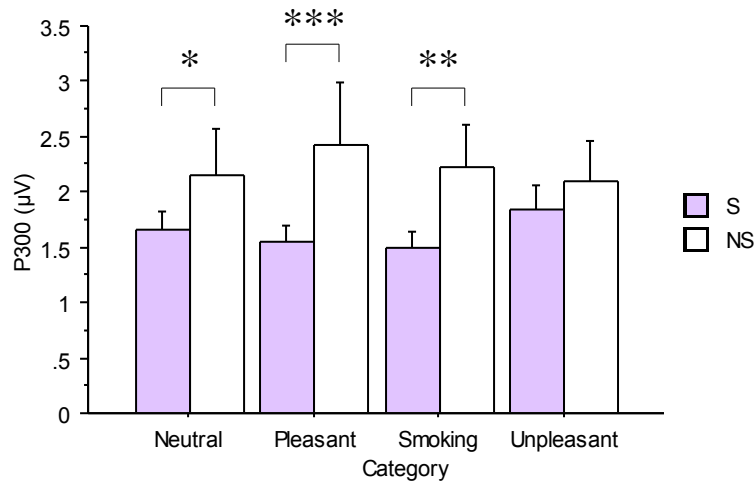
Figure 4.8. P3 amplitude at CZ. Smokers showed smaller P3 amplitudes than non-smokers in response to all stimuli except unpleasant. Values represent means and ±SEM. * = p < 0.05, ** = p < 0.01, *** = p < 0.001.

Significant effects were also observed at CPZ, $\eta p2 = 0.762$, showing that smokers elicited significantly lower P3 for pleasant images than non-smokers, $q_{N-K} = 4.37$, $p = 0.048$, Figure 4.8. There were also significantly lower amplitudes for pleasant images relative to unpleasant images in smokers, $q_{N-K} = 4.36$, $p = 0.029$, while no difference for non-smokers, $q_{N-K} = 2.05$, $p = 0.319$, Figure 4.9. There was a trend for P3 in response to pleasant images to be larger than that for neutral images in non-smokers, however this was not significant, $q_{N-K} = 3.92$, $p = 0.092$. There were no other significant differences observed within or between groups.
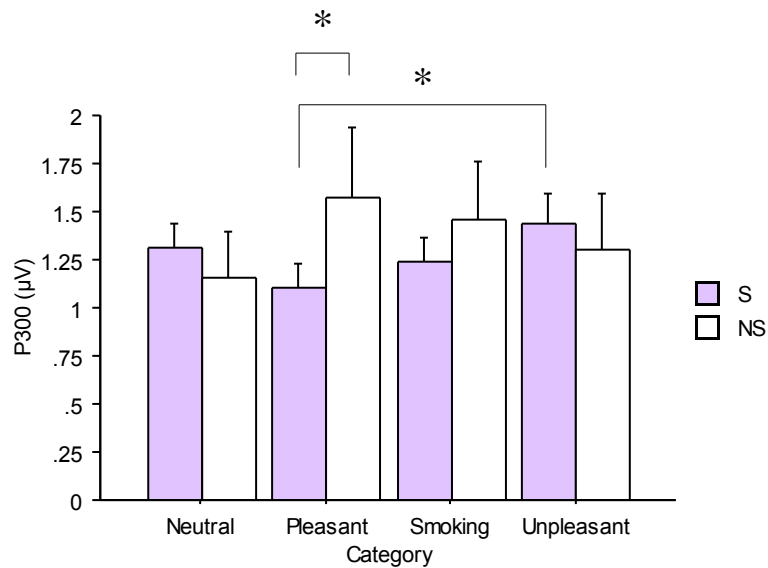
Figure 4.9. P3 amplitude at CPZ. Smokers showed smaller P3 amplitudes for pleasant stimuli compared to non-smokers and to P3 elicited by unpleasant stimuli in smokers. Values represent means and ±SEM. * = p < 0.05.

4.3.1.2 Early LPP

Early LPP was measured at F1, F2, FZ, FCZ, and CZ. It was not measured at CPZ or PZ because the time window crossed over to an adjacent negative component, which could not be definitively related to the LPP. Multiple comparisons for E.LPP showed significant differences at F2, $\eta p2 = 0.023$. Figure 4.10 suggests that smokers showed lower E.LPP amplitudes than non-smokers for smoking, pleasant, and neutral images. However this was only significant for smoking images, $q_{N-K} = 4.25$, $p = 0.036$. Smokers also showed lower amplitudes for smoking stimuli compared to neutral stimuli, which only just reached significance, $q_{N-K} = 3.35$, $p = 0.050$.
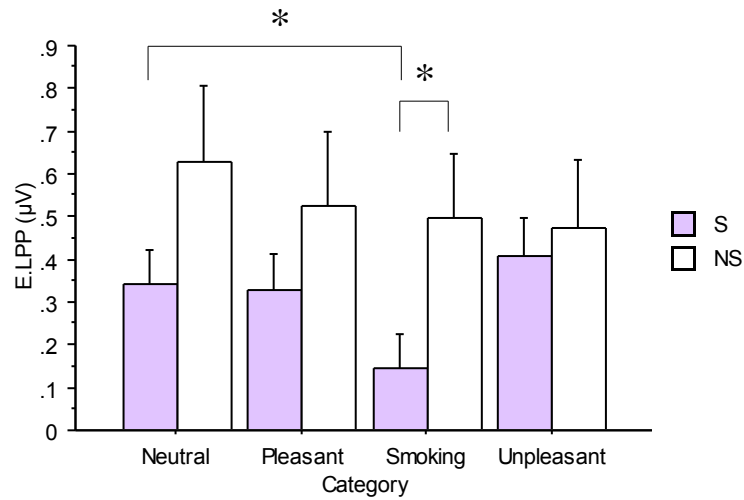
Figure 4.10. E.LPP amplitude at F2. Smokers showed lower E.LPP amplitudes for smoking images compared to that elicited in non-smokers and to amplitudes for neutral images elicited in smokers. Values represent means and ±SEM. * = p < 0.05.

4.3.1.3 Late LPP

Multiple comparisons at P2, $\eta p2 = 0.045$, showed lower L.LPP amplitudes for unpleasant stimuli compared to neutral stimuli for non-smokers, $q_{N-K} = 4.79$, $p = 0.005$, but not smokers, $q_{N-K} = 0.23$, $p = 0.984$, Figure 4.11. No other significant differences were found within groups or between groups, but there was a trend for amplitudes to be lower in response to neutral images in smokers compared to non-smokers, $q_{N-K} = 3.06$, $p = 0.081$.
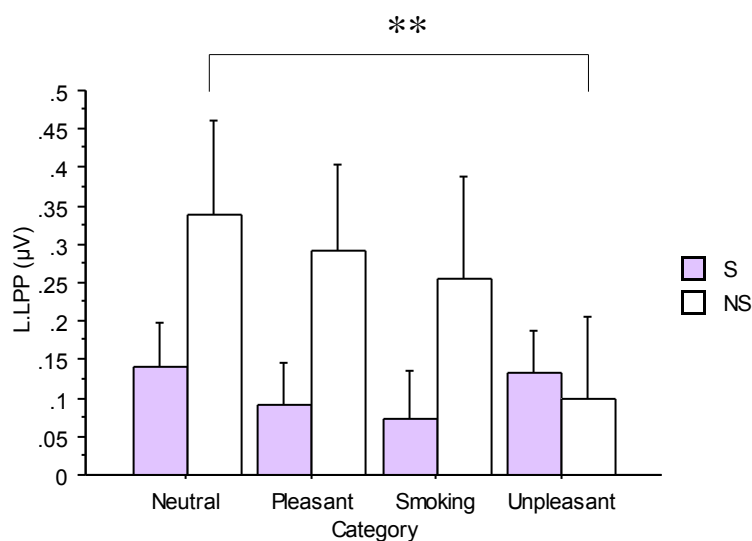
Figure 4.11. L.LPP amplitude at P2. Lower amplitudes for were observed for unpleasant compared to neutral images but in non-smokers only. Values represent means and ± SEM. ** = p < 0.01.

Figure 4.12 suggests that L.LPP amplitude is decreased for smoking images in smokers compared to non-smokers at F2, $\eta p2 = 0.014$, but this was not significant, $q_{N-K} = 2.89$, $p = 0.457$.
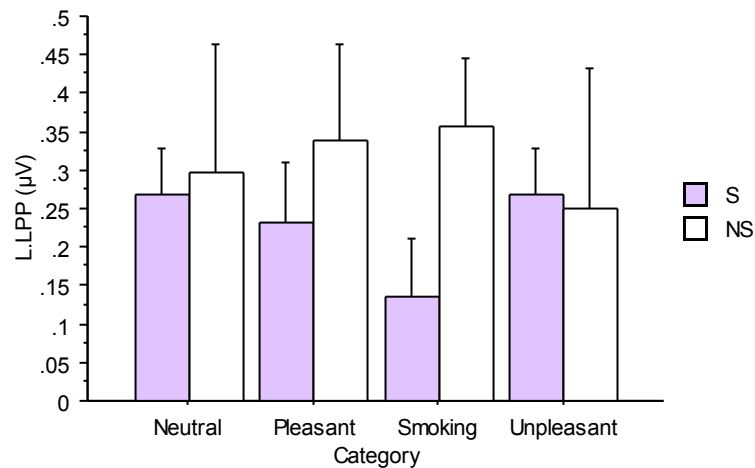

Figure 4.12. L.LPP amplitude at F2 suggests lower amplitudes in smokers compared to non-smokers for smoking images, but this was not significant. Values represent means and ± SEM.

4.3.2 Inhibitory control: Go/NoGo task

4.3.2.1 P3

P3 was analysed at FCZ, CZ, C1, C2, and CPZ, as P3 is known to be largest in these regions (Luijten et al. 2011). Multiple comparisons showed small but significant effects at C1, $\eta p2 = 0.000$. Smokers showed significantly higher amplitudes for NoGo stimuli compared to Go stimuli, $q_{N-K} = 4.45$, $p = 0.008$, however non-smokers showed no difference between these 2 categories, $q_{N-K} = 2.21$, $p = 0.272$, Figure 4.13. No differences were observed between groups for either category.
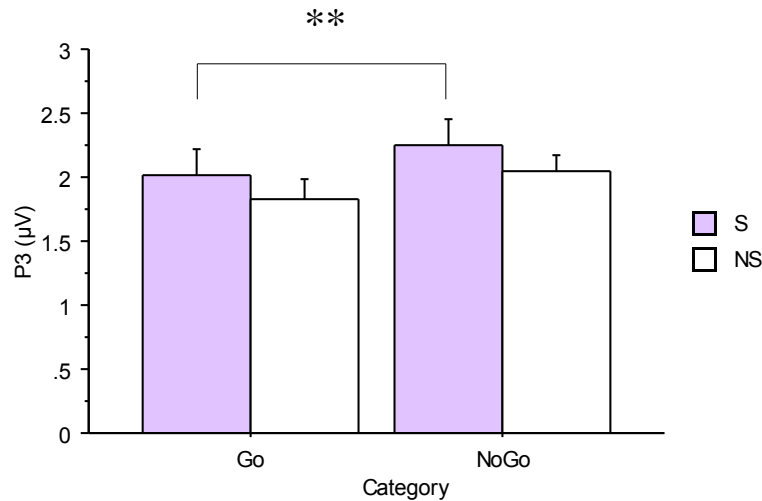
Figure 4.13. P3 amplitudes at C1. Lower P3 amplitudes were observed in response to Go compared to NoGo stimuli for smokers only. Values represent means and ±SEM. ** = p < 0.01.

4.3.2.2 N2

Multiple comparisons of N2 showed significant differences at CZ, $\eta p2 = 0.102$. N2 elicited for NoGo stimuli was no different to that elicited for Go stimuli in smokers or non-smokers. Smokers showed significantly enhanced N2 compared to non-smokers for Go stimuli, $q_{N-K} = 8.85$, $p < 0.001$, and NoGo stimuli, $q_{N-K} = 8.36$, $p < 0.001$, Figure 4.14.

Another significant interaction effect was observed at F1, $\eta p2 = 0.127$, showing opposite effects to those at CZ. At F1, smokers showed lower N2 amplitudes for NoGo stimuli than non-smokers, $q_{N-K} = 4.35$, $p = 0.018$. In addition, non-smokers showed significantly larger N2 for NoGo stimuli than Go stimuli, $q_{N-K} = 6.05$, $p = 0.0003$, while smokers did not, $q_{N-K} = 0.84$, $p = 0.824$, Figure 4.15.
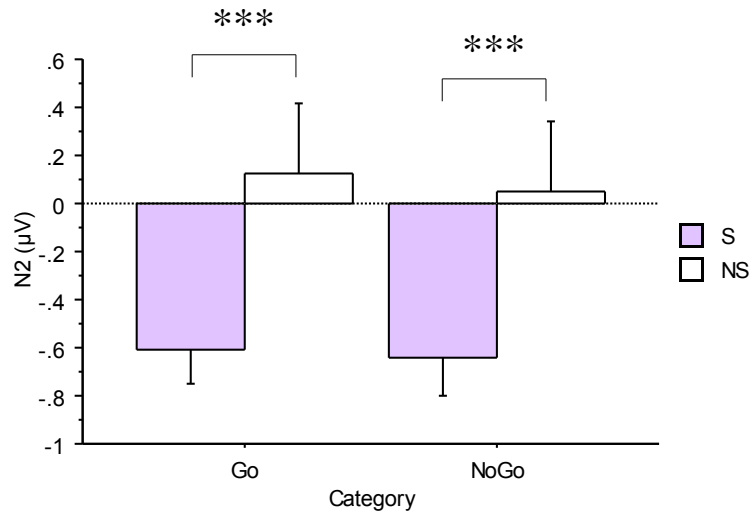
Figure 4.14. N2 amplitude at CZ shows higher amplitudes for smokers compared to non-smoker for Go and NoGo stimuli. Values represent means and ±SEM. *** = p < 0.001.
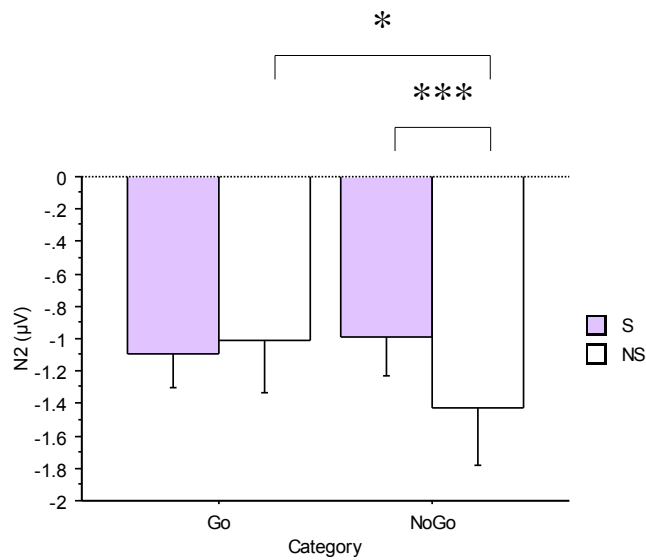

Figure 4.15. N2 amplitude at F1 shows lower NoGo N2 amplitude in smokers compared to non-smokers. Plot also shows difference between Go and NoGo stimuli for non-smokers while no difference for smokers. Values represent means and ±SEM. * = p < 0.05, *** = p < 0.001.

4.3.2.3   Accuracy and reaction time

Multiple comparisons showed significant differences in accuracy on the Go/NoGo task, $\eta p2 = 0.010$. Smokers and non-smokers were significantly less accurate responding to NoGo stimuli than Go stimuli with $q_{N-K} = 10.49$, $p < 0.001$, and $q_{N-K} = 4.60$, $p = 0.006$, for smokers and non-smokers, respectively, Figure 4.16. There was a trend for smokers to have lower accuracy in response to NoGo stimuli than smokers, however this was not significant, $q_{N-K} = 2.48$, $p = 0.086$.
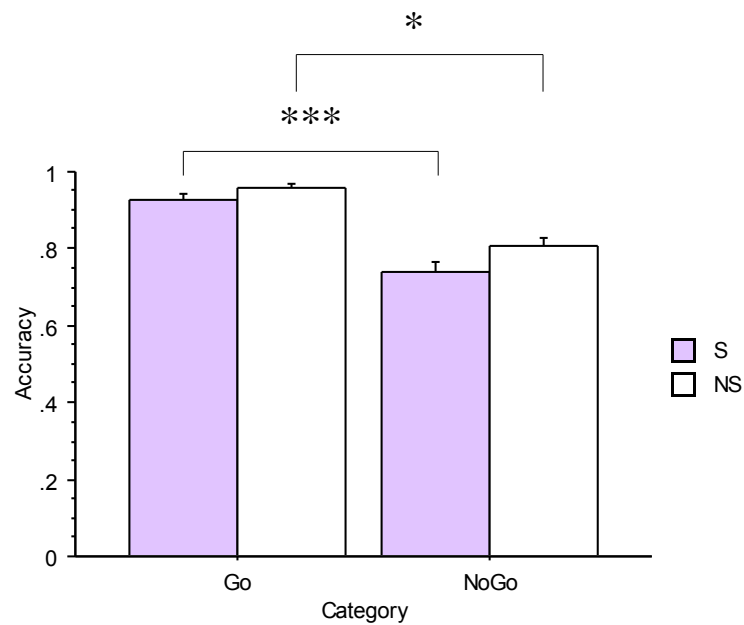
Figure 4.16. Accuracy on the Go/NoGo task shows that smokers and non-smokers were both less accurate in response to NoGo stimuli than Go stimuli. Values represent means and ±SEM. * = p < 0.01, *** = p < 0.001.

There were also significant differences in reaction time at baseline, $\eta p2 = 0.030$. Smokers and non-smokers both had significantly faster reaction times in response to false alarms (NoGo) compared to correct hits (Go), with $q_{N-K} = 17.74$, $p < 0.001$, and $q_{N-K} = 10.77$, $p < 0.001$, for smokers and non-smokers, respectively, Figure 4.17. No differences were found between groups for reaction time of Go and NoGo stimuli.
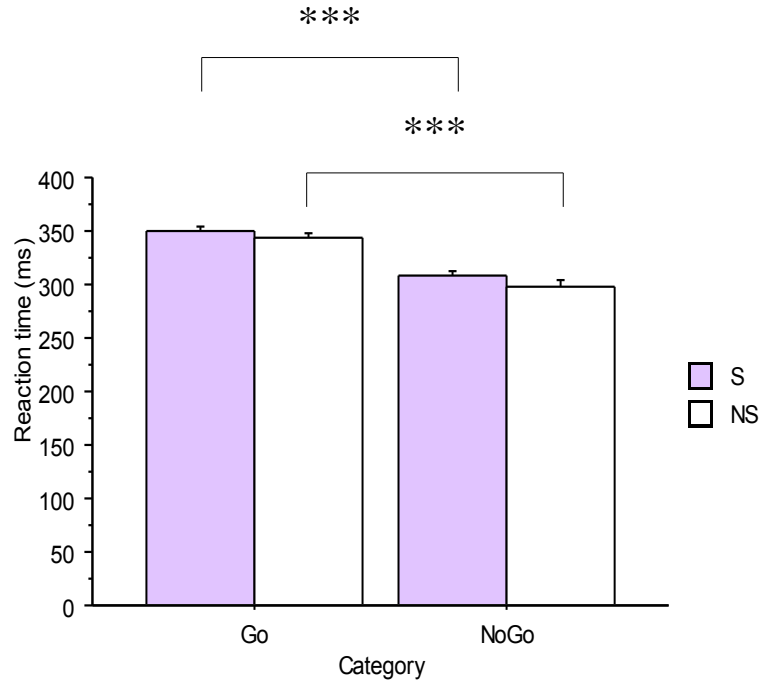
Figure 4.17. Reaction time on the Go/NoGo tasks shows that smokers and non-smokers responded faster to false alarms than correct hits. Values represent means and ±SEM. * < p < 0.001.**

4.3.2.4 Mindfulness: FFMQ

Baseline analyses of the FFMQ showed no differences between groups for any of the five facets of mindfulness at baseline (Table 4.8).

Table 4.8: Five facets of mindfulness (FFMQ) at baseline. Man-Whitney tests show no difference between smokers and non-smokers.

FFMQ facet	Non-smokers median	Smokers median	U	z	p	r
Observing	29	27	199.00	-0.92	0.357	-0.13
Describing	16	15	232.50	-0.18	0.858	-0.03
Awareness	27	24	200.50	-0.89	0.375	-0.13
Non-judging	26	28	205.00	-0.79	0.431	-0.11
Non-reactivity	24	22	195.50	-0.99	0.318	-0.14

4.3.2.5 Craving and smoking status

One participant had missing baseline data for cigarettes smoked/day and one had missing baseline data for QSU. Average rating on QSU-brief was M = 37.78, SD = 13.69 with a range of 10–63, and average number of cigarettes smoked/day was M = 16.61, SD = 6.58.

There was no significant correlation between craving and smoking status at baseline, among all smokers recorded at baseline, $r = 0.035$, $p = 0.420$, and when only the compliant smokers were analysed, $r = 0.282$, $p = 0.200$.

4.4 Follow-up analyses

4.4.1 Attentional and emotional image processing bias: image slideshow task

4.4.1.1 P3

Figure 4.18 shows multiple comparisons at F1, $\eta p2 = 0.042$. The figure suggests that P3 in response to pleasant images, increased at follow-up for smokers, but this was not significant, $q_{N-K} = 3.42$, $p = 0.373$. There also looked to be lower amplitudes for smoking images compared to neutral images in non-smokers at Session 2, but this was also not significant, $q_{N-K} = 3.87$, $p = 0.158$. In contrast to baseline results, smokers showed no difference in amplitude for smoking images compared to neutral images at Session 2, $q_{N-K} = 2.12$, $p = 0.666$.
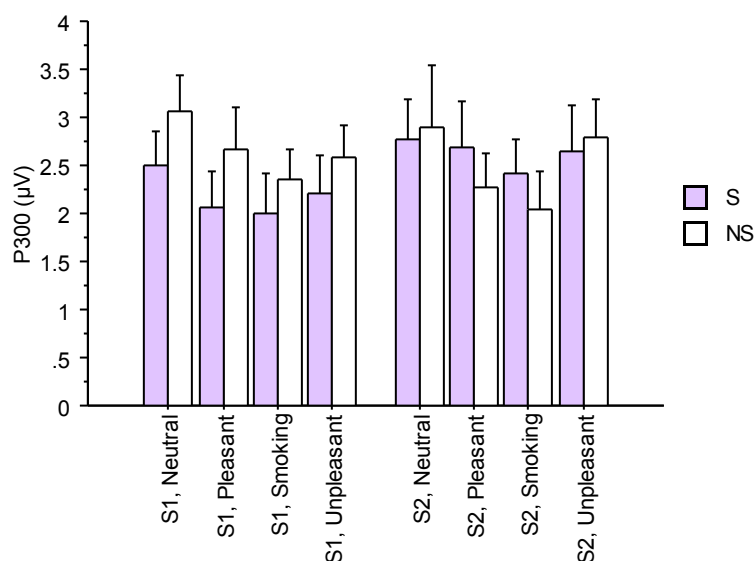

Figure 4.18. P3 amplitudes at F1 for Sessions 1 and 2 for individual categories in smokers and non-smokers showed no significant effects. Values represent means and ±SEM.

Multiple comparisons at CZ, $\eta p2 = 0.119$, show that non-smokers' responses to pleasant images decreased at follow-up, $q_{N-K} = 6.80 \ p = 0.001$, while there was no change in amplitude for smokers, $q_{N-K} = 2.17$, $p = 0.902$, Figure 4.19. In contrast to baseline there was no difference in amplitude for P3 elicited by pleasant images compared to neutral images at Session 2 for non-smokers, $q_{N-K} = 2.85 \ p = 0.539$. Likewise, there was no difference between P3 elicited for pleasant images between smokers and non-smokers at Session 2, $q_{N-K} = 2.95 \ p = 0.591$, or for any other category.

Figure 4.20 shows multiple comparisons at CPZ, $\eta p2 = 0.125$, suggesting decreased P3 for pleasant images in non-smokers at Session 2 compared to Session 1, however this was not significant, $q_{N-K} = 4.07$, $p = 0.224$. In contrast to baseline analyses, there was no difference observed for P3 elicited by pleasant images between smokers and non-smokers, $q_{N-K} = 0.68$, $p = 0.881$.
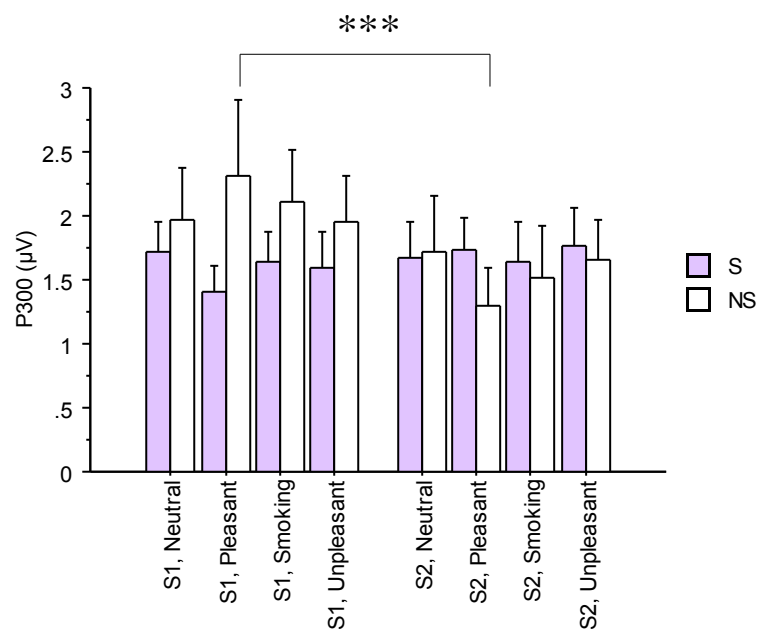

Figure 4.19. P3 amplitudes at CZ for Sessions 1 and 2 for individual categories in smokers and non-smokers. P3 for pleasant images decreased at time 2 for non-smokers, while there was no change for smokers. Values represent means and ±SEM. *** p < 0.001
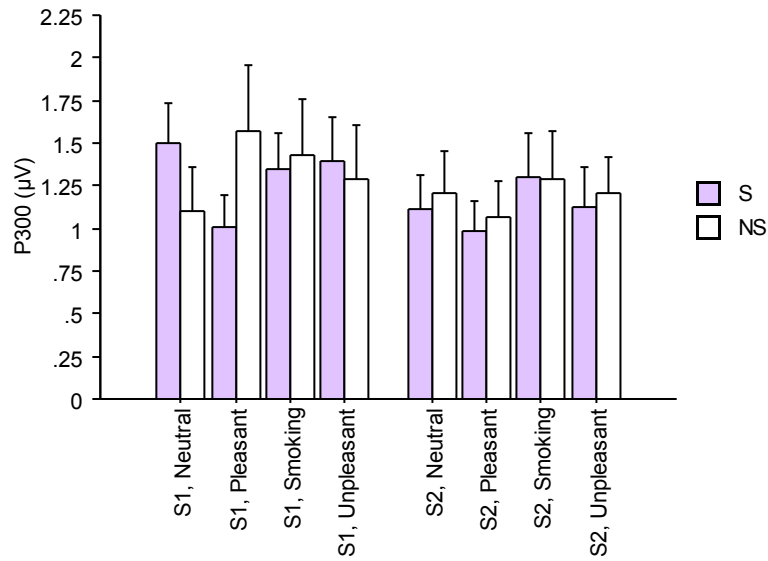
Figure 4.20. P3 amplitudes at CPZ for Sessions 1 and 2 for individual categories in smokers and non-smokers. No significant effects were observed. Values represent means and ±SEM.

4.4.1.2 Early LPP

Figure 4.21 shows multiple comparisons for early LPP at follow-up at F2, $\eta p2 = 0.014$, suggesting that E.LPP increased for pleasant images in smokers at Session 2 compared to Session 1, however this was not significant, $q_{N-K} = 1.69$, $p = 0.632$. In contrast to baseline, there was no significant different between smokers and non-smokers at Session 2 for E.LPP elicited by smoking images, $q_{N-K} = 1.78$, $p = 0.910$.
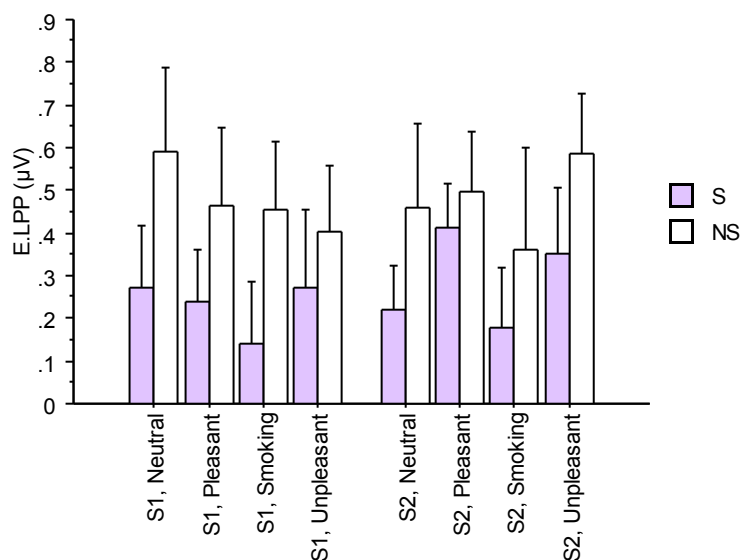

Figure 4.21. E.LPP amplitudes at F2 for Sessions 1 and 2 for individual categories in smokers and non-smokers. No significant effects were observed. Values represent means and ±SEM.

4.4.1.3 Late LPP

Figure 4.22 shows the multiple comparisons at FCZ, $\eta p2 = 0.011$. The figure suggests that smokers had increased L.LPP for pleasant images at follow-up compared to baseline, however this was not significant, $q_{N-K} = 2.77$, $p = 0.787$. It looked like smokers had a larger L.LPP than non-smokers in response to pleasant images at Session 2, however this was also not significant, $q_{N-K} = 1.91$, $p = 0.911$. Similar effects looked to have appeared at F2, $\eta p2 = 0.040$, but these were also not significant, Figure 4.23.
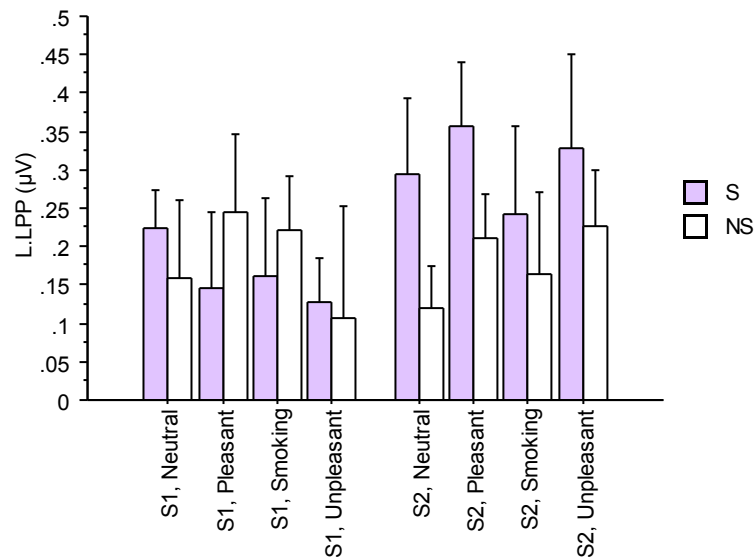

Figure 4.22. L.LPP amplitudes at FCZ for Sessions 1 and 2 for individual categories in smokers and non-smokers. No significant effects were observed. Values represent means and ±SEM.

Figure 4.24 shows the multiple comparisons at P2, $\eta p2 = 0.075$, suggesting that smokers showed lower L.LPP at Session 2 in response to all categories, compared to non-smokers. This effect was only significant for smoking images, $q_{N-K} = 7.19$, $p < 0.001$, and nearly for pleasant images, $q_{N-K} = 4.66$, $p = 0.093$, but not for neutral, $q_{N-K} = 2.22$, $p = 0.702$, and unpleasant images, $q_{N-K} = 3.98$, $p = 0.222$.
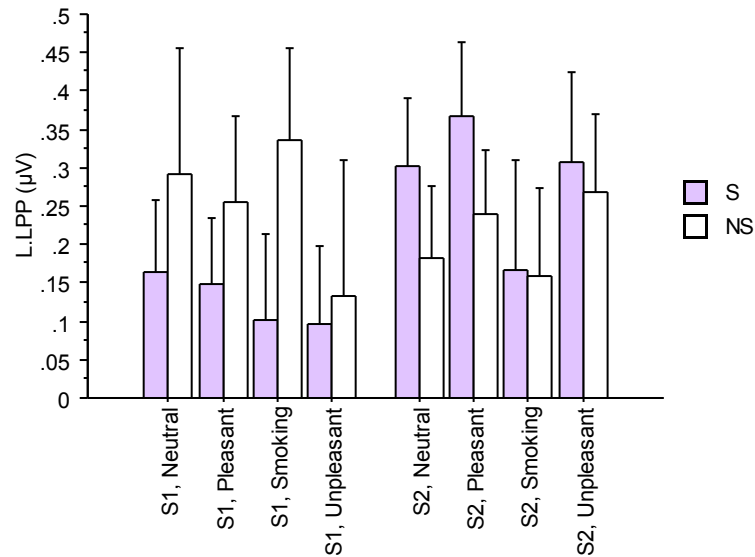
Figure 4.23. L.LPP amplitudes at F2 for Sessions 1 and 2 for individual categories in smokers and non-smokers. No significant effects were observed. Values represent means and ±SEM.
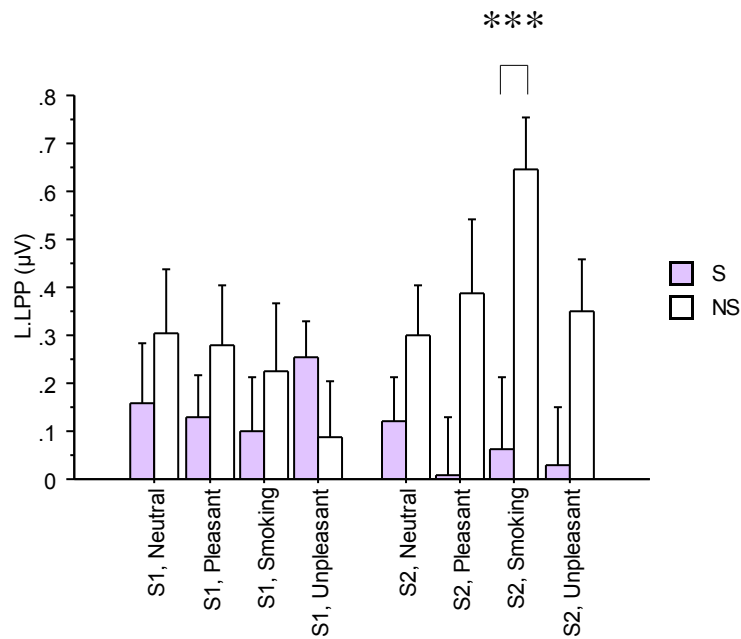

Figure 4.24. L.LPP amplitudes at P2 for Sessions 1 and 2 for individual categories in smokers and non-smokers. Smokers had blunted L.LPP for smoking images at Session 2 compared to non-smokers. Values represent means and ±SEM. *** = p < 0.001

4.4.2 Inhibitory control: Go/NoGo task

4.4.2.1 P3 ERPs

Multiple comparisons showed significant differences at CPZ, $\eta p2 = 0.051$. Smokers showed increased P3 amplitudes for NoGo stimuli, $q_{N-K} = 6.18$, $p = 0.005$, and Go stimuli, $q_{N-K} = 4.12$, $p = 0.039$ at Session 2 compared to Session 1, Figure 4.25. Non-smokers showed a trend for a decrease in P3 at Session 2 for NoGo stimuli, $q_{N-K} = 3.52$, $p = 0.093$, and no change for Go stimuli, $q_{N-K} = 2.55$, $p = 0.301$. At Session 2 P3 was significantly larger for NoGo stimuli compared to Go stimuli in smokers, $q_{N-K} = 4.12$, $p = 0.040$, but there was no difference between categories in non-smokers, $q_{N-K} = 1.94$, $p = 0.374$, or between groups.
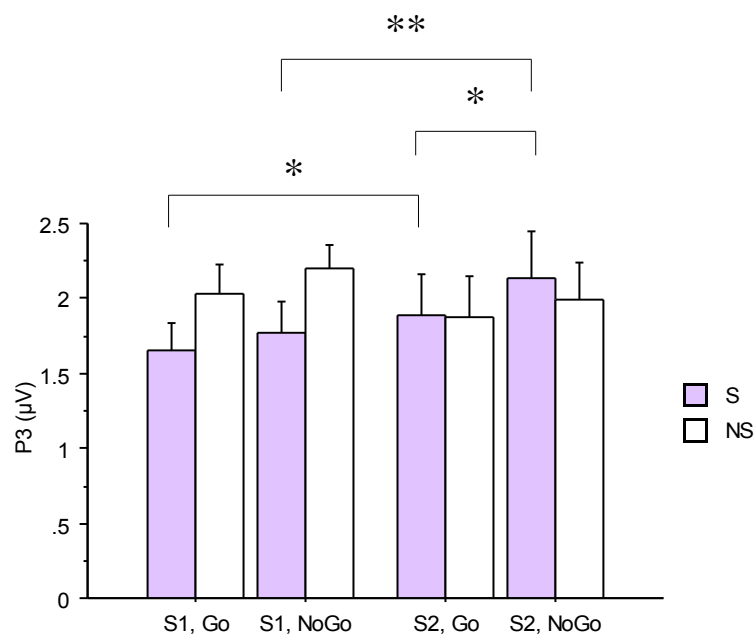

Figure 4.25. P3 amplitude at CPZ for Go and NoGo stimuli in smokers and non-smokers. Values represent means and ±SEM. * = p < 0.05, ** = p < 0.01.

4.4.2.2 N2 ERPs

Multiple comparisons showed significant interactions at F1, $\eta p2 = 0.198$. N2 amplitudes were significant reduced at Session 2 compared to Session for NoGo stimuli, $q_{N-K} = 7.06$, $p = 0.001$, and Go stimuli, $q_{N-K} = 5.03$, $p = 0.027$ in non-smokers, Figure 4.26. There were no other significant differences within or between groups.
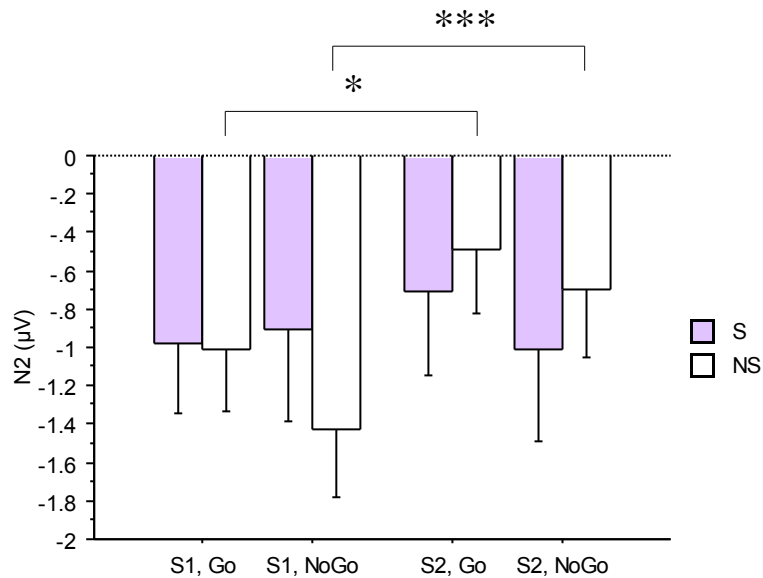
Figure 4.26. N2 amplitudes F1. N2 decreased at Session 2 for non-smokers for both Go and NoGo stimuli. Values represent means and ±SEM. * = p < 0.05, *** = p < 0.001

Other effects occurred at F2, $\eta p2 = 0.149$. At Session 2 smokers showed larger N2 amplitudes for NoGo stimuli than non-smokers, $q_{N-K} = 4.97$, $p = 0.029$, Figure 4.27. Non-smokers also showed a significant decrease in N2 for NoGo stimuli at Session 2 compared to Session 1, $q_{N-K} = 5.63$, $p = 0.008$. Figure 4.27 suggests a slight increase of NoGo N2 at Session 2 for smokers, however, this was not significant, $q_{N-K} = 2.62$, $p = 0.279$.
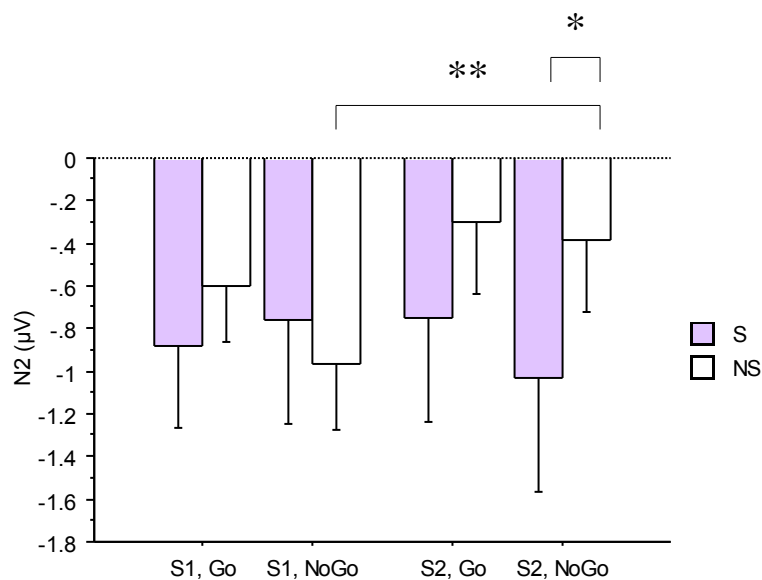

Figure 4.27. N2 amplitudes F2. NoGo N2 for non-smokers decreased at Session 2 compared to Session 1, and was also smaller than NoGo N2 for smokers at Session 2. Values represent means and ±SEM. * = p < 0.05, ** = p < 0.01.

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4.4.2.3   *Accuracy and reaction time*

Figure 4.28 shows the main comparisons for accuracy, $\eta p2 = 0.015$. At Session 2 smokers had significantly lower accuracy for NoGo stimuli than non-smokers, $q_{N-K} = 8.30$, $p < 0.001$. At Session 2, accuracy was greater for Go compared to NoGo stimuli in both smokers, $q_{N-K} = 13.68$, $p < 0.001$, and non-smokers, $q_{N-K} = 9.02$, $p < 0.001$. There was also a trend for NoGo accuracy to decrease for smokers at follow-up, but this did not reach significance, $q_{N-K} = 2.85$, $p = 0.057$. There was no change in NoGo accuracy at follow-up for non-smokers, $q_{N-K} = 0.54$, $p = 0.706$. There was also no change in accuracy for Go stimuli in either group.

Figure 4.29 shows multiple comparisons for reaction time at follow-up, $\eta p2 = 0.030$. Reaction time was slower at Session 2, in response to Go stimuli compared to NoGo stimuli for both smokers, $q_{N-K} = 19.15$, $p < 0.001$, and non-smokers, $q_{N-K} = 22.64$, $p < 0.001$. There was no significant difference between groups for either category.
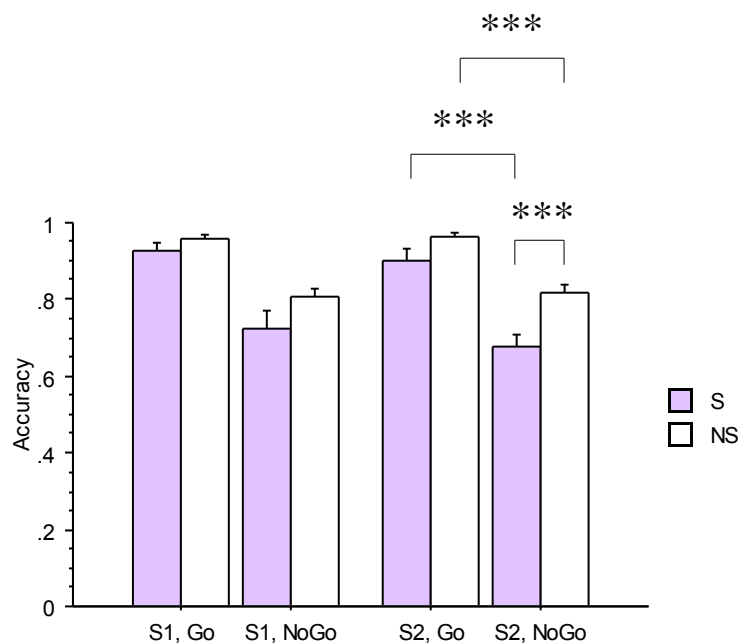

Figure 4.28. Accuracy in the Go/NoGo task for Sessions 1 and 2, for smokers and non-smokers. Values represent means and ±SEM. *** = p < 0.001.
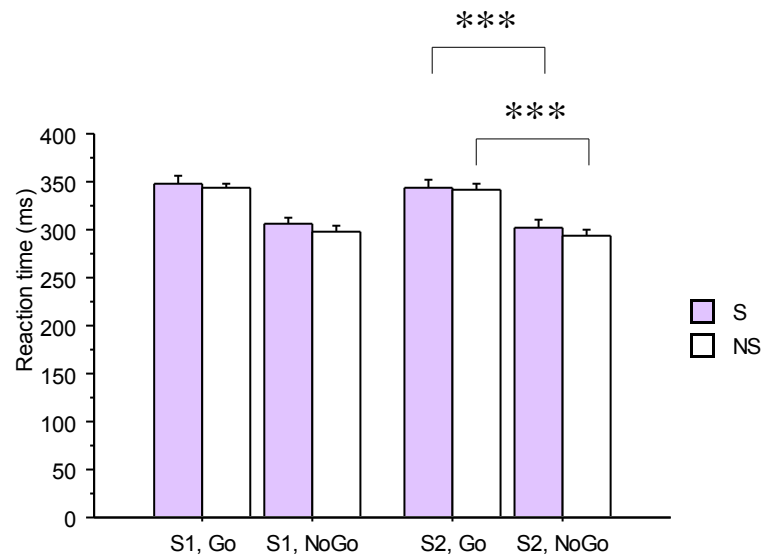
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Figure 4.29. Reaction time in the Go/NoGo task for Sessions 1 and 2, for smokers and non-smokers. Values represent means and ±SEM. *** = p < 0.001.

4.4.2.4 Mindfulness: FFMQ

Analyses of FFMQ facets showed no significant changes at follow-up among smokers or non-smokers (Table 4.9).

4.4.2.5 Craving and smoking status

There was a significant drop in smoking status (cigarettes/day) at 1-2 month follow-up among those who completed at least 70% of the app and came to their EEG session (M at baseline = 37.9, SD = 18.9, M at 1-2 month follow-up = 8.20, SD = 6.60). This difference, 29.7, 95% CI [17.0 – 42.4], was significant $t_{(9)}$ = 5.29, p = 0.001, and presented a large effect size, d = 1.67 (Figure 3.38).

Conversely, there was no significant decline in craving (QSU-brief) at 1-2 month follow-up, baseline Mdn = 33, follow-up Mdn = 30, z = -1.20, p = 0.230, r = -0.36. Follow-up ratings of craving ranged from 10–62.

Among smokers there was a medium correlation between craving and smoking status at follow-up, which showed a trend towards significance, r = 0.495, p = 0.073.

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Table 4.9. Values for the Five Facets of Mindfulness Questionnaire (FFMQ) did not change at Session 2. Analysed using Wilcoxon signed-rank tests.

| FFMQ facet by group	Baseline median	Follow-up median	z	p	r
NS Observing	29	28	-1.31	0.191	-0.28
S Observing	27	29	-0.35	0.724	-0.07
NS Describing	16	16	-0.11	0.916	-0.02
S Describing	14	15	-0.60	0.549	-0.12
NS Awareness	27	25	-0.16	0.877	-0.03
S Awareness	23	27	-1.23	0.218	-0.26
NS Non-judging	26	27	-1.05	0.293	-0.22
S Non-judging	28	29	-1.07	0.285	-0.23
NS Non-reactivity	24	23	-1.06	0.288	-0.23
S Non-reactivity	25	26	-0.36	0.721	-0.08
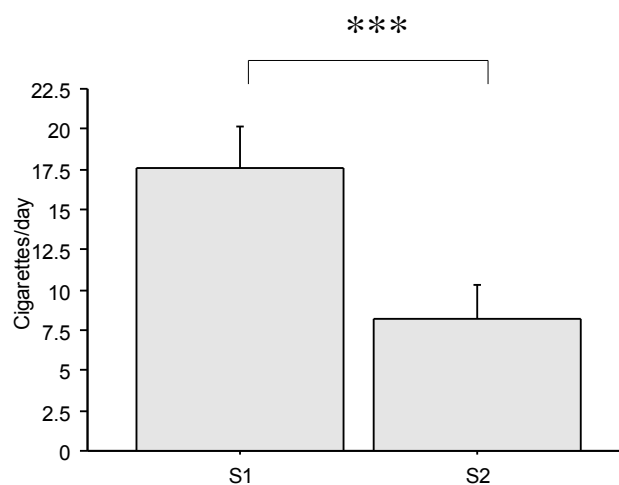
Figure 4.30 Smoking status (cigarettes/day) was lower at Session 2 than Session 1. Values represent means and ±SEM. *** = p < 0.001.

5 Discussion

The aim of the current study was to test the effectiveness of a potential new mainstay treatment for smoking-cessation delivered via smartphones and to elucidate the potential mechanisms of a mindfulness-based intervention for smoking-cessation.

Findings show promise for using a mindfulness-based intervention for smoking-cessation in terms of reducing cigarette consumption at follow-up although more research is needed to isolate its proposed mechanisms. Baseline and follow-up findings will be discussed first, then limitations, and proposed changes for a larger-scale study.

5.1 Baseline

The first aim of our study was to replicate an image processing bias to smoking cues, and deficits in behavioural and neural markers of inhibitory control at baseline. We also expected to find no difference between smokers and non-smokers for image processing of pleasant, neutral and unpleasant stimuli at baseline. We observed no smoking-related image processing bias and found blunted processing of all types of stimuli, except unpleasant stimuli, in smokers relative to non-smokers. Smokers also showed a trend for reduced accuracy in the Go/NoGo task and showed reduced NoGo N2 (marker of conflict monitoring) relative to non-smokers, but no significant differences were observed in NoGo P3 (marker of motor inhibitory control).

5.1.1 Image slideshow task

We expected a smoking-related processing bias in smokers as a reflection of drug-related incentive salience, which may be implicated in the maintenance of addiction. The lack of this effect in the current study was incongruent with our hypothesis and with past literature (Littel & Franken, 2007, 2011; McDonough & Warren, 2001; Minnix et al., 2013) and indicates, that smokers in our study did not exhibit attentional bias for smoking cues. Furthermore, smokers in the current study had a blunted response to smoking images, compared with neutral images in smokers, and to smoking images in non-smokers. There is evidence that suggests heavier smokers show less attentional bias than light smokers, at least behaviourally (Hogarth, Mogg, Bradley, Duka, & Dickinson, 2003), but this is unlikely to be the cause of our unexpected results, as smokers in the current study showed similar nicotine

dependence and daily smoking status (number of cigarettes smoked/day) to those in previous studies. Also, even though smokers in the current study abstained for substantially longer before testing than those in previous studies, this is unlikely to account for our different results, as McDonough & Warren (2001) have shown that abstinence does not affect P3 amplitude. Abstinence is also unlikely to affect the LPP. While no study has tested effects of abstinence on the LPP, it seems likely that factors affecting a lack of smoking-related image processing bias would be the same for both P3 and LPP, because they are closely-related components.

An alternative explanation for the lack of smoking-related image processing bias could be that participants became habituated to the smoking images. While potential for habituation of P3 and LPP has not been investigated, it may have occurred in the current study. This could be because the content of smoking images was very similar (often a close-up of a cigarette between pursed lips), which contrasts to the varied content in other image categories (e.g., night, day, people, objects, one person, several people etc.). This does not explain why the blunting was specific for smokers, however, image processing bias to smoking-cues may have been more likely in the current study if a greater variety of content was used within the smoking category (e.g., people smoking and images of common NZ cigarette packets).

We also did not expect neutral images to elicit similar P3, and LPP amplitudes in response to pleasant and unpleasant categories. Perhaps the available normed ratings were not appropriate for the tested population. Neutral images may have elicited a stronger valence and arousal in participants of the current study than what was indicated in the normed values. Conversely, affective images may have elicited a weaker valence.

Another potential explanation for the lack of processing separation between neutral and affective categories is that categories were not controlled for luminosity, contrast and spatial frequencies as it has been in other studies including Blakemore, Rieger, & Vuilleumier (2016). Within the current study, neutral images typically had a higher contrast than images from other categories. While no research has tested whether these image-related variables affect the P3 and/or the LPP, previous research has shown that pictures within the IAPS can vary in spatial frequency, and suggest that this could affect results in studies which test emotional influence on visual processing (Delplanque, N'diaye, Scherer, & Grandjean, 2007). Delplanque et al. (2007) suggest that when using the IAPS, picture categories should be controlled for on spatial frequency. Future studies are needed to confirm whether contrast, spatial frequency and luminosity affect the P3 and LPP.

In contrast to Aim 3 and results of Minnix et al. (2013), the current study showed reduced image processing in smokers relative to non-smokers for all categories except unpleasant. This was shown by reduced P3 for neutral, pleasant and smoking categories at baseline in smokers compared to non-smokers. The pattern also appeared in graphs for early and late LPP, although these were not significant. Because mean amplitudes of LPP were a lot smaller than those for P3, it is possible that we did not have enough power to detect differences. It is intriguing that smokers had a blunted processing to all types of stimuli except unpleasant and that smokers showed greater P3 amplitudes for unpleasant stimuli compared to pleasant stimuli. Because arousal for pleasant and unpleasant stimuli was matched, results suggest that unpleasant stimuli were more salient to smokers than pleasant stimuli. This could be because smokers were required to abstain from nicotine for at least 8 hours prior to the EEG session. According to Koob & Le Moal (2001) acute withdrawal from nicotine would have produced a state of anhedonia. It is possible that this made smokers more sensitive to unpleasant stimuli than if they were satiated. This could also explain why smokers in Minnix et al. (2013), who were asked to "smoke normally" before the EEG session, showed no differences in processing to neutral, pleasant and unpleasant stimuli, compared to non-smokers. Although McDonough & Warren (2001) have shown that abstinence does not alter P3 in response to smoking images, there is no evidence to suggest that it does not alter responding to pleasant and unpleasant images. Future research should test the effects of abstinence on processing of affective stimuli in smokers.

Although this blunted processing did not occur in the study by Minnix et al. (2013), which compared smokers with non-smokers, it has been observed in another study, which compared different "clusters" of smokers. In Versace et al. (2012) results of smokers were separated into 2 clusters based on sensitivity to pleasant stimuli. The cluster of smokers who were less responsive to pleasant stimuli were less likely to be abstinent at follow-up (Versace et al., 2012). This finding, in combination with our results, suggests that measuring ERP responses to intrinsically affective stimuli is just as useful as measuring that in response to smoking-related stimuli.

5.1.2 Go/NoGo task

Parts of Aim 2, relating to the Go/NoGo task, were supported by the results. The current study showed a trend for lower accuracy for NoGo stimuli on the Go/NoGo task in smokers compared to non-smokers, which was supported by lower NoGo N2 amplitudes at F1. These results follow studies of Luijten et al. (2011) and Buzzell et al. (2014).

Interestingly, we showed a trend for differences in behavioural accuracy while Buzzell et al. (2014) did not. It was suggested by Buzzell et al. (2014) that they did not observe differences in behaviour because they tested smokers with low nicotine dependence. They posed that N2 is a more sensitive measure of inhibitory control than behaviour and that behavioural task deficits would be more apparent in smokers with greater levels of dependence (Buzzell et al. 2014). The average level of nicotine dependence of participants in the current study was moderate, which could explain why we showed differences in behaviour while Buzzell et al. (2014) did not. Unexpectedly, we saw higher N2 for both Go and NoGo stimuli at CZ in smokers compared to non-smokers. This finding is perplexing and may have little meaning considering that the average N2 at CZ was nearly half the size of that at frontal electrodes. Because N2 is more prominent at frontal electrodes in both our study and previous studies, any changes at F1 are likely to be more reliable than those at CZ. Alternatively, this could reflect inefficient recruitment of appropriate neural resources in smokers, which future research should explore.

An aim relating to the Go/NoGo task, which was not supported by our findings, was that smokers would show reduced NoGo P3 amplitudes compared to smokers. This is not surprising as neither Luijten et al. (2011) nor Buzzell et al. (2014) showed any group effects on NoGo P3. This could suggest that NoGo P3 is a less sensitive measure of inhibitory control than N2, or that unlike other impulsive populations (Luijten et al. 2011) NoGo P3 is not different in smokers compared to non-smokers.

An alternative explanation to observing no group effects for NoGo P3 could be that we did not measure the correct component. This could be indicated by observations of a large, unanticipated, positive peak occurring between 600–800 ms after Go and NoGo stimuli. This was observed at frontal through to parietal electrodes and was highest in response to NoGo stimuli, which follows the typical pattern of the Go/NoGo P3. The average peak amplitude of this potential was much higher than that occurring between 300–500 ms (analysed P3), which could suggest that in the current study, Go/NoGo P3 peaked within a later time-window. Subsequently, this could suggest that we did not analyse the true Go/NoGo P3, which may explain why we found no group differences at baseline. However, no previous literature has reported Go/NoGo P3 later than 500 ms. Because of this we could not reliably categorise a positive peak between 600–800 ms as the Go/NoGo P3 and so we decided not to analyse it statistically.

Future studies should report unexpected positive components that are observed 600 ms post-stimulus in the Go/NoGo task. This could help confirm whether it is possible for the

Go/NoGo P3 to occur this late, or if positive peaks at this latency reflect a separate neural process.

5.2 Follow-up

All of our hypotheses (1–7, see section 2.2) and Aim 4 were related to follow-up results. We hypothesised that those exposed to *Craving to Quit* would show a reduced smoking-related processing bias, increased processing to neutral and affective (pleasant and unpleasant) stimuli, and would have increased NoGo N2, NoGo P3, and NoGo accuracy. We found no significant reduction in smoking-related image processing bias, and no change in processing to neutral and affective stimuli within smokers. Smokers showed a significant increase in P3 at follow-up for both Go and NoGo stimuli while non-smokers showed no change. There was no change for smokers' N2 but a significant decrease for NoGo and Go N2 in non-smokers at follow-up. There was no change in accuracy on the Go/NoGo task for non-smokers but a trend for decreased NoGo accuracy for smokers.

5.2.1 Go/NoGo

At Session 2, smokers showed significantly lower accuracy for NoGo stimuli in the Go/NoGo task than non-smokers. Because this was only a trend at baseline, results suggest that smokers were worse at the task at follow-up. This is supported by a trend for decreased NoGo accuracy in smokers at follow-up while there was no change in accuracy for non-smokers. Hypothesis 1 of increased behavioural markers of inhibitory control was therefore not supported.

Although smokers' amplitudes for NoGo N2 at follow-up were not significantly different to those at Session 1, they were significantly larger than those of non-smokers' at follow-up. This is because non-smokers showed significantly decreased N2 amplitudes for both Go and NoGo stimuli at follow-up compared to baseline. This could reflect a decrease in neural resources needed to perform the task again, with a similar accuracy. In contrast to decreased N2 in non-smokers, there was an increase in P3 for Go and NoGo stimuli at follow-up among smokers. This partially supports Hypothesis 2, but is incongruent with smokers' trend for decreased NoGo accuracy. Following a similar interpretation to the results of non-smokers, increased P3 in smokers may reflect increased neural resources required to perform the Go/NoGo task at a similar accuracy to baseline. This could be due to a reduced capacity of inhibitory control during a quit attempt, as quit attempts require continual inhibition of

smoking behaviour. This could explain the discrepancy between behavioural and neural results in smokers. Another interpretation of our results could be that changes in NoGo P3 amplitudes are precursors for changes in accuracy. As suggested by Buzzell et al. (2014), ERPs may be more sensitive markers of inhibitory control than behaviour. Future studies are needed to test these interpretations. Such studies should test inhibitory control in participants who attempt to quit without *Craving to Quit* and include a longer-term EEG follow-up. If participants who attempt to quit with no intervention show greater deficits in accuracy as well as NoGo N2 and P3 compared to those who do use the app, this could suggest that *Craving to Quit* can mitigate deficits of inhibitory control during a quit-attempt.

5.2.2 Image slideshow

Other than reduced P3 for pleasant images in non-smokers at follow-up, no significant ERP changes occurred in response to the slideshow between sessions meaning that results did not support Hypothesis 3 or 4. Despite lack of significance, Figures 4.22 and 4.23 indicate striking differences in late LPP at frontal electrodes between sessions for smokers, which cannot be ignored. In the same direction as Hypothesis 3, there was a non-significant tendency for late LPP amplitudes to increase at Session 2 in smokers for neutral and affective categories. Results may have failed to reach significance because, as with baseline, mean amplitudes for LPP were very small. One of the reasons of these small amplitudes could be due to the high-pass filtering that we used, which was higher in comparison to previous studies. This is visible in Figure 4.1, comparing a high-pass filter or 0.1 Hz with 1.0 Hz. Correcting for multiple comparisons (up to 16) may have also reduced our ability to detect differences, but this method was chosen to reduce the likelihood of committing Type 1 error. These striking Figures suggest that a design with greater statistical power might reveal this potential mechanism of mindfulness, i.e., increased neural processing related to increased awareness.

Figure 4.25, at P2, showed an opposite direction of effect to frontal electrodes, with non-smokers showing a non-significant tendency for late LPP to increase at follow-up, while smokers showed no change. While the most obvious reason for this separation is that we used different time-windows within our late LPP definition, it is also possible that the different electrode locations reflect activity generated from different brain areas. In support of this, both Liu et al. (2012) and Sabatinelli et al. (2013) have shown that both cortical and subcortical areas can be activated within the LPP time frame. Because of the proximity, frontal electrodes may reflect cortical activity, related to cognitive processing and attention.

Likewise, parietal electrodes could reflect subcortical activity related to emotional reactivity. It is possible that increased expectancy from seeing the images twice made non-smokers more "emotionally reactive" at Session 2 than at Session 1, which was shown as a tendency for increased L.LPP at P2. Increased awareness with mindfulness may have increased cognitive processing and attention indicated by a tendency for increased frontal L.LPP in smokers. Increased cognitive processing and attention may then have a top-down effect on emotional reactivity, mitigating any expectancy-related increases of L.LPP at P2.

Support of this ability to illustrate top-down emotion-regulation with EEG comes from Littel & Franken (2011). Compared to passive viewing, cognitive reappraisal of smoking images increased frontal LPP activity but with no differentiation between types of reappraisal, i.e., focusing on the positive feelings associated with smoking ("enhance") gave the same LPP amplitudes as "distraction". In contrast to frontal electrodes, using "distraction" over "enhance" techniques was associated with lower parietal LPP. This could represent that continued cognitive processing during reappraisal increases frontal LPP, irrespective of reappraisal type, whereas parietal LPP can decrease, dependent on reappraisal type. Further research is needed to confirm this suggested separation of frontal and parietal LPP and the proposed top-down emotion-regulation mechanism of mindfulness.

Although we hypothesised decreased image processing bias for smoking cues in smokers compared to non-smokers at follow-up (Hypothesis 4), it was not possible to show because there was no image processing bias at baseline. Another reason for not supporting this hypothesis is that changes in conditioned stimulus reactivity of smoking-related images, are unlikely to be the only factor that can affect P3 and LPP. We even hypothesised that because mindfulness encourages an increased awareness to the present moment, this is likely to increase P3 and LPP (Hypothesis 3). Therefore any decreases in P3 and LPP, related to decreased conditioned responses for smoking stimuli, may be competed by a concurrent increase in P3 and LPP, related to increased awareness. From the above discussion, any decreases in smoking-related image processing bias would most likely be observed at parietal electrodes, which potentially reflect emotional reactivity. We did not show specific decreases for the smoking category, which could be due to a combination of a small sample size and the small number of people who had completed the whole programme by the second session. Future studies could examine the ERP effects of mindfulness for smoking-cessation at a longer-term follow-up among participants who fully complete the programme.

5.2.3 Mindfulness (FFMQ)

Hypothesis 5 was that those in the smoking group would have increased mindfulness on the FFMQ compared to non-smokers. However, here was no change in any subscale for either group, thus this hypothesis is rejected. However, in hindsight it makes sense that participants did not change significantly on these facets, as the FFMQ has been used to measure "trait mindfulness" (Garland et al., 2012) rather than state mindfulness. Given the short length of the study, a state-mindfulness questionnaire may have been more appropriate.

5.2.4 Smoking and craving

Our final hypotheses were related to smoking status and craving at 1-2 month follow-up. Smokers showed substantially reduced smoking status (cigarettes/day) compared to baseline but no changes in craving. While this suggests that there was no correlation between smoking and craving at follow-up, we did not replicate the "decoupling" of craving and smoking observed by Elwafi et al. (2013). In an opposite pattern to Elwafi et al. (2013) we found no correlation between craving and smoking at baseline, but a trend for a medium correlation at follow-up. Therefore, while we supported Hypothesis 6, results did not support Hypothesis 7. The lack of correlation between craving and smoking at baseline may be because all smokers might have had similarly high baseline craving due to being required to abstain from smoking for 8 hours before their test session (compared to around 1 hour in previous studies). Results showed that this was not the case and craving showed a normal distribution with values ranging from 10 to 63. Nevertheless a correlation between baseline craving and smoking status may have existed if participants were satiated at the time of testing, as in other studies. In hindsight it is not surprising that we did not replicate a decoupling. This is because we measured craving and smoking status at about 6-weeks follow-up, instead of 4 weeks, as used in Elwafi et al (2013). While Elwafi et al. (2013) observed a decoupling at 4-week follow-up, a significant correlation re-emerged at 6 weeks. It is unfortunate that we had low compliance on the experience sampling. If we had more participants complete this aspect of the experiment we may have been able to show when in the programme a correlation between craving and smoking re-emerges.

5.2.5 Compliance

A main but unexpected finding in our results was the low compliance rate for the intervention, with more than 60% of participants not completing at least 70% of the intervention within 2 months of starting. In addition, many people did not answer multiple

phone calls, texts, voicemails, or emails regarding continuing use of the app. Of the participants who used at least 70% of the app, follow-up rate was high at nearly 85%, and was 100% for non-smokers.

A follow-up questionnaire for non-compliant smokers showed that the main reasons for not using more of the app was that the exercises were too long and feelings of failure. Although the length of daily activities ranged 2–30 min/day the mean length per day of the programme was around 6 min (although more was encouraged). The "Rain" exercise took an extra 3 min and could be used each the user had a craving. The perception that the C2Q exercises take too long may stem from the fact that quitting smoking using mindfulness requires users to set aside time for training (meditation), while skills-training strategies, such as cognitive reappraisal, can be integrated into day-to-day life relatively easily. It also may be more practical to use a skills-training strategy than a mindfulness exercise when dealing with craving out in public. This could be the case at least initially when C2Q users rely on listening to an audio recording called the "rain exercise" to mindfully cope with craving. The negative impact of the "exercises being too long" relates to findings of Buller et al. (2014) and Whittaker, Merry, et al. (2012) who both found that simpler text interventions were more effective than use of an app. Smokers may be more likely to engage in an intervention when more external guidance is offered and less self-directed practice is required. For example, during the day, smokers may be more likely to read a craving tip that is sent to their direct inbox than to search for the tip themselves within an app. In addition to this, for a population which shows high delay discounting (Secades-Villa, Weidberg, García-Rodríguez, Fernández-Hermida, & Yoon, 2014), smokers might find it difficult to practise formal mediation, when they are unlikely to receive any immediate benefits.

Another interesting finding from the non-compliant follow-up questionnaire was that half of responders felt that they had "failed the programme" when they missed 1 of more days. This indicates that the intervention programme may have been too strict or that the participants were sensitive to failure (e.g., from previous quit attempts) or a mixture of both. Each smoking lapse within a quit attempt reduces the smoker's self-efficacy to quit (Shiffman et al., 2000). Because it takes a smoker an average of 3–4 quit attempts to succeed (Raw et al., 1998), it is likely that many smokers in the study had low self-efficacy for quitting, especially those who have been smoking for a long time. Because poor self-efficacy has shown to be related to relapse (Castro et al., 2014), future interventions for smoking cessation should aim at increasing self-efficacy before or during the quit attempt so that smokers are not deterred from the quit attempt and engaging in the intervention altogether.

5.3 Limitations

Overall results of the intended analyses show promising evidence of decreased smoking status at follow-up, and a potential increase in a neural marker of inhibitory control in smokers that used *Craving to Quit*. However, it is not possible to conclude whether these trends of change are related to mindfulness, or to use of a quit-smoking app, or simply, to a quit attempt, or some other factor of being in the study. The original study had aimed to control for alternative interpretations by including another group receiving an app based on skills-training called QuitPal. This group would have received additional messaging to match the C2Q group on all components other than mindfulness. This would have allowed for interpretations regarding the use of mindfulness in smoking-cessation. Unfortunately poor recruitment led to changes in the design, which limits our ability to draw firm conclusions on this matter.

In addition to poor recruitment and needing to drop the study's comparison intervention group, other limitations include specifics of the ERP tasks, different EEG filtering, and poor compliance with the intervention. All of these factors somewhat hinder the interpretation of our findings and call for a larger-scale version of the study, which are discussed below.

Firstly, categories in the image slideshow should be matched on luminosity and contrast, and spatial frequency and smoking images should be chosen with a greater variety of content. These changes would reduce the likelihood of other image variables affecting the results.

Secondly, as a whole the image slideshow was very long and participants found it difficult to maintain attention. Other experiments were shorter because they used a lower number of trials (Dunning et al. 2011) or compared a lower number of categories (Littel & Franken, 2007, 2011). However, it was important that the current study had more trials than Dunning et al. (2011) to compensate for the low sample size. Using a greater sample size in a future study would allow for the number of trials and task time to be reduced.

Another limitation that could be due to the ERP task design is the notably noisy pre-stimulus baseline of the Go/NoGo task. This may have derived from averaging late ERP components in previous trials, which could have been because we used a shorter inter-trial interval (Dong et al. 2010) than was used in previous studies (Buzzell et al. 2014; Luijten et al. 2011). It could also indicate a low signal to noise ratio and hence a need for more trials for averaging. This complicates the interpretations of the Go/NoGo results and future studies

should focus on increasing both numbers of trials for averaging plus longer inter-trial intervals.

Poor recruitment was another major limitation in the study, which led to dropping of the comparison intervention group. Difficulties in recruitment were observed at two stages: (i) the screening questionnaire, and (ii) recruitment for full participation after sending the information sheet. It is likely that many of the people who were eligible from the screening survey were put off full participation by reading the expected time involved in the information sheet (2 x 2 hr sessions, daily texts, and app compliance over 22 days). Each session was about an hour longer than previous ERP studies (Littel & Franken, 2007, 2011; Luijten et al., 2011; Versace et al., 2011) and is generally because we tested two tasks while others tested only one. In addition to this, the current study required two sessions while others, only one. As well as affecting recruitment, a long test session is likely to stop participants from coming back for a second session. In a future study the number of electrodes (68) that were recorded in each session could be reduced to only the handful that were statistically analysed. This would dramatically reduce session time and allow for more focus on reducing impedances.

Another limitation comes from differences of filtering between experimental groups within the current study and between the current study and previous studies. Although our results suggest that difference in online filtering did not affect the main amplitude differences between groups, latency differences indicate that files were not entirely equivalent. Therefore we cannot rule out filtering as a potential confound in our results.

In addition to the aforementioned limitations, because approximately half of our data was recorded using an online high-pass filter of 1.0 Hz, we were unable to match filtering of previous studies, which used a high-pass filter of 0.1 Hz (Buzzell et al., 2014; Littel & Franken, 2007, 2011; Luijten et al., 2011; Versace et al., 2011). From our results we have shown that changing the high-pass filter does affect the ERPs, and especially the late positive components elicited by the image slideshow. Although the higher high-pass filter made the LPP peaks more recognizable, it removed much of the positive drift that is characteristic of the LPP. Because of this, whether the LPP in our studies was really equivalent to that in other studies is questionable. Our interpretations are also limited by assigning different definitions to the LPP depending on the electrode position. Similarly, interpretation of the P3 is hampered by not being able to measure it at parietal electrode sites, where it is typically most prominent (Foti et al., 2009). Future studies are likely to avoid these limitations by recording all data online using the widest possible bandpass.

The final limitation of the study is that we had a high non-compliance rate (>60%), which is substantially greater than that of a previous study (<15%), which also tested mindfulness for smoking-cessation (Brewer et al., 2011). Unlike the current study, that by Brewer et al. (2011) tested the effectiveness of mindfulness for smoking-cessation in the form of group therapy sessions with take home homework and audio recordings. This suggests that it is not the mindfulness intervention that led to low compliance, but rather the current application of it to smartphones. As suggested above, smokers may benefit more from external guidance than self-directed practice and future studies could incorporate external guidance/support by testing the app, alongside weekly group mindfulness sessions. This would be an inexpensive way to increase compliance through providing users with more tangible support.

As well as addition of group sessions, it might be beneficial to re-label the programme's daily modules as "steps" which, unlike "daily activities," are not time-locked. This would retain any benefits from having a structured programme but allow users to progress at a comfortable pace without being put off by feelings of failure early in the programme. In turn, the may substantially increase compliance.

5.4   Concluding comments

Overall results showed a significant reduction in smoking status (cigarettes/day) for smokers who received the *Craving to Quit* intervention. However, because we had to remove an experimental group receiving an alternative intervention, we could not conclude whether reductions were due to the app, mindfulness, being in the study, other features associated with the intervention, or simply to a quit attempt.

We found that smokers had reduced NoGo N2 and a trend for reduced NoGo accuracy compared to non-smokers at baseline. This trend for reduced accuracy became significant at follow-up. Smokers showed increased NoGo P3 at follow-up, but future research is needed to determine whether this reflects increased neural markers of inhibitory control preceding increased accuracy or increased requirement of neural resources to perform the task during a quit attempt, when capacity for inhibitory control may be depleted.

Smokers showed no smoking-related processing bias at baseline and had blunted P3 amplitudes compared to non-smokers for all categories, except unpleasant. This could reflect increased motivational salience of unpleasant stimuli from anhedonia during nicotine withdrawal. This is the first study to show a blunted response for smoking, neutral and

pleasant categories in smokers relative to non-smokers. No significant changes occurred at follow-up.

Observed reductions in smoking status may be related to an increased neural marker of inhibitory control (NoGo P3) however, future research that compares *Craving to Quit* with an alternative intervention is needed to confirm this. In addition larger sample sizes and a wider filter band-pass may reveal significant increases in image processing at frontal electrodes after using *Craving to Quit*.

It is difficult to know whether *Craving to Quit* can reduce smoking-related processing bias, as smokers did not show this bias to begin with. In addition, effects of increased awareness could confound any decreases in smoking-related processing bias. Future studies should investigate frontal and parietal differences within the LPP range. Such studies could show that activity within these areas reflect separate psychological processes, which could add to understanding of the mechanisms involved in mindfulness-based interventions for smoking-cessation.

The study had a range of limitations and a larger study is needed with several amendments. These include an alternative and more careful selection of images, dropping of number of repeats within the image slideshow, and number of tested electrodes, relabeling "days" as "steps" in the C2Q app, a larger sample size (with addition of skills-training group), addition of weekly group sessions as an adjunct to each intervention, and longer-term EEG follow-ups. In addition to this, all data should be recorded with a broad bandpass filter so that comparisons with previous studies can be more readily made. These changes to the design would allow for more accurate interpretations of the mechanisms and long-term effectiveness of mindfulness as an isolated intervention for nicotine addiction. Using group sessions in conjunction with the C2Q app may lead to greater compliance and would still reflect a cost-effective way to target smoking-cessation on a national scale.

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7 Appendices

7.1 Appendix A. Key psychological processes involved in QuitPal and C2Q

Table 7.1. **Key psychological processes involved in QuitPal. Crossed-out text is of app components that were to not be used in the original experiment. Italicised text represents an added component designed for the original experiment.**

Process	App feature
Positive Reinforcement	Reminders
	Saving Goal
	Summary
	Graphs (money saved)
	Tracking
	Tips
Negative Reinforcement	Facts
	My Health
	Tips
Exercise	Tips
Substitution (gum, lollies)	Tips
Relaxation	Tips
- Progressive relaxation, yoga (note-no instructions)	
- Deep breathing	
- "Quiet time"	
Changing routine	Tips
~~Encourage NRT~~	~~Tips~~
Distraction	Tips
Avoidance of cues	Tips
Social Support	Videos
	Tips
	~~NCI Quitline phone line~~
Professional Support	NCI Quitline (chat online)
	~~NCI Quitline phone line~~
Awareness of triggers (mood and context)	Tracking
	Tips
Expression of achievement	Friend Alert
Goals	Saving goal
Structured intervention guide	*Additional texts (see section 6.9.2).*

Table 7.2. **Key psychological processes involved in C2Q. Crossed-out text is of app components that will not used in the experiment**

Process	App feature
Positive reinforcement	Quitting pact, morning stats
Negative reinforcement	Costs and benefits video
Meditation exercises	Exercises
Notifications/reminders	Night reflection, morning stats, goal reminder, and check-in
Awareness of triggers (mood and context)	Check-in
Social support and expression of achievement	Community
Professional support	Ask the Dr
Structured intervention guide	Daily activities
Educational videos about how habits are learnt and reinforced using analogies	Daily activities videos
Goals	Daily goals and quitting pact.
A constant mentor/guide	Videos, daily activities
Informal mindfulness exercises	Check-in, RAIN, mindful smoking, noting
Mantra	Day 21
Quit smoking ceremony	Day 21

7.2 Appendix B. Advertisement for the study

7.3 Appendix C. Human Ethics Committee approval

HUMAN ETHICS COMMITTEE

Secretary, Lynda Griffioen
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2014/108

15 October 2014

Stephanie Henderson
Department of Psychology
UNIVERSITY OF CANTERBURY

Dear Stephanie

The Human Ethics Committee advises that your research proposal "Altering smokers' attentional bias, emotional processing and inhibitory control using mindfulness" has been considered and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your email of 4 October 2014.

Best wishes for your project.

Yours sincerely

Lindsey MacDonald
Chair
University of Canterbury Human Ethics Committee

7.4 Appendix D. Information Sheet

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Department of Psychology

New Zealand
Brain Research
Institute

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Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

INFORMATION SHEET

You are invited to participate in the research project:

"Neural responding in smokers and the effectiveness of smartphone-based smoking-cessation aids."

The aim of this project is to test the effectiveness of smartphone-based smoking-cessation aids in altering psychological and neurophysiological variables associated with smoking.

The project involves:

a) FOR SMOKERS AND NON-SMOKERS:

Two morning visits (beginning between 7.30AM and 9.30AM) to the New Zealand Brain Research Institute (NZBRI), that last 1 ½ − 2 ½ hours each. These will be approximately 1 month apart. Smokers will be required to abstain from smoking overnight (at least 8 hours) before each visit.

When you visit the NZBRI you will perform a couple of cognitive tasks while having neural responses measured by a non-invasive neurophysiological recording apparatus called an electroencephalograph. You will then be given a brief (5-minute) questionnaire that measures aspects of your personality. **All participants are expected to return to the NZBRI and repeat the tasks approximately 1 month after their first visit.**

b) FOR SMOKERS ONLY:

Intervention: At the end of the first visit to the NZBRI, smokers will be given a brief questionnaire on craving (takes about a minute to complete). They will then be given a smartphone-based smoking-cessation application and will be instructed how to use it. The app. involves a 21-day programme for quitting smoking. Each day of the programme has set videos and recordings to watch and listen to. These take on average 6.5 minutes a day with additional usage of the app. encouraged. Participants will be expected to use the app. everyday but it is understandable that on some days they may forget. **It is important that you do not miss more than 7 days in total over the month.** It is likely that you will have greater benefits from using the application **regularly.**

Additional Data Collection: Between the 2 EEG sessions participants will be asked to keep a daily record of their morning craving levels (on a scale of 1-10, 10 = high craving) and the number of cigarettes smoked each day. Daily entry should be quick and easy. Participants will be provided with the printed sheets to fill and return with their second session. Additional data of craving and smoking habits will be collected through the app. during the day as well as a record of compliance with the app. programme. This data is useful for the research.

Participants will be sent a link to a follow-up questionnaire approximately 1 month after their first visit. This will take approximately 5 minutes to complete.

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Other important information:

In addition to receiving an exciting EEG experience, those who participate will each be given a petrol or supermarket voucher to the value of $20. This will be given at the end of the second visit. Participants who turn up to both EEG sessions will also go in the draw to win a $200 voucher.

You will be asked to abstain from smoking overnight before each test session. **It is also important that you do NOT use any other help to quit smoking during the study period (e.g. Quitline, champix, nicotine patches, counselling).**

If you participate, you will have the right to withdraw from the project and withdraw any information at any time without penalty.

Part of the cognitive tasks carried out at the NZBRI will involve viewing unpleasant images, which you may find distressing.

The results of the project may be published, but you may be assured of the complete confidentiality of data gathered in this investigation: the identity of participants will not be made public without their consent. To ensure confidentiality only, Dr Juan Canales, Prof. Richard Jones, Prof. Randolph Grace, Judson Brewer, and myself will be authorised to see the data, which at other times will be securely stored on a locked computer at the NZBRI. If we require another researcher to view the data we will ask for consent from you first.

The project is being carried out as an MSc thesis by me, Stephanie Henderson, under the supervision of Prof. Richard Jones and Dr. Juan Canales. You can contact Richard or I at Richard.jones@canterbury.ac.nz or Stephanie.henderson@pg.canterbury.ac.nz, respectively. Either of us will be pleased to discuss any concerns you may have about participation in the project.

The project has been reviewed and approved by the University of Canterbury Human Ethics Committee.

If you are a smoker that wants to take part in this study, it is important that you are highly motivated to quit over the intervention period and agree to not use any other smoking-cessation aid (including nicotine-replacement therapy) over the course of the study (~ 2 months including follow-up).

If you are keen to take part in this study after reading and understanding the above, please email me at stephanie.henderson@pg.canterbury.ac.nz to arrange your visits to the NZBRI. I look forward to hearing from you. ☺

Location of NZBRI:

2

105
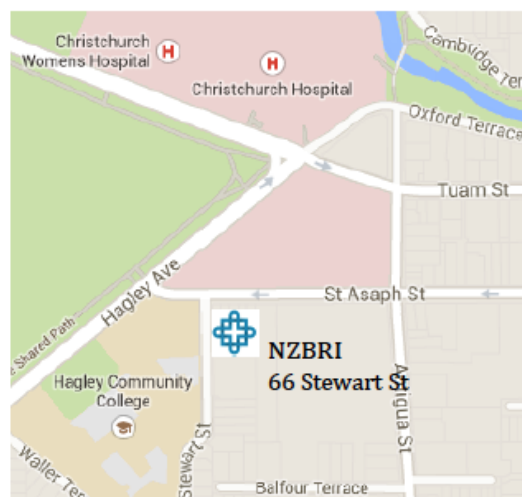
7.5 Appendix E. Email preparation

Hi *Name,*

Here is some information for your first visit:

Preparation:
In order to get good contact with your scalp for the EEG recordings, please arrive with clean and dry hair. When you wash your hair before your visit (on the morning or night before), please don't use conditioner or any extra hair products other than shampoo. If you have a brush or comb you might like to bring this with you. I will ask you to brush your hair just before we put on the cap. Again, this is to make sure we get good contact with your scalp. If you forget to bring a comb we have one in the lab.

Please bring your smartphone for setting up the smoking-cessation app.

Please abstain from using cigarettes and any other form of nicotine (e.g. gum and patches) overnight (at least 8 hours) and until after your test session.

Transport and parking:
If you are driving we have a few parks available by the entrance into the building off Stewart St. These are free. There is also a bike stand here (see map). If you are unable to get a park in these spots there is a large car park down the road, on St. Asaph St (see map, blue square). This charges $2/hour. There are also several bus stops nearby (see map, blue circles).

Getting into the NZBRI building:
Please enter the building through the Stewart St entrance. At the top of the stairs enter through the door to your right and check in with reception. If you have an issues you can text or ring me on 022 341 0867. **This entrance is locked until 8.30AM. If you are coming before 8.30AM please ring the doorbell and text or call me to be let in.**

Afterwards:
The EEG procedure involves inserting conductive gel into holes within the cap. This is needed to record your brain activity. The gel is harmless but means your hair may look messy after the procedure. We have a basin and shower available for you to rinse and/or wash your hair. We provide shampoo, conditioner, a fresh towel, and hair dryer for you to use.

Let me know if you have any questions.

Kind regards,

Steph

7.6 Appendix F. Handouts

7.6.1 Control handout

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HANDOUT

Neural responding in smokers and the effectiveness of smartphone-based smoking-cessation aids.

Thank-you for participating in our study. Our aim is to measure the therapeutic effectiveness of smartphone-based smoking cessation aids. Your data will serve as part of the control group, which is an important component of our study. We look forward to seeing you in approximately 30 days. Until then please continue life as normal and do not hesitate to email me at stephanie.henderson@pg.cantebury.ac.nz if you have any questions. ☺

You will receive a text reminder the day before your next visit.

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7.6.2   Craving to Quit handout

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Department of Psychology

New Zealand Brain Research Institute

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HANDOUT

Neural responding in smokers and the effectiveness of smartphone-based smoking-cessation aids.

Congratulations you have been assigned to a smoking-cessation application called **Craving to Quit!** Beginning from today you will be using this application as a means to help you quit smoking. After 22 days you are no longer required to continue its use although it is encouraged.

"Craving to Quit is a 21-day program based on a successful smoking cessation program developed and tested at Yale University (USA). A clinical trial of this program delivered as a group-based in-person training over 4 weeks proved to be twice as effective as the gold standard treatment.

The Craving to Quit app provides daily instruction through playlists of audio and video tracks, goal-setting tools, and daily reminders. As you progress through the program, we will walk you down to 0 cigarettes/day by giving you the tools you need to successfully quit smoking – one step at a time."

(taken from: https://itunes.apple.com/us/app/craving-to-quit/id585558426?mt=8)

Getting started:

1. Video: https://www.youtube.com/watch?v=ZhRirH5LIjg
2. Go into App Store on your smartphone and type in the search bar "Craving to Quit." Find this and install.
3. Open Craving to Quit and follow prompts on screen.
4. Have a play around the application.
5. Feel free to email me if you have any questions about the app ☺

Expectations:

1. Starting from tomorrow, we expect you to enter the application everyday until you have finished the 21-day programme. This includes listening to and/or watching the full length of the "activities" assigned for each day. **It is important to do this everyday to unlock activities of the next day!** We also encourage you to complete each day's "goals."
2. Starting from today, please fill out the "Smoking Diary" handout to return at your second visit to the NZBRI. Use the tracker function on the Craving to Quit application to help you remember the number of cigarettes. Please continue this until you have completed the 21-day programme.

Please be honest in your smoking diary. There is no wrong answer ☺

* It is important that you try to use the application everyday (or close to). It is likely that you will benefit more from the application if you use it regularly. For this reason, try not to go longer than 2 days without using the application.

Please do not use any other smoking-cessation aid (including nicotine-replacement therapy) for the course of the study (7-8 weeks).

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<u>We will next see you:</u>

In approximately 1 month where you will complete the same tasks. After your second visit at the NZBRI you will receive 1 follow-up email with a link to a short questionnaire about smoking habits and craving. This is important for the research.

Enjoy the application and if you have any questions do not hesitate to e-mail me on stephanie.henderson@pg.canterbury.ac.nz ☺

* If you have any technical problems with your application, please reinstall it for starters. If the problem is not solved by reinstallation, contact info@cravingtoquit.com as soon as possible. Cc: me in the email so can keep track and follow-up if need be ☺

You will receive a text reminder the day before your next visit.

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7.7 Appendix G. "Getting back on track" e-mail

"Hi *Name*,

I can see you have been finding use of the app. over the past week a little difficult. I know it's hard to give up and find time for the app.

Your use of the app. is really helpful to my research and hopefully to you as well :)

Your participation and use of the app., when you can is greatly appreciated. It will enable me to finish the study and add to research on the development of effective treatments for smoking-cessation.

- To help get you back on track I suggest you set aside a regular time each day to spend 5 minutes on completing the "daily activities".
- Some people find the "check-in" notifications off-putting so I suggest you turn these off if you think that would be helpful. If you want reset the "cut-down" notifications I can also send you instructions on how to do this.
- If you need more motivation, here is a Ted talk by the researcher who helped design the app. (Judson Brewer): https://www.youtube.com/watch?v=jE1j5Om7g0U

I hope that I can help you become smokefree!

Kind regards,

Steph"

7.8 Appendix H. Debriefing sheet

Department of Psychology
College of Science

New Zealand Brain Research Institute

UC
UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

DEBRIEFING FORM:

"Neural responding in smokers and the effectiveness of smartphone-based smoking-cessation aids."

The aim of this study is to test the effectiveness and expose the mechanisms of a mindfulness-based smartphone app. for smoking-cessation.

Mindfulness is based on promoting a non-judgmental awareness of the present moment. Instead of avoiding craving, often encouraged in other interventions for smoking-cessation, mindfulness teaches smokers to experience cravings with an accepting attitude from moment-to-moment. The app. also provides some positive and negative reinforcement as well as social support to increase motivation to quit.

To study the mechanisms and effectiveness of a mindfulness-based smartphone app. for smoking-cessation we designed 2 groups of participants. One included non-smokers receiving no intervention while the other was of smokers receiving the mindfulness-based intervention.

A different study title is used for participants to hide the variables that we are testing. This way we can make sure that any differences between groups are due to the intervention and not due to any expectations associated with knowledge of the tested variables. The real title of the project is "Altering smokers' attentional bias, emotional processing and inhibitory control using mindfulness."

Using EEG, previous research has shown that smokers have increased attention and emotional processing to smoking-related images (e.g. ashtray) relative to neutral images (e.g., chair). We measured this in the current study using the image slideshow. EEG research has also shown that smokers have decreased inhibitory control. Inhibitory control describes the ability to inhibit an inappropriate but automatic response tendency. This can be observed by measuring both EEG and behavior in the Go/NoGo task (this was the M/W task in the current study). The current study will test if the mindfulness-based intervention can change any of these behavioral and neurophysiological anomalies associated with nicotine addiction. We can also test if these changes increase with time spent using mindfulness-exercises in the app. This will allow us to make more specific inferences about mindfulness.

In addition to hiding the true study title, we disguised the 'Five Factor Mindfulness Questionnaire' as a "questionnaire that measures aspects of your personality." As with the tested variables above, we did not want knowledge of this questionnaire to effect participants' expectations.

Each participant's involvement in this study is greatly appreciated and will help further the understanding of addiction, current treatments and development of new ones. However, you are able to withdraw your data if you wish.

We are still collecting data from other participants so please do not expose the true nature of this study to anyone.

If you have any questions about the study please feel free to contact my supervisor (Richard.jones@canterbury.ac.nz) or myself (stephanie.henderson@pg.canterbury.ac.nz).

Thank-you again for your participation.

7.9 Appendix I. The alternative intervention that was not included in that final experiment: NCI QuitPal

7.9.1 NCI QuitPal (QuitPal) intervention: Methods summary

Participants would be asked to set their quit date in the settings for the day they begin using the app. This is so that participants receive the positive reinforcement that comes from going to the "progress summary" button. This button gives a tally of how much money has been saved and how many smoke-free days the participant has had since quit day. Participants would be instructed to use the "tracking" function everyday, immediately before sleep and, if possible, more often. This records the total number of cigarettes smoked each day, which is used for the "Progress summary."

The app involves several other buttons that participants can interact with which are designed to aid smoking cessation. By clicking on the "videos" button they can add short inspirational video messages of loved ones for them to play back later when they need motivation to quit. A "My health" button has a list of positive health consequences that occur with increasing time of abstinence. The "Saving goals" button allows participants to set personalized goals for saving money (e.g., to buy a new phone) and they can check the progress of these goals. Using the "Reminder" button, participants can set times for the application to alert them with personalized messages to not smoke in high-risk situations. A "Friend alert" button allows the participant to post information about how their cessation attempts are going on social networking sites such as Facebook and Twitter. Using "NCI Quitline," participants can chat online with a specialist from NCI's Cancer Information Service. "Smoking facts" includes a series of random facts, which are either about the negative effects of smoking or positive effects of quitting. "Tips" include suggestions for dealing with cravings, including distraction, avoidance substitution, and some which suggest slow breathing, relaxation, and meditation. Unlike *Craving to Quit*, these tips do not give specific instructions on how to meditate. Figure 7.1 shows the home screen of the QuitPal app, with all features.

Participants would be encouraged to use the app whenever they feel a craving to smoke. This is to encourage a similar amount of time spent interacting with the application as in the Craving to Quit condition. To simulate the list of "daily activities" that are given in the Craving to Quit application, we planned to provide 21 days of "daily activities" in QuitPal. These suggestions of daily activities would be sent via text (see section 7.9.2).
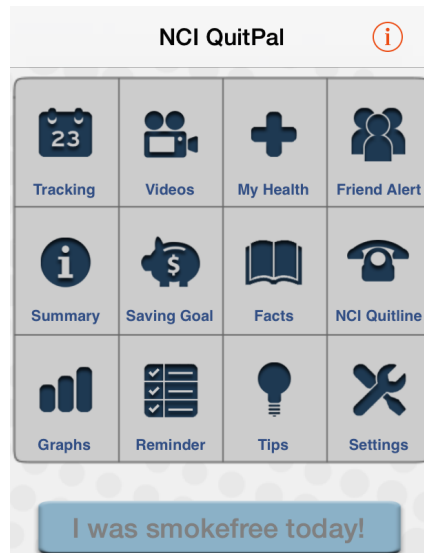
Figure 7.1. NCI QuitPal app home screen showing all of its features

7.9.2 Experience-sampling and QuitPal texts that were designed for the original study

CONTENT OF DAILY TEXTS

Designed by Stephanie Henderson for "Neural responding in smokers & the effectiveness of smartphone-based smoking-cessation aids."

8am daily reminder for QuitPal & Craving to Quit (experience-sampling):

C2Q: "Check-in: How much r u craving right now & how many cigarettes did u smoke yesterday?"

QuitPal: "Check-in: How much r u craving right now, how many cigarettes did u smoke yesterday, how much time did u spend doing activities suggested in "Tips" (& what were these)?"

Daily QuitPal texts sent at 8am:

1. Welcome to Day 1 of ur 22-day trial of QuitPal! Today's activities: Use "Tracking" if & when u smoke, read 3 "Facts." For each craving read tips til u find 1 that is applicable. Do ur best to carry it out ☺

2. QuitPal! D2 activities: Use "Tracking" if & when u smoke, read 3 "Facts," set a new goal using the "Saving Goals" function. For each craving read "Tips" til u find 1 that is applicable. Do ur best to carry it out ☺

3. QuitPal! D3 activities: Use "Tracking" if & when u smoke, read 3 "Facts," record a 30s inspirational message of a close friend using the "Videos" module. This is for u to play back later. For each craving read tips til u find 1 that is applicable. Do ur best to carry it out ☺

4. QuitPal! D4 activities: Use "Tracking" if & when u smoke, read 3 "Facts." For each craving read tips til u find 1 that is applicable. Do ur best to carry it out ☺

5. QuitPal! D5 activities: Use "Tracking" if & when u smoke, read 3 "Facts." For each craving read tips til u find 1 that is applicable. Do ur best to carry it out. Another response to cravings could be watching ur recorded video & calling the featured friend for support ☺

6. QuitPal! D6 activities: Use "Tracking" if & when u smoke, read 3 "Facts," set 3 reminders for the following week ("Reminders"). For each craving read tips til u find 1 that is applicable. Do ur best to carry it out ☺

7. QuitPal! D7 activities: Use "Tracking" whenever u smoke, read 3 "Facts," look over all ur "Tracking" entries from the previous week & take note of ur most common triggers. For each craving read tips til u find 1 that is applicable. Do ur best to carry it out ☺

8. QuitPal! D8 activities: Use "Tracking" if & when u smoke, read 3 "Facts." Look at the "Summary" & "Graphs" modules & reflect on ur progress. For each craving read "Tips" til u find 1 that is applicable. Do ur best to carry it out. Another response to cravings could be watching ur recorded video & calling the featured friend for support ☺

9. QuitPal! D9 activities: Use "Tracking" if & when u smoke, read 5 "Facts." For each craving read tips til u find 1 that is applicable. Do ur best to carry it out ☺

10. QuitPal! D10 activities: Use "Tracking" if & when u smoke, press the "Next" tab in "My Health" & read all that is listed. For each craving read tips til u find 1 that is applicable. Do ur best to carry it out ☺

11. QuitPal! D11 activities: Use "Tracking" if & when u smoke, read 5 "Facts," make an inspirational video of urself (without deleting the previous 1). For example, u could mention the reasons for wanting to quit. For each craving read tips til u find 1 that is applicable. Do ur best to carry it out ☺

12. QuitPal! D12 activities: Use "Tracking" if & when u smoke, read 5 "Facts," check the status of ur goal; if it has been met go & buy it then make a new 1. If it hasn't been met, appreciate ur progress. For each craving read tips til u find 1 that is applicable. Do ur best to carry it out ☺

13. QuitPal! D13 activities: Use "Tracking" if & when u smoke, read 5 "Facts," set 3 new "Reminders." For each craving read tips til u find 1 that is applicable. Do ur best to carry it out ☺

14. QuitPal! D14 activities: Use "Tracking" if & when u smoke, read 5 "Facts," look over all ur "Tracking" entries from the previous week & take note of ur most common triggers, also consider if these are different from the previous week. For each craving read tips til u find 1 that is applicable. Do ur best to carry it out ☺

15. QuitPal! D15 activities: Use "Tracking" if & when u smoke, read 3 "Facts," look at "Summary" & "Graphs" & reflect on ur progress. For each craving read tips til u find 1 that is applicable. Do ur best to carry it out. Another response to a craving could be watching ur recorded videos & calling the featured friend from the first for support ☺

16. QuitPal! D16 activities: Use "Tracking" if & when u smoke, read 3 "Facts." For each craving read tips til u find 1 that is applicable. Do ur best to carry it out ☺

17. QuitPal! D17 activities: Use "Tracking" if & when u smoke, read 3 "Facts," make an inspirational video of someone new (keep the old ones). For each craving read tips til u find 1 that is applicable. Do ur best to carry it out ☺

18. QuitPal! D18 activities: Use "Tracking" if & when u smoke, read 3 "Facts," press the "Next" tab in "My Health" & read all. For each craving read tips til u find 1 that is applicable. Do ur best to carry it out ☺

19. QuitPal! D19 activities: Use "Tracking" if & when u smoke, read 3 "Facts." For each craving read tips til u find 1 that is applicable. Do ur best to carry it out ☺

20. QuitPal! D20 activities: Use "Tracking" if & when u smoke, look at "Summary" & "Graphs" & reflect on ur progress, read 3 "Facts." For each craving read tips til u find 1 that is applicable. Do ur best to carry it out. Another response to cravings could be watching ur recorded videos & calling the featured friends from the first &/or third for support ☺

21. QuitPal! D21 activities: Look over the last week of "Tracking" entries & consider what ur most common triggers are (& if they differ from previous wks), read 3 "Facts." For each craving read "Tips" til u find 1 that is applicable. Do ur best to carry it out. Make a new inspirational video, congratulating urself on ur progress & briefly list the key "Tips" that will keep u smoke-free ☺

22. Congratulations on making it to Day 22 of QuitPal! Today's activities: Watch the video that u made yesterday & continue to use the QuitPal tools as needed. Good-luck with staying smoke-free ☺

7.9.3 QuitPal handout

HANDOUT

Neural responding in smokers and the effectiveness of smartphone-based smoking-cessation aids.

Congratulations you have been assigned to a smoking-cessation application called **NCI QuitPal!** Beginning from today you will be using this application as a means to help you quit smoking. After 22 days you are no longer required to continue its use although it is encouraged.

"NCIQuitPal is a free smartphone app to support smokers working to become smoke-free. This interactive app is developed using proven quit strategies and tools to help change behavior and assist you with giving up smoking.

NCIQuitPal's features:
- Set a quit date, financial goals, and reminders
- Track daily smoking habits with an easy-to-use calendar
- See graphs tracking money saved and number of packs not smoked
- Receive health milestones and craving tips to stay motivated
- Connect with social network to give milestone updates
- Create a video diary, and watch personalized video messages from loved ones
- Access NCI's Cancer Information Service by ~~toll-free phone line~~ or live chat

QuitPal was developed by the National Cancer Institute (National Institutes of Health, USA) using the latest smoking cessation evidence and behavior change theory."

(taken from https://itunes.apple.com/nz/app/nci-quitpal/id561732676?mt=8)

Getting started:

1. Video: https://www.youtube.com/watch?v=O79nmEYtXHI
2. Go into App Store on your smartphone and type in the search bar "QuitPal." Find NCI QuitPal and install.
3. Open QuitPal and key in age and other prompted details. Set your quit date for tomorrow.
4. Have a play around the application.
5. Feel free to ask me now or email later if you have any questions.

From tomorrow:

1. From tomorrow, try to use the application as often as needed. Use the "Tips" icon to help you get through cravings. The "Get Another" tab allows you to surf the tips until you find one that suits the trigger of your craving. These triggers could be alcohol, stress, coffee, etc. Some tips will suggest activities, e.g., walks, bath, list-making, reading, yoga.

   Each time you look for a tip(s) to deal with a specific craving, it is important that you do your best to carry it out.

2. Also make use of the other functions such as "Facts," which will remind you of reasons to quit.
3. Unfortunately you cannot make free calls to NCI Quitline from New Zealand, but you can access live online help from an information specialist at NCI's Cancer Information Service.

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They do not provide individualized counseling but will answer any questions about the quit process. You can access this through the NCI Quitline icon in the app, between the hours of 2am and 5pm, Tuesday to Saturday.
4. Each time you have a cigarette try to record it in the "Tracking" icon. If you are unable to at the time, try to remember for later, taking note of the mood and context in which you smoke. This will help you with point 6.

<u>Texts:</u>

5. Starting from tomorrow, each day you will receive a "Today's activities" text. These are a daily guideline on how to use the app. Please do your best to follow these.
6. Each day you will be prompted to text your level of craving (out of 10, 10 = a lot) and the number of cigarettes you smoked the previous day. It is important that you do this before you smoke your first cigarette. Use the "Tracking" icon on QuitPal to help you remember the number of cigarettes. Please do this for the following 22 days. You will also be prompted to give an estimate of how long you spent doing activities the previous day that were suggested by the "Tips" icon (in minutes). Because many of these tips aren't recordable activities (e.g., "Know what kind of foods increase your urge to smoke and stay away from them."), we accept that on some days your response could be "0." Also, in one or 2 words give an indication of what the activity was.

Example of how you may respond to a morning text: "10, 15, 15 (walk)." This indicates a craving level of 10, 15 cigarettes smoked the previous day, and an estimate of 15 minutes spent engaging in QuitPal-related activities (in this case it was a walk).

Please be honest in the daily texts. There is no wrong answer.

Here is the number that you will receive the above texts from: <u>022 341 0867</u>

* Please do not use any other smoking cessation aid (including nicotine-replacement therapy) for the course of the study (7-8 weeks, including follow-up emails).

It is important that you do not talk about the application you received with other smokers who may be part of this study. Each application is expected to help smokers quit.

<u>We will next see you:</u>

In approximately 23 days, where you will complete the same tasks. After your second visit at the NZBRI you will receive 4 follow-up emails. Each will have a link to a short questionnaire about smoking habits and craving. These will be sent every 7-days for 4 weeks.

Enjoy the application and if you have any questions do not hesitate to e-mail me on stephanie.henderson@pg.canterbury.ac.nz ☺

You will receive a text reminder the day before your next visit.

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7.10 Appendix J. ERP graphs

7.10.1 Baseline ERPs
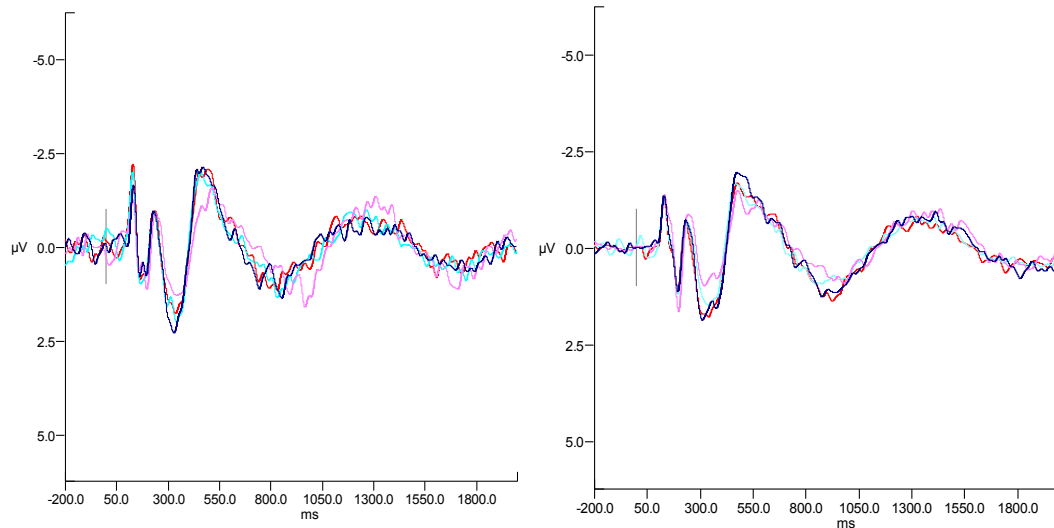
Figure 7.2. Baseline grand-average ERPs of 12 NS (left) and 37 S (right) at FZ elicited during the image slideshow. Picture categories: neutral (navy), pleasant (light blue), smoking (pink), unpleasant (red). Vertical grey line marks stimulus onset (i.e., 0 ms).
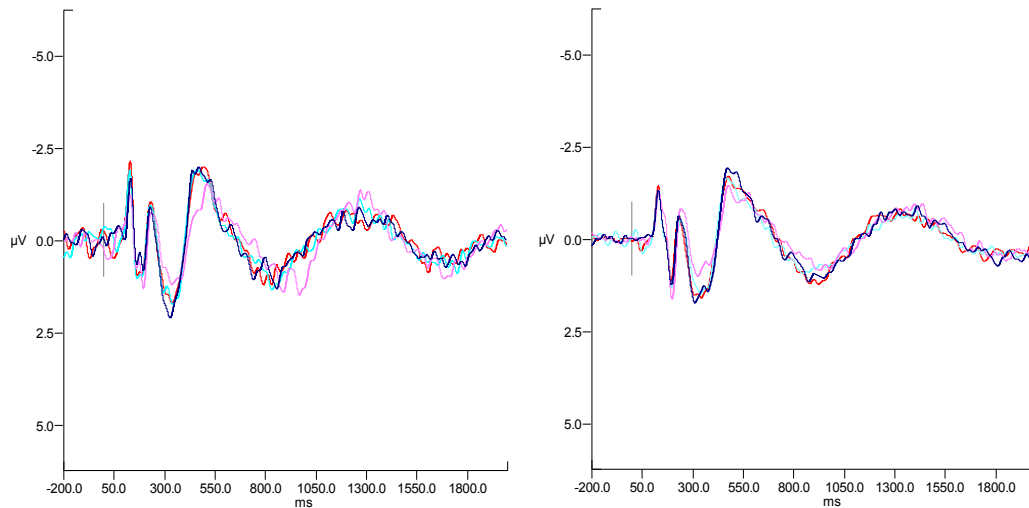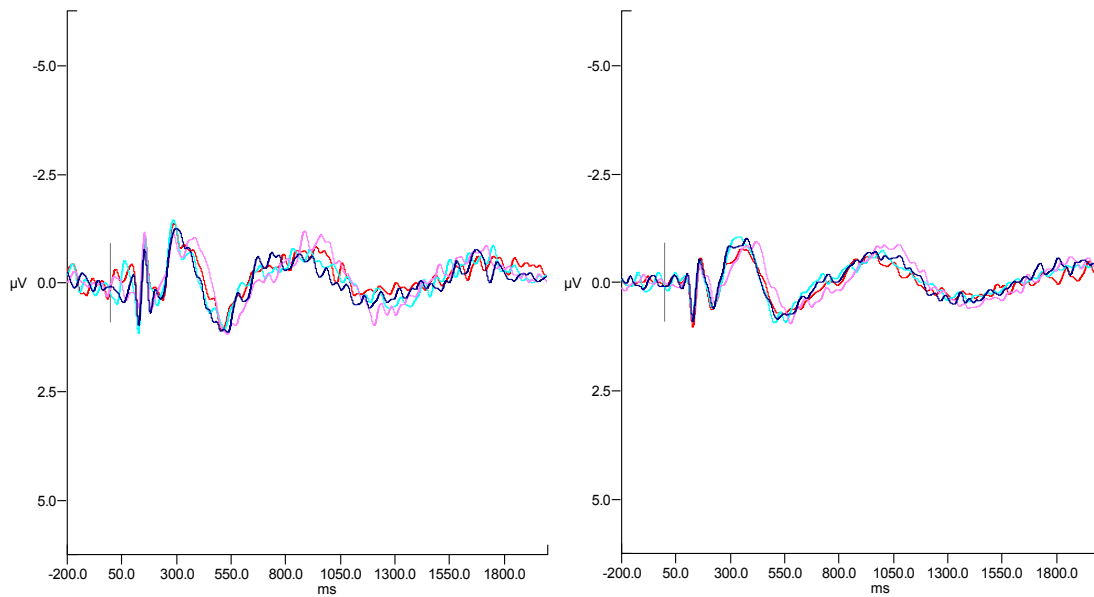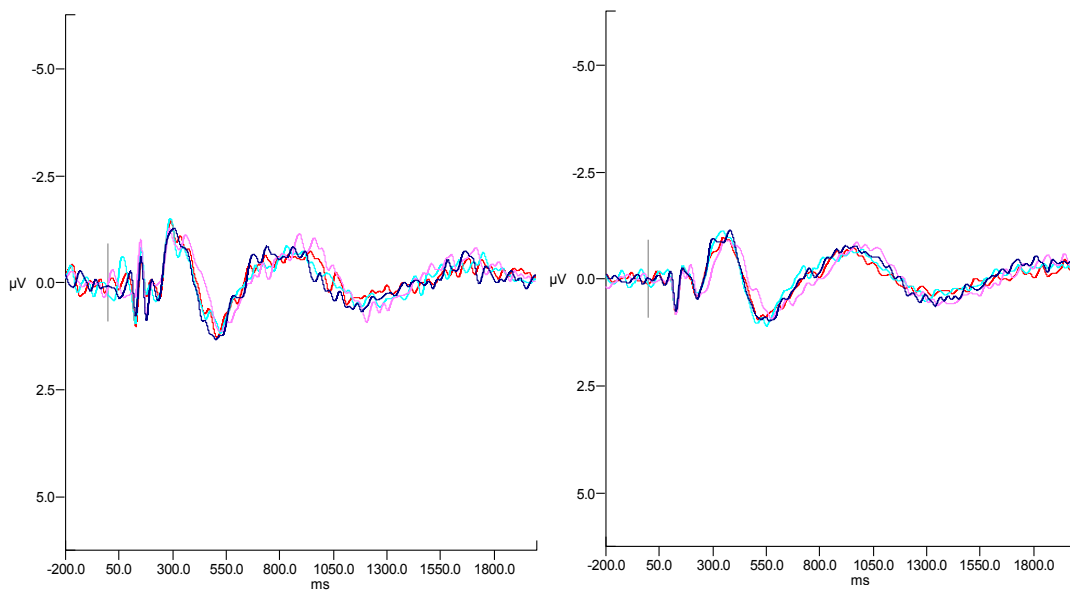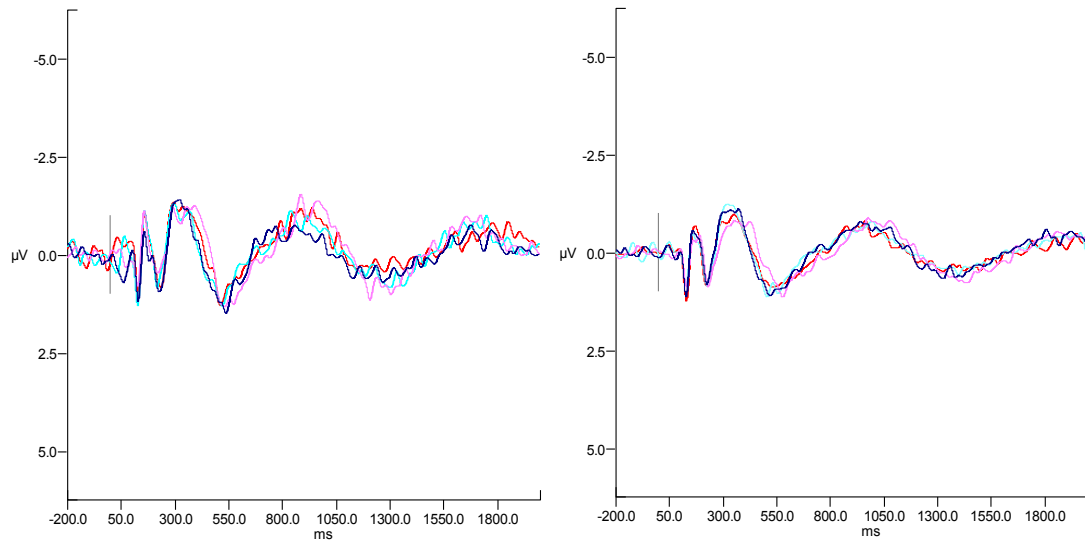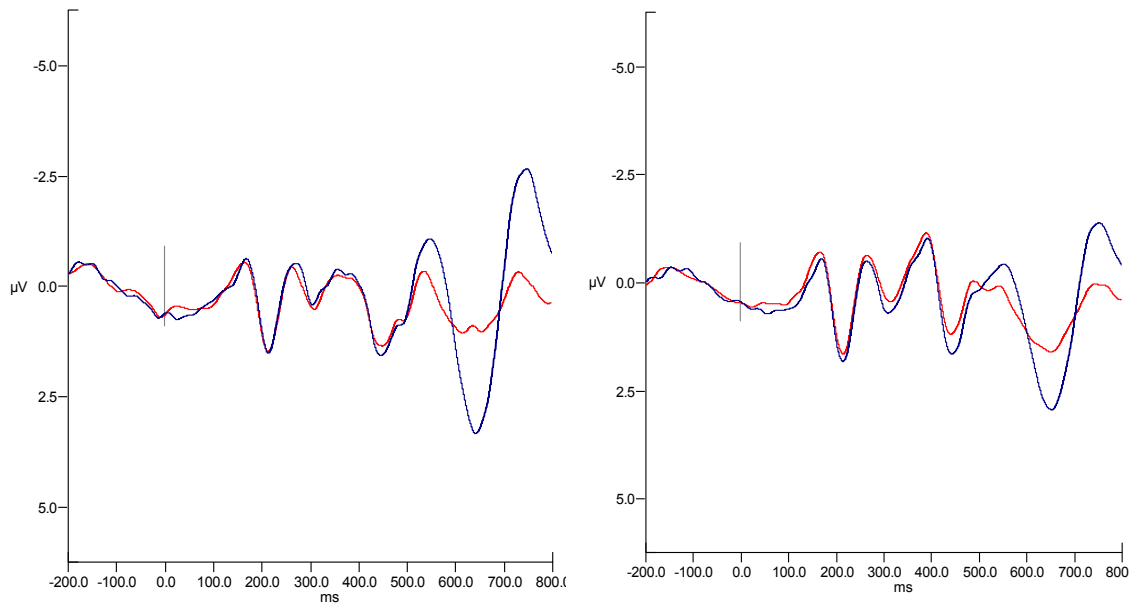

Figure 7.3. Baseline grand-average ERPs of 12 NS (left) and 37 S (right) at F1 elicited during the image slideshow. Picture categories: neutral (navy), pleasant (light blue), smoking (pink), unpleasant (red). Vertical grey line marks stimulus onset (i.e., 0 ms).
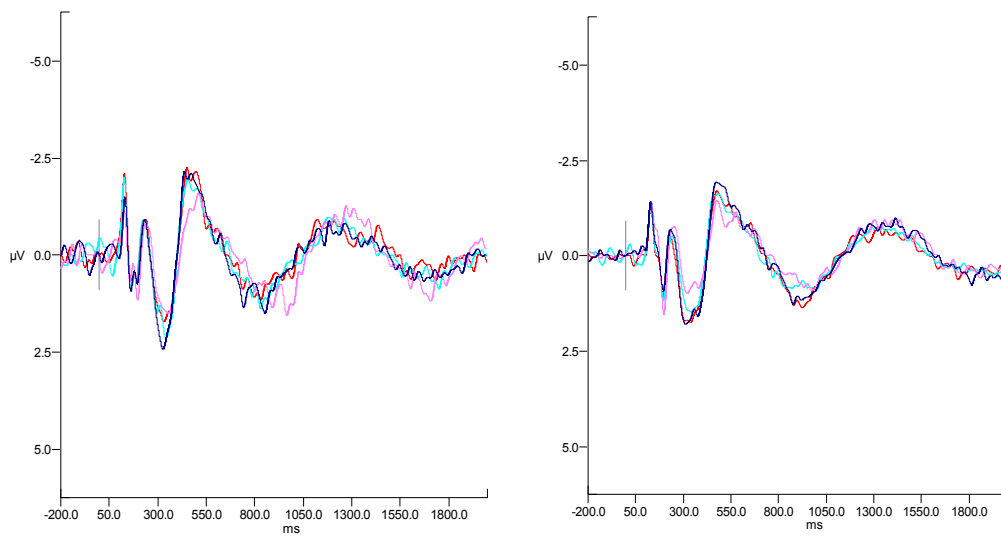
Figure 7.4. Baseline grand-average ERPs of 12 NS (left) and 37 S (right) at F2 elicited during the image slideshow. Picture categories: neutral (navy), pleasant (light blue), smoking (pink), unpleasant (red). Vertical grey line marks stimulus onset (i.e., 0 ms).
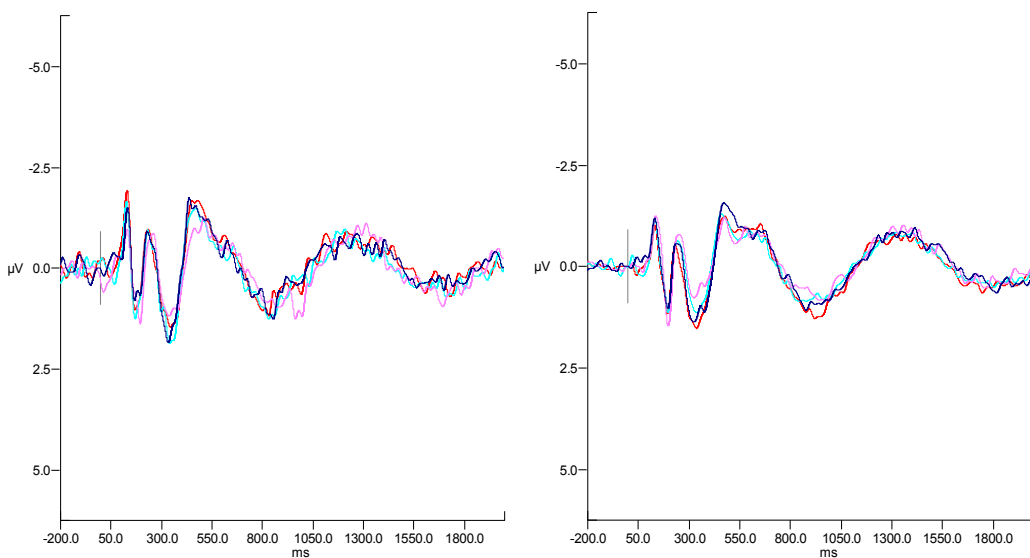
Figure 7.5. Baseline grand-average ERPs of 12 NS (left) and 37 S (right) at FCZ elicited during the image slideshow. Picture categories: neutral (navy), pleasant (light blue), smoking (pink), unpleasant (red). Vertical grey line marks stimulus onset (i.e., 0 ms).
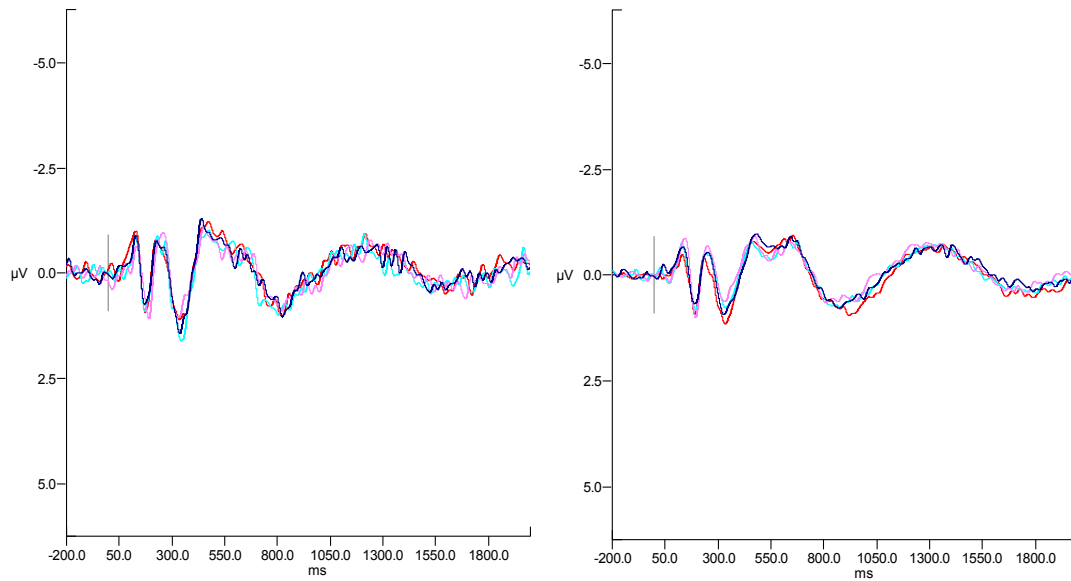
Figure 7.6. Baseline grand-average ERPs of 12 NS (left) and 37 S (right) at CZ elicited during the image slideshow. Picture categories: neutral (navy), pleasant (light blue), smoking (pink), unpleasant (red). Vertical grey line marks stimulus onset (i.e., 0 ms).
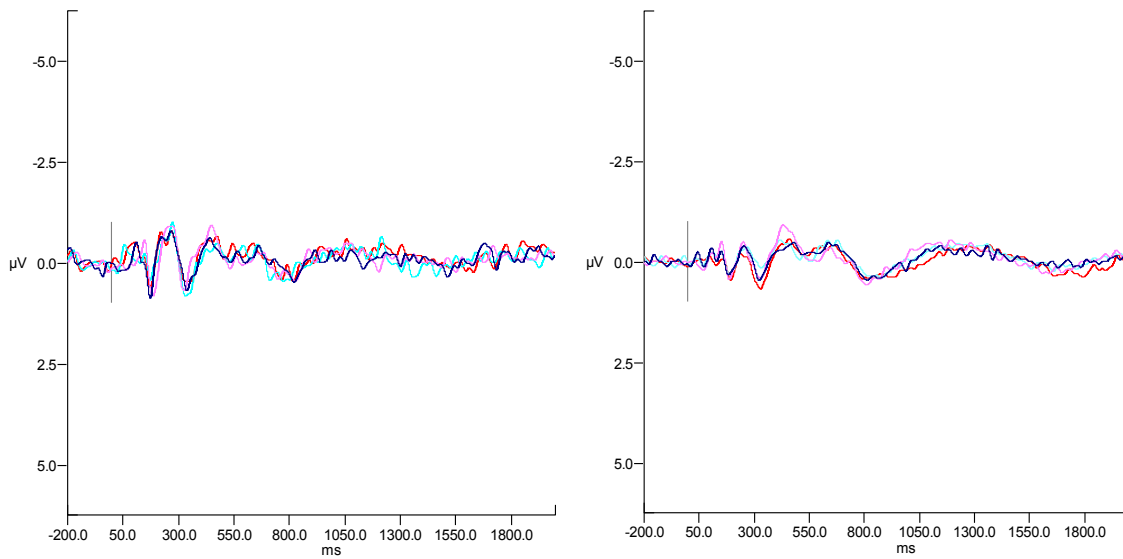
Figure 7.7. Baseline grand-average ERPs of 12 NS (left) and 37 S (right) at CPZ elicited during the image slideshow. Picture categories: neutral (navy), pleasant (light blue), smoking (pink), unpleasant (red). Vertical grey line marks stimulus onset (i.e., 0 ms).

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Figure 7.8. Baseline grand-average ERPs of 12 NS (left) and 37 S (right) at PZ elicited during the image slideshow. Picture categories: neutral (navy), pleasant (light blue), smoking (pink), unpleasant (red). Vertical grey line marks stimulus onset (i.e., 0 ms).

Figure 7.9. Baseline grand-average ERPs of 12 NS (left) and 37 S (right) at P1 elicited during the image slideshow. Picture categories: neutral (navy), pleasant (light blue), smoking (pink), unpleasant (red). Vertical grey line marks stimulus onset (i.e., 0 ms).

Figure 7.10. Baseline grand-average ERPs of 12 NS (left) and 37 S (right) at P2 elicited during the image slideshow. Picture categories: neutral (navy), pleasant (light blue), smoking (pink), unpleasant (red). Vertical grey line marks stimulus onset (i.e., 0 ms).

Figure 7.11. Baseline grand-average ERPs of 11 NS (left) and 37 S (right) at FZ elicited during the Go/NoGo task, showing Go (red) and NoGo (navy) stimuli. Vertical grey line marks stimulus onset (i.e., 0 ms).
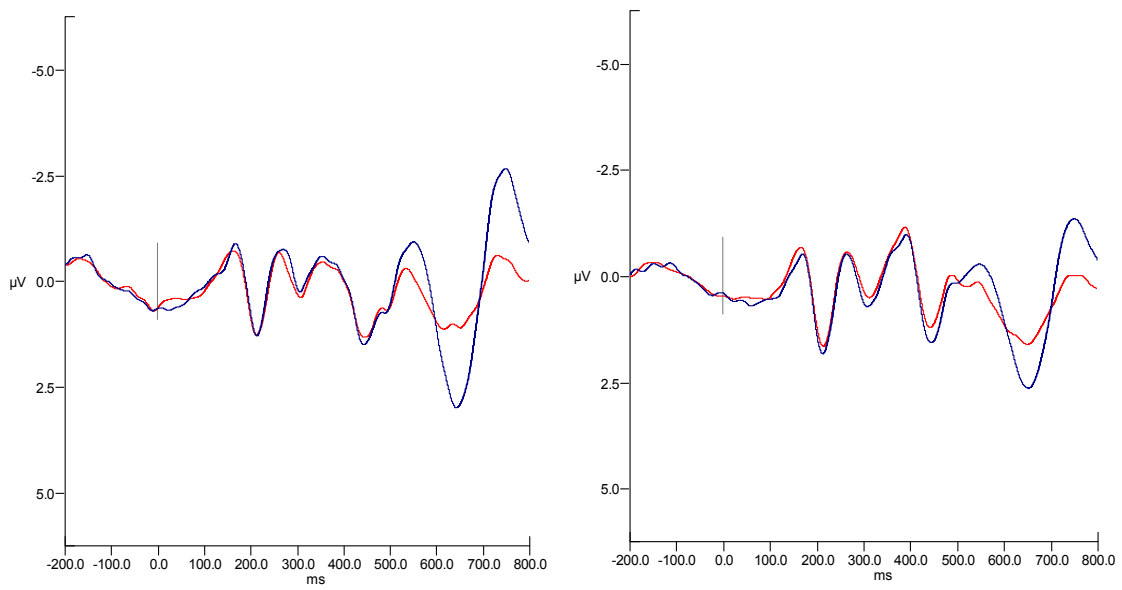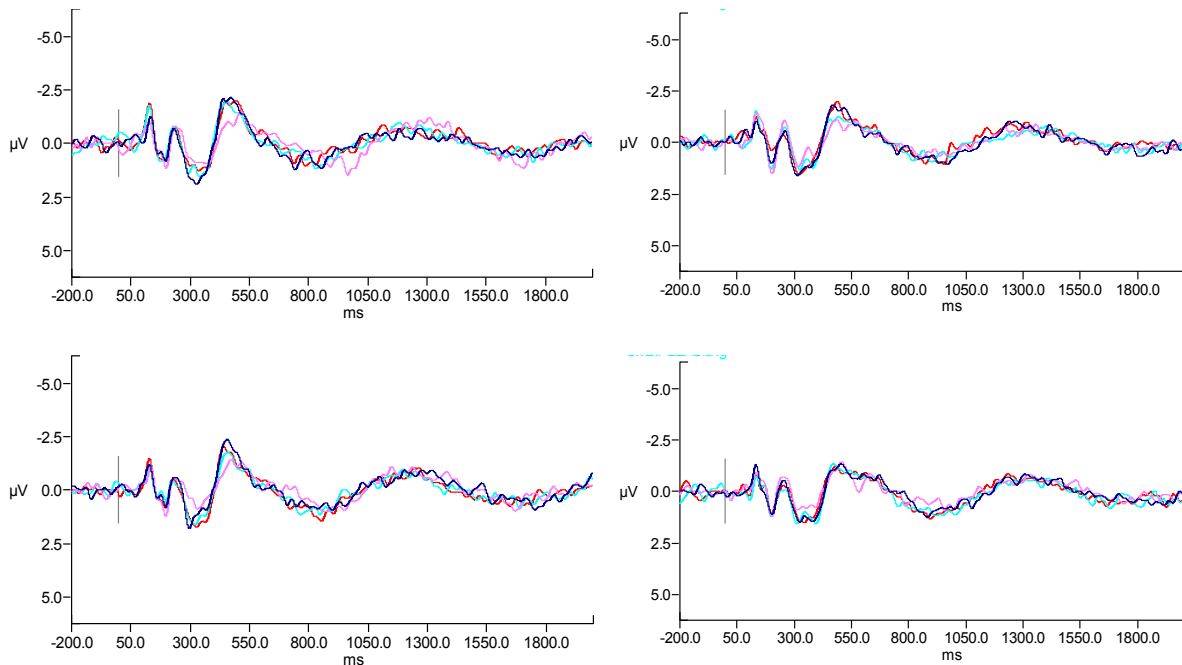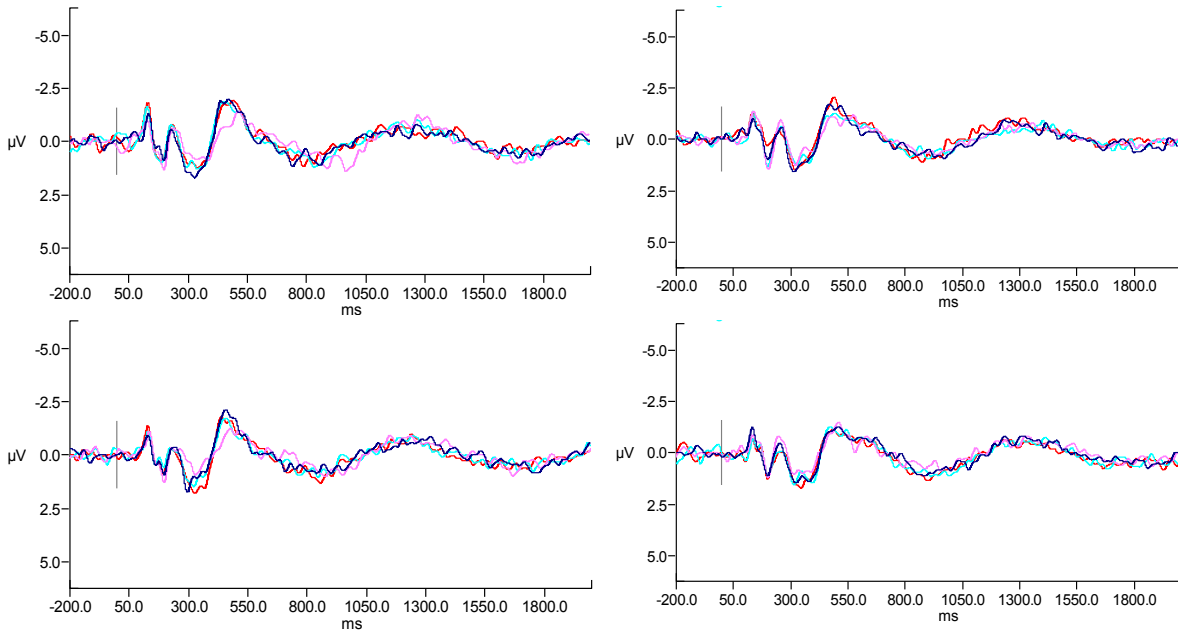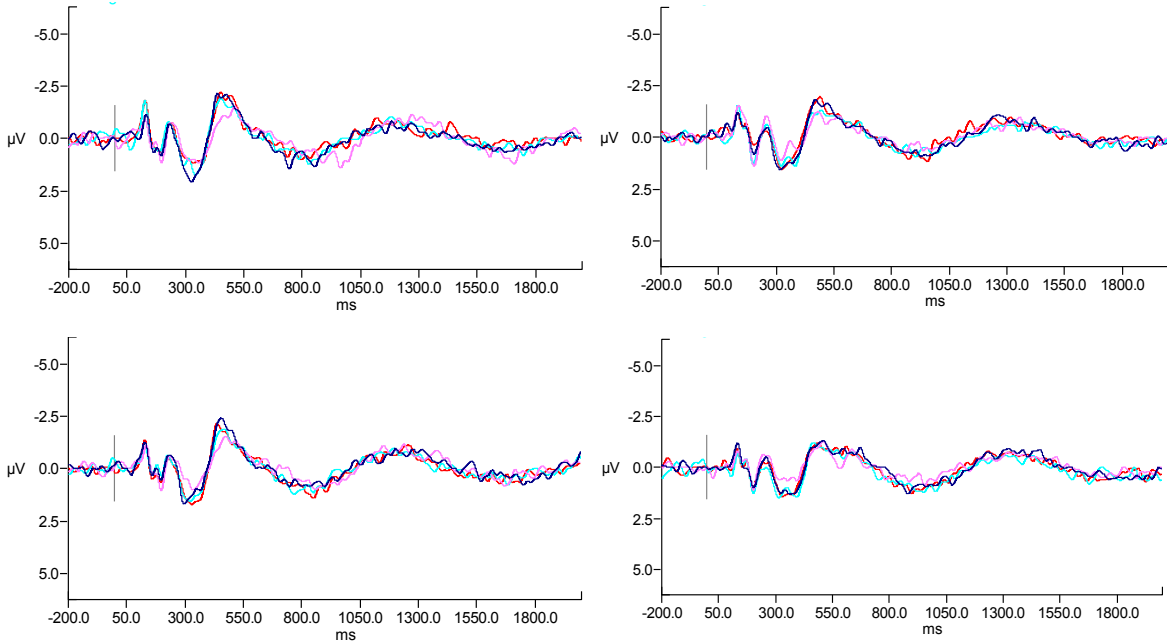
Figure 7.12. Baseline grand-average ERPs of 11 NS (left) and 37 S (right) at F1 elicited during the Go/NoGo task, showing Go (red) and NoGo (navy) stimuli. Vertical grey line marks stimulus onset (i.e., 0 ms).
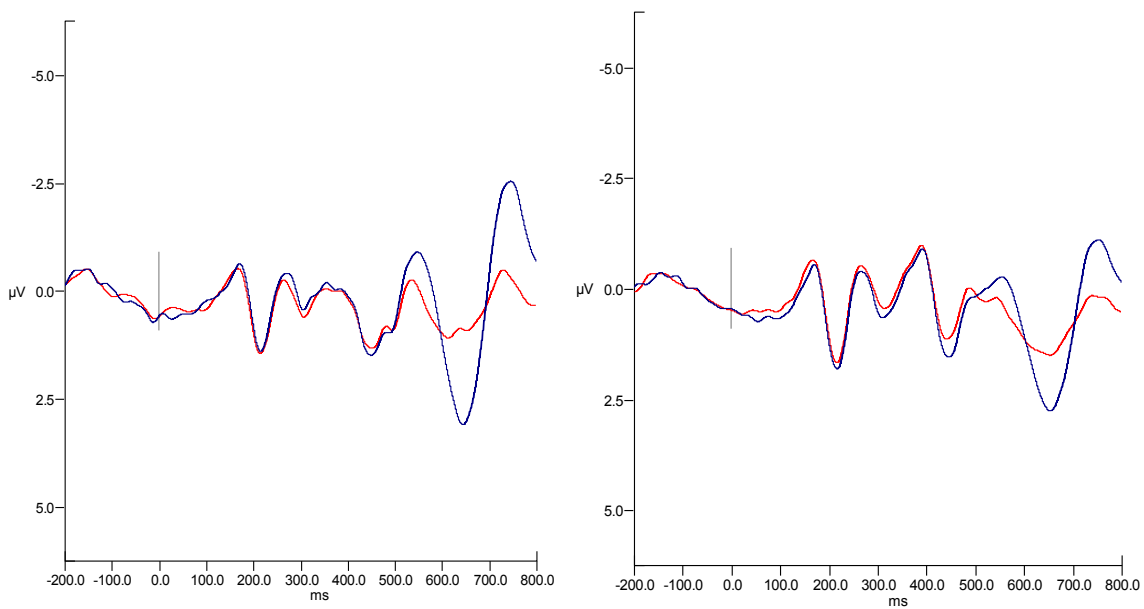
Figure 7.13. Baseline grand-average ERPs of 11 NS (left) and 37 S (right) at F2 elicited during the Go/NoGo task, showing Go (red) and NoGo (navy) stimuli. Vertical grey line marks stimulus onset (i.e., 0 ms).
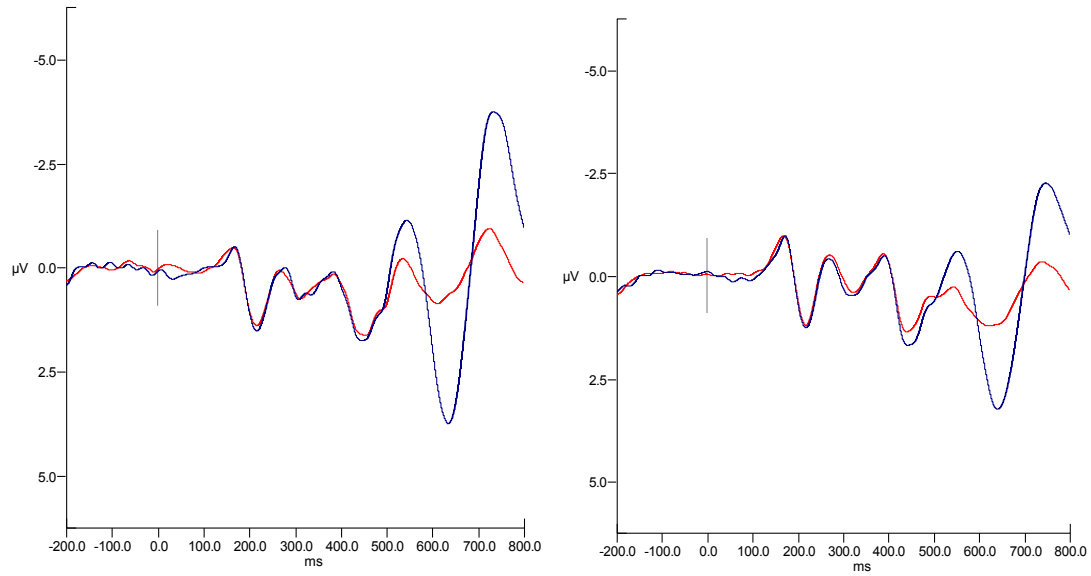
Figure 7.14. Baseline grand-average ERPs of 11 NS (left) and 37 S (right) at FCZ elicited during the Go/NoGo task, showing Go (red) and NoGo (navy) stimuli. Vertical grey line marks stimulus onset (i.e., 0 ms).
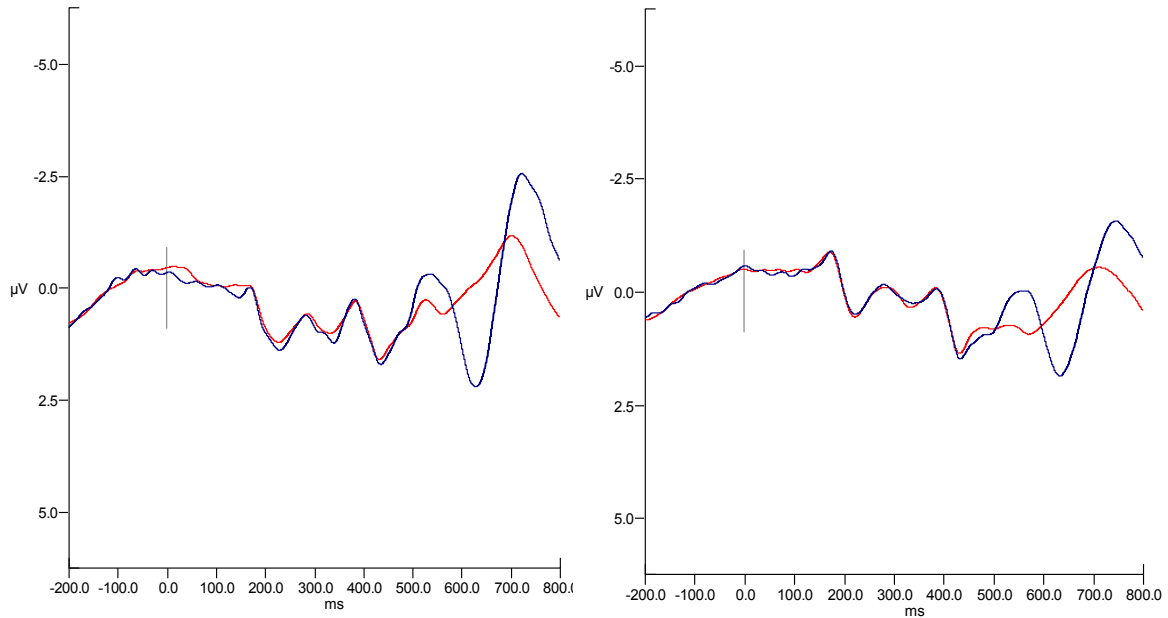
Figure 7.15. Baseline grand-average ERPs of 11 NS (left) and 37 S (right) at CZ elicited during the Go/NoGo task, showing Go (red) and NoGo (navy) stimuli. Vertical grey line marks stimulus onset (i.e., 0 ms).
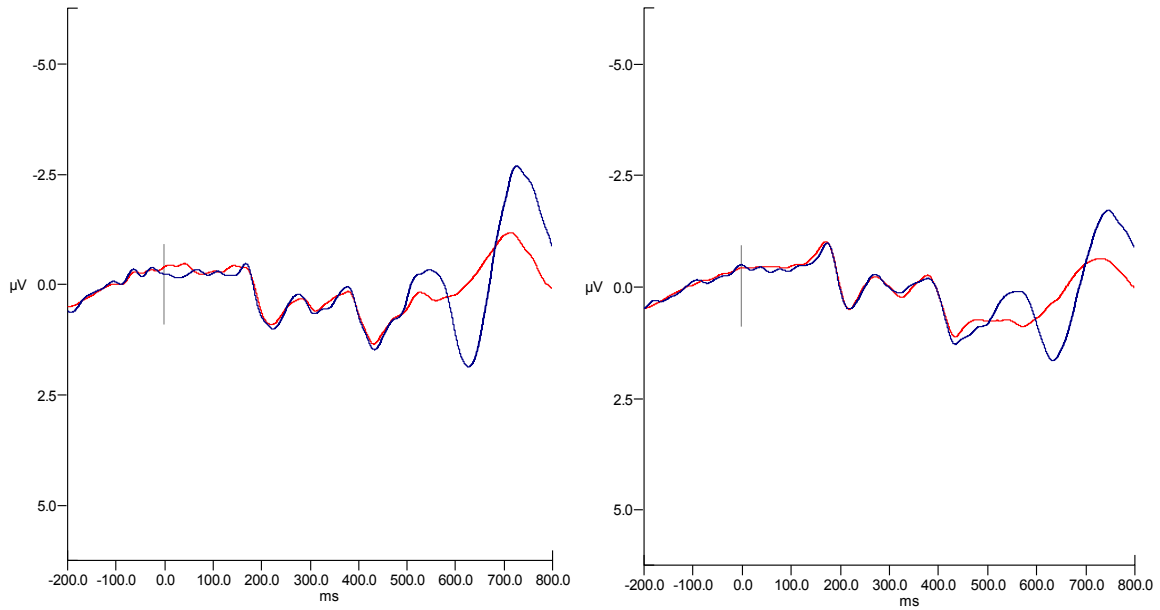
Figure 7.16. Baseline grand-average ERPs of 11 NS (left) and 37 S (right) at C1 elicited during the Go/NoGo task, showing Go (red) and NoGo (navy) stimuli. Vertical grey line marks stimulus onset (i.e., 0 ms).
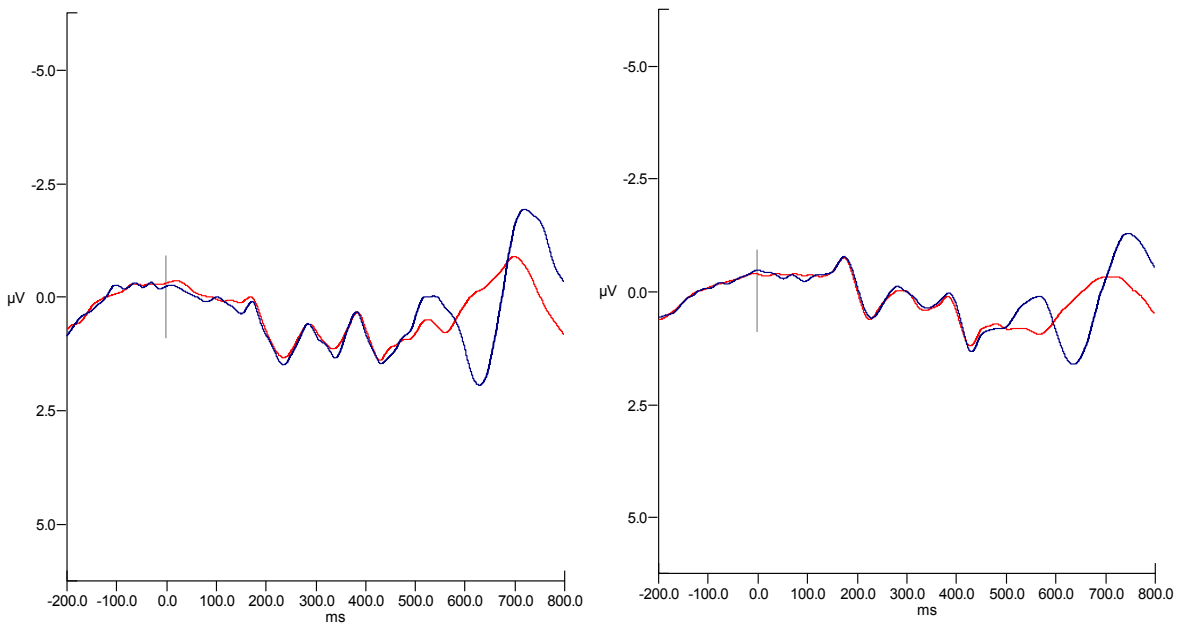
Figure 7.17. Baseline grand-average ERPs of 11 NS (left) and 37 S (right) at C2 elicited during the Go/NoGo task, showing Go (red) and NoGo (navy) stimuli. Vertical grey line marks stimulus onset (i.e., 0 ms).
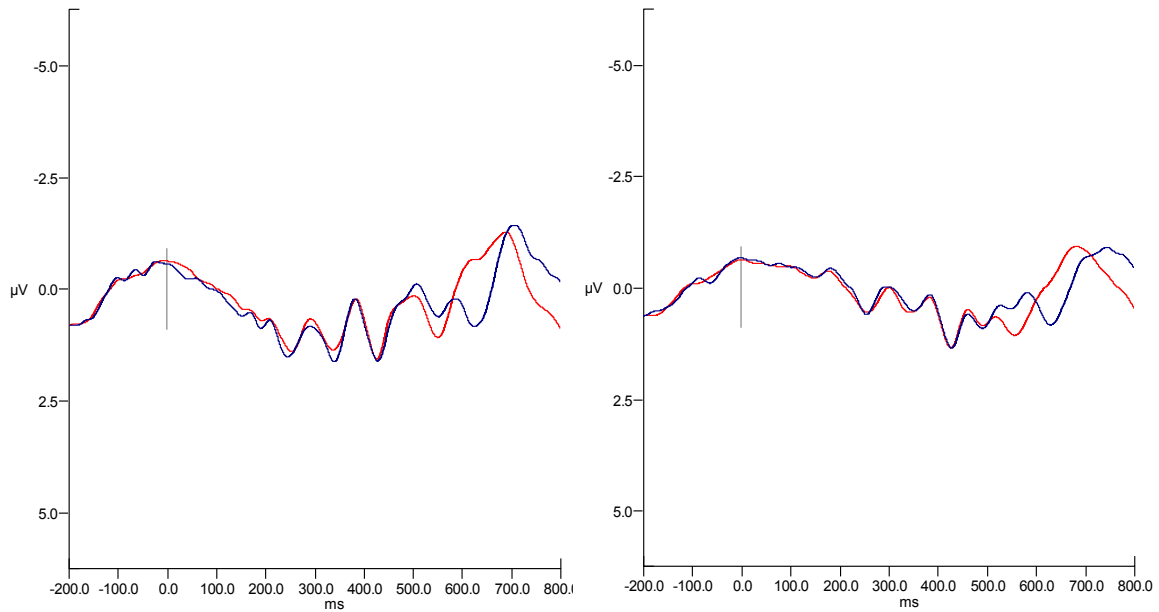
Figure 7.18. Baseline grand-average ERPs of 11 NS (left) and 37 S (right) at CPZ elicited during the Go/NoGo task, showing Go (red) and NoGo (navy) stimuli. Vertical grey line marks stimulus onset (i.e., 0 ms).
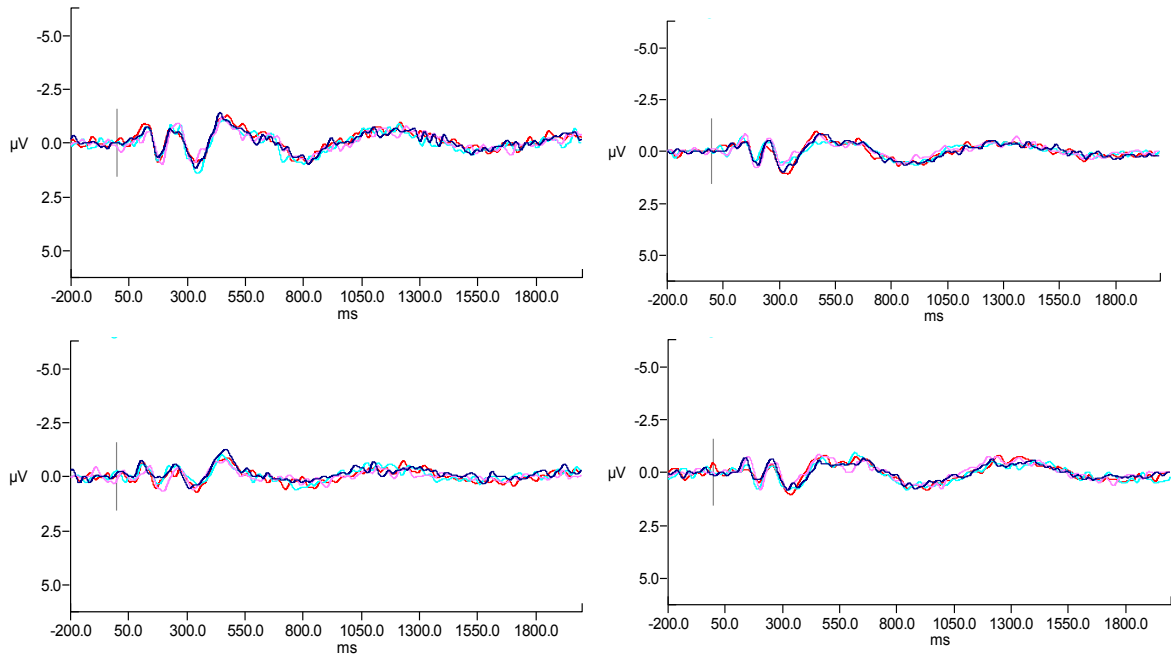
7.10.2 Follow-up ERPs

Figure 7.19. Baseline grand-average ERPs of 11 NS (left) and 11 S (right) at baseline (top) and follow-up (bottom) at FZ elicited during the image slideshow. Picture categories: neutral (navy), pleasant (light blue), smoking (pink), unpleasant (red). Vertical grey line marks stimulus onset.
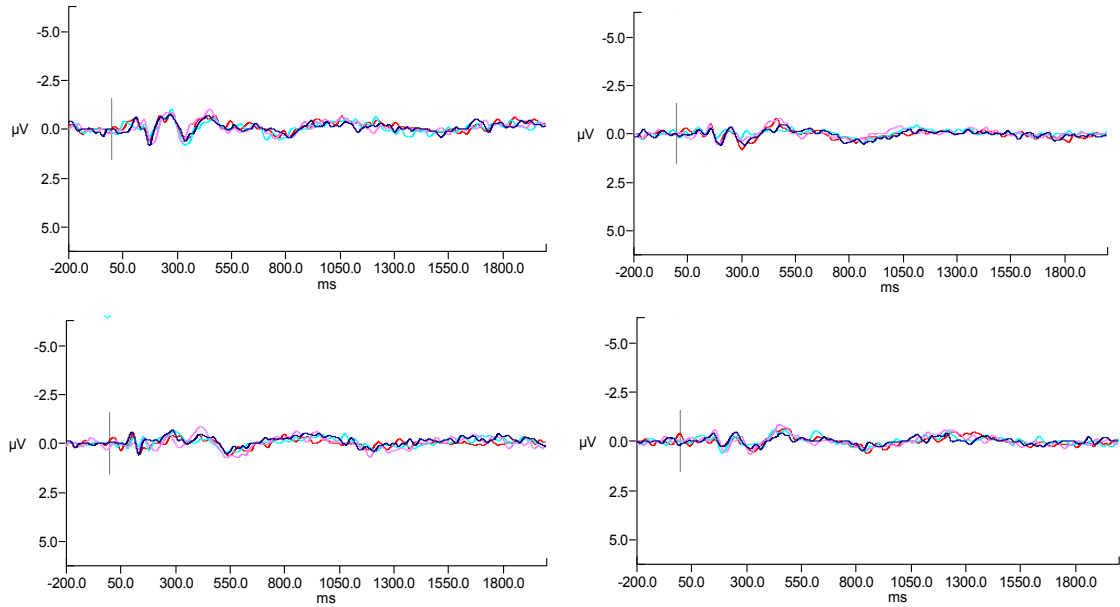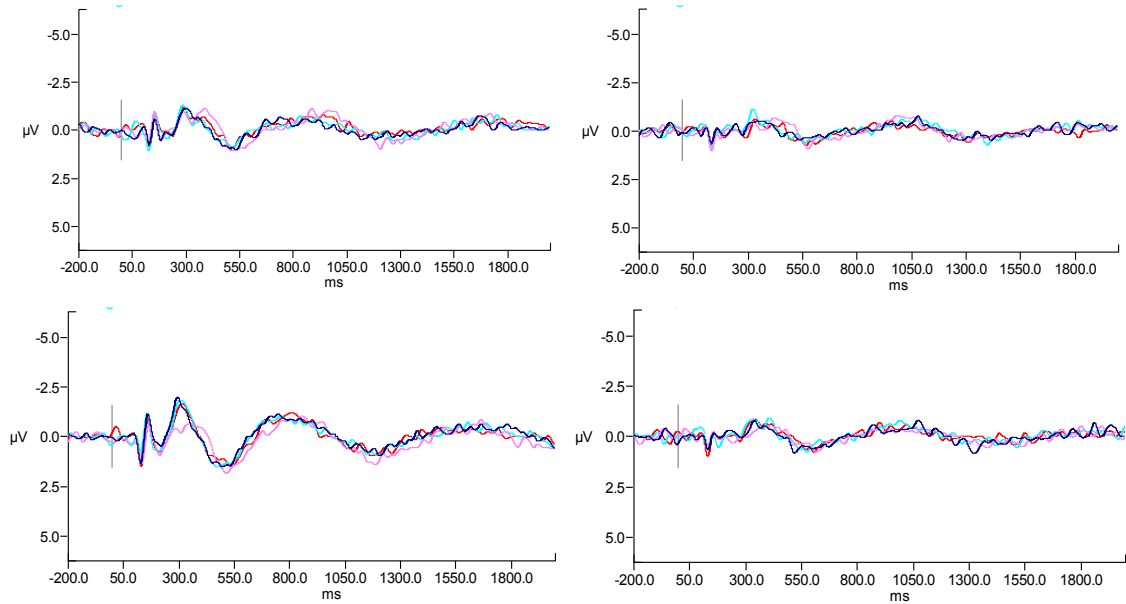
Figure 7.20. Baseline grand-average ERPs of 11 NS (left) and 11 S (right) at baseline (top) and follow-up (bottom) at F1 elicited during the image slideshow. Picture categories: neutral (navy), pleasant (light blue), smoking (pink), unpleasant (red). Vertical grey line marks stimulus onset.

Figure 7.21. Baseline grand-average ERPs of 11 NS (left) and 11 S (right) at baseline (top) and follow-up (bottom) at F2 elicited during the image slideshow. Picture categories: neutral (navy), pleasant (light blue), smoking (pink), unpleasant (red). Vertical grey line marks stimulus onset.
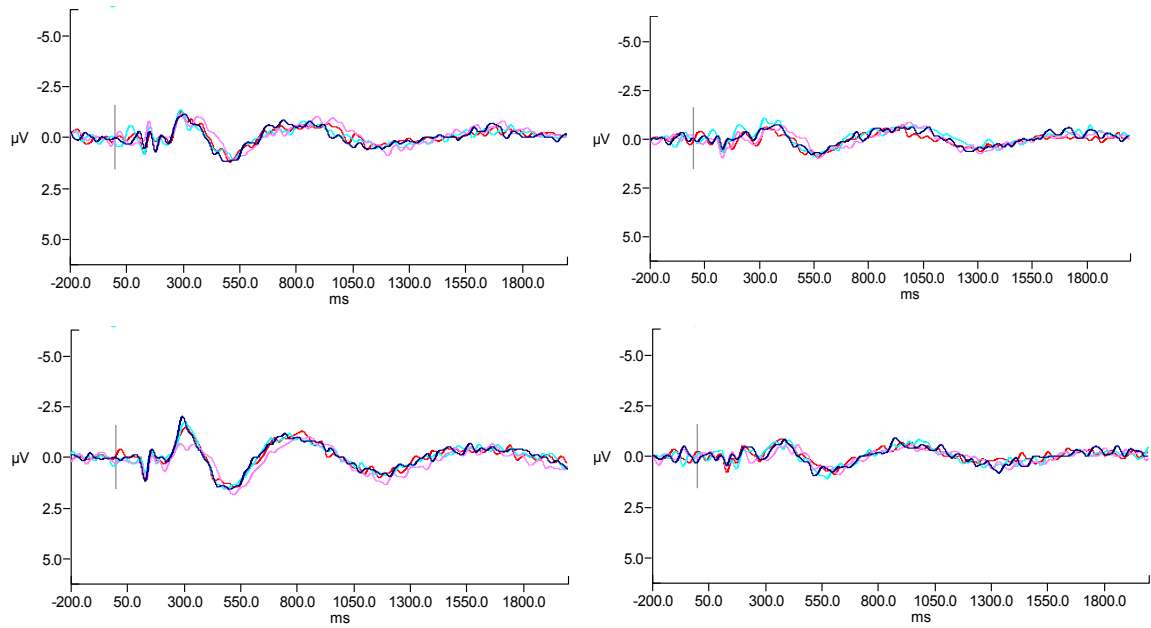
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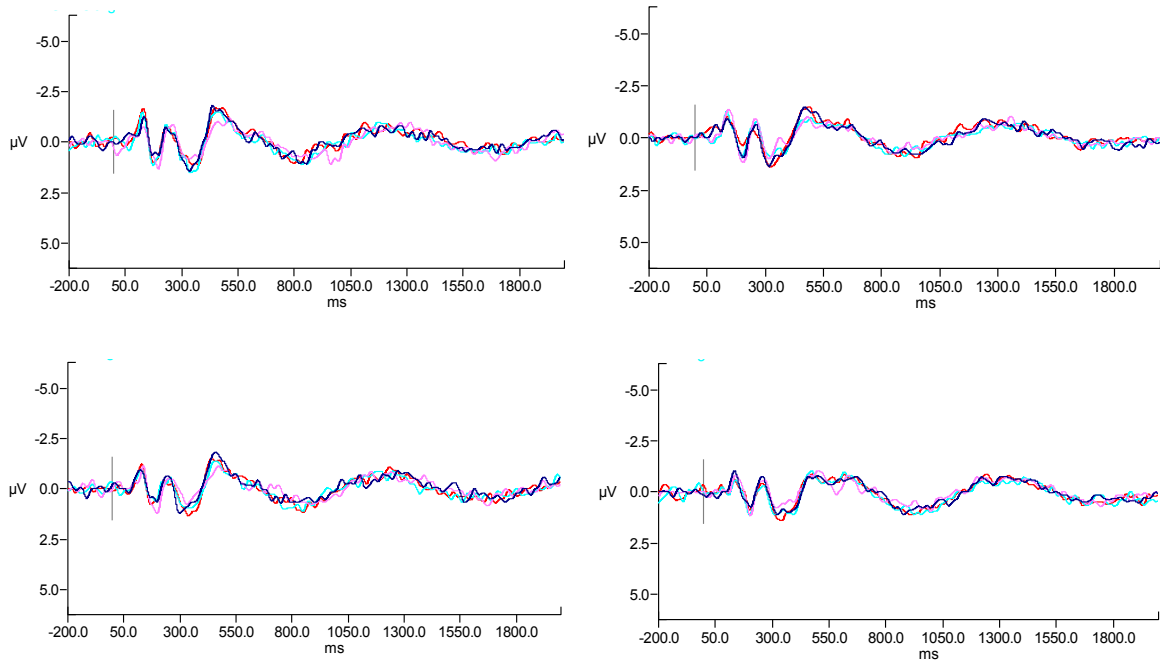
Figure 7.22. Baseline grand-average ERPs of 11 NS (left) and 11 S (right) at baseline (top) and follow-up (bottom) at FCZ elicited during the image slideshow. Picture categories: neutral (navy), pleasant (light blue), smoking (pink), unpleasant (red). Vertical grey line marks stimulus onset.
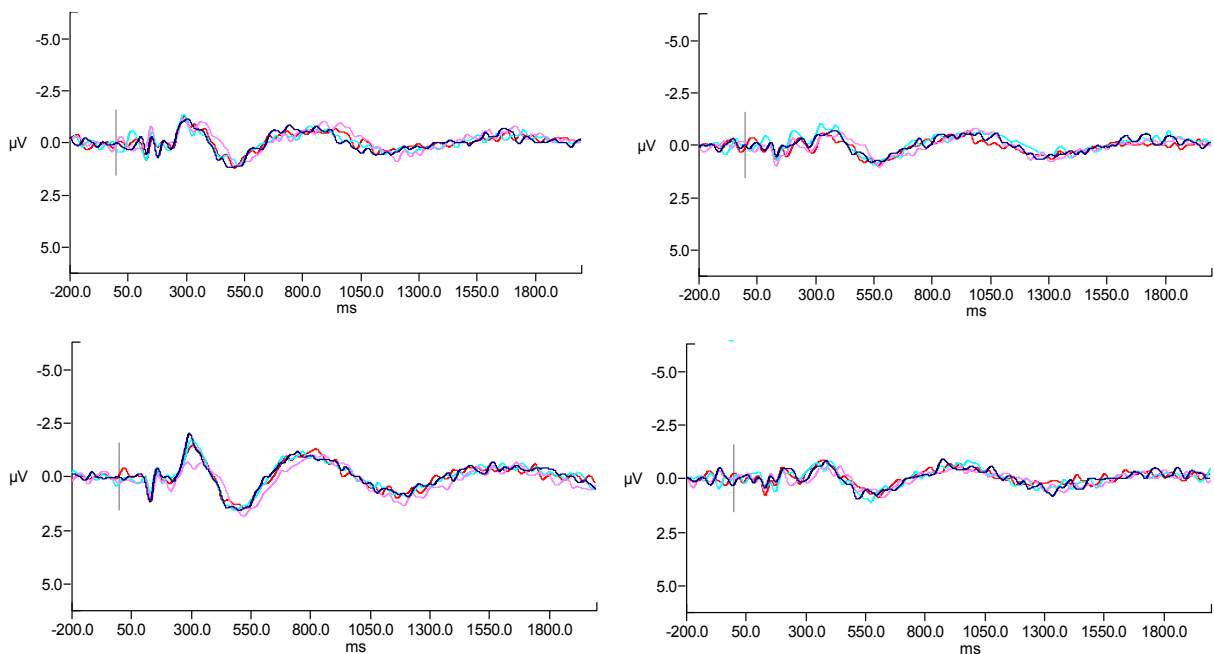

Figure 7.23. Baseline grand-average ERPs of 11 NS (left) and 11 S (right) at baseline (top) and follow-up (bottom) at CZ elicited during the image slideshow. Picture categories: neutral (navy), pleasant (light blue), smoking (pink), unpleasant (red). Vertical grey line marks stimulus onset.

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Figure 7.24. Baseline grand-average ERPs of 11 NS (left) and 11 S (right) at baseline (top) and follow-up (bottom) at CPZ elicited during the image slideshow. Picture categories: neutral (navy), pleasant (light blue), smoking (pink), unpleasant (red). Vertical grey line marks stimulus onset.
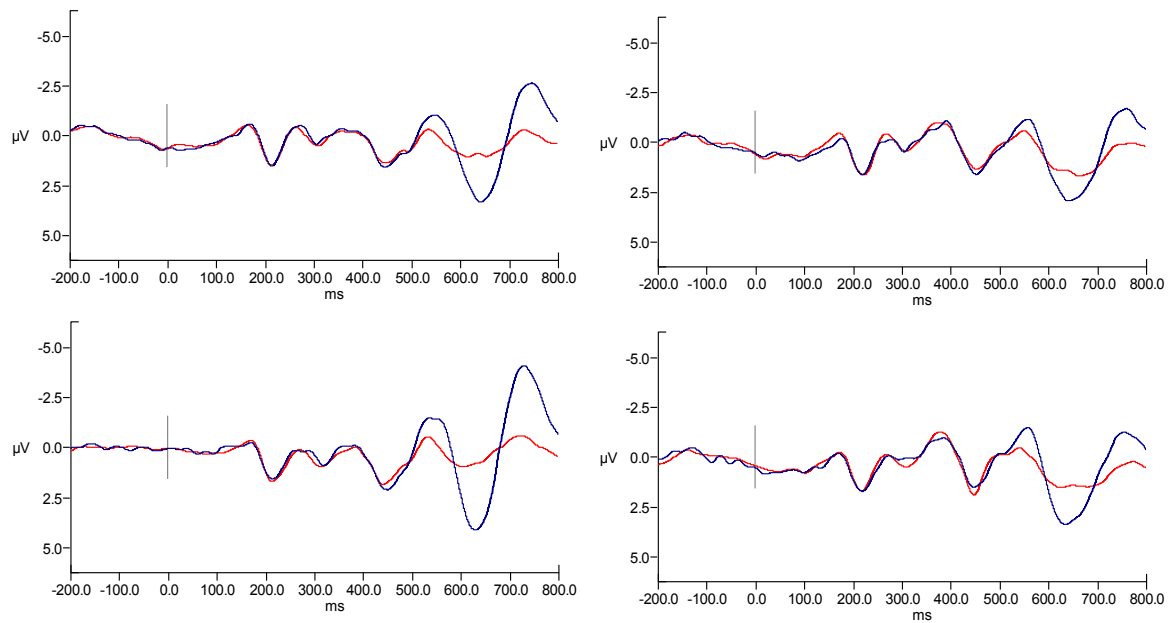

Figure 7.25. Baseline grand-average ERPs of 11 NS (left) and 11 S (right) at baseline (top) and follow-up (bottom) at PZ elicited during the image slideshow. Picture categories: neutral (navy), pleasant (light blue), smoking (pink), unpleasant (red). Vertical grey line marks stimulus onset.
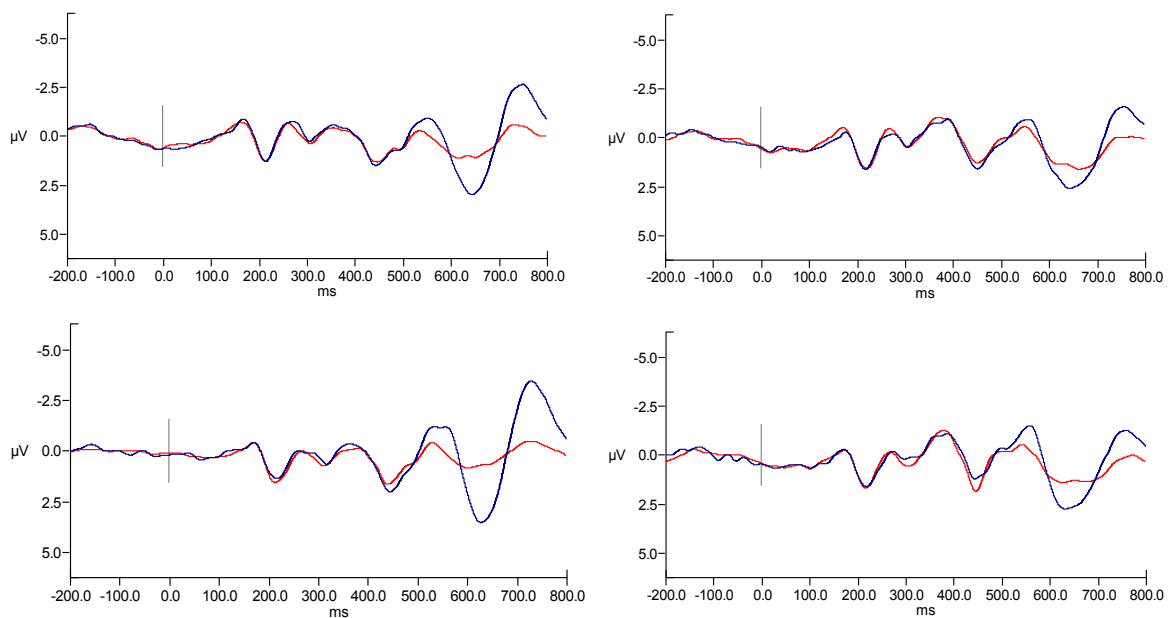
Figure 7.26. Baseline grand-average ERPs of 11 NS (left) and 11 S (right) at baseline (top) and follow-up (bottom) at P1 elicited during the image slideshow. Picture categories: neutral (navy), pleasant (light blue), smoking (pink), unpleasant (red). Vertical grey line marks stimulus onset.

Figure 7.27. Baseline grand-average ERPs of 11 NS (left) and 11 S (right) at baseline (top) and follow-up (bottom) at P2 elicited during the image slideshow. Picture categories: neutral (navy), pleasant (light blue), smoking (pink), unpleasant (red). Vertical grey line marks stimulus onset.

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Figure 7.28. Baseline grand-average ERPs of 11 NS (left) and 11 S (right) at baseline (top) and follow-up (bottom) at FZ elicited during the Go/NoGo task, showing Go (red) and NoGo (navy) stimuli. Vertical grey line marks stimulus onset (i.e., 0 ms).
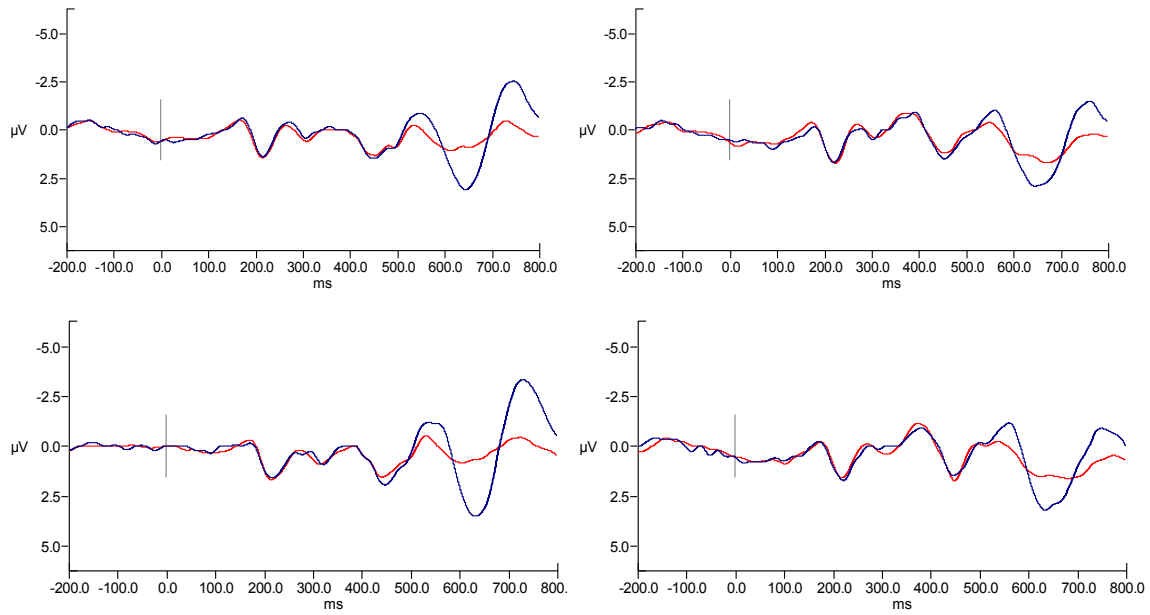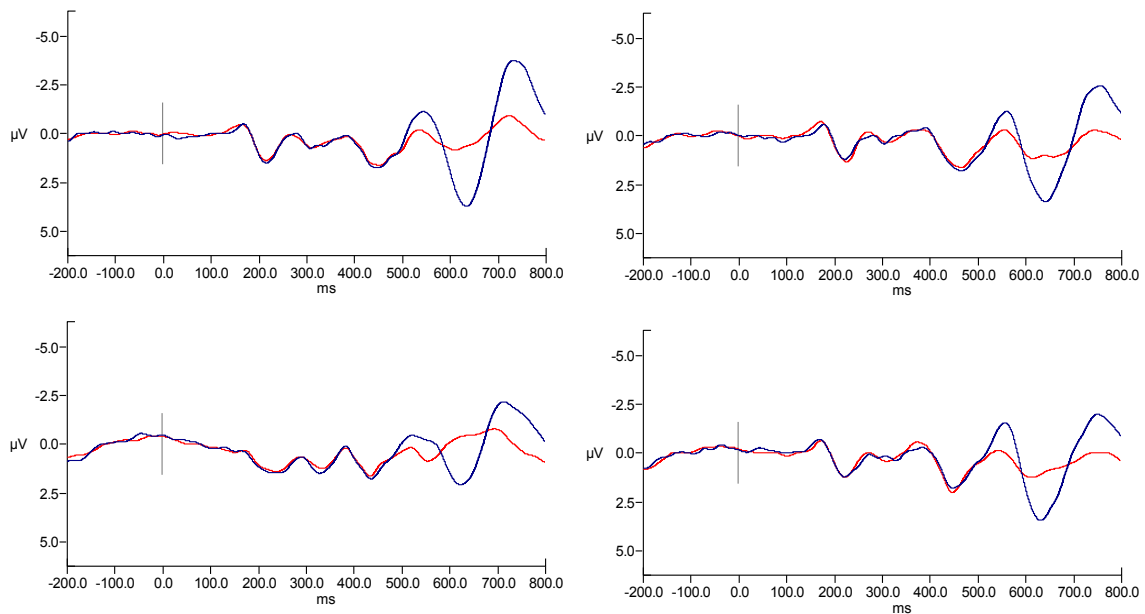

Figure 7.29. Baseline grand-average ERPs of 11 NS (left) and 11 S (right) at baseline (top) and follow-up (bottom) at F1 elicited during the Go/NoGo task, showing Go (red) and NoGo (navy) stimuli. Vertical grey line marks stimulus onset (i.e., 0 ms).

Figure 7.30. Baseline grand-average ERPs of 11 NS (left) and 11 S (right) at baseline (top) and follow-up (bottom) at F2 elicited during the Go/NoGo task, showing Go (red) and NoGo (navy) stimuli. Vertical grey line marks stimulus onset (i.e., 0 ms).
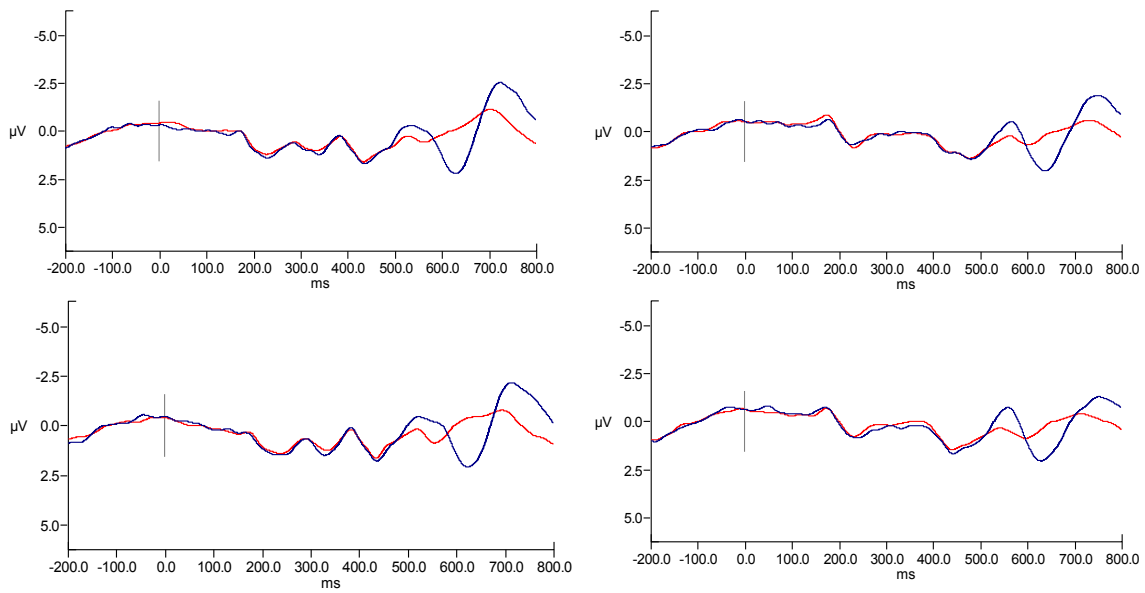

Figure 7.31. Baseline grand-average ERPs of 11 NS (left) and 11 S (right) at baseline (top) and follow-up (bottom) at FCZ elicited during the Go/NoGo task, showing Go (red) and NoGo (navy) stimuli. Vertical grey line marks stimulus onset (i.e., 0 ms).
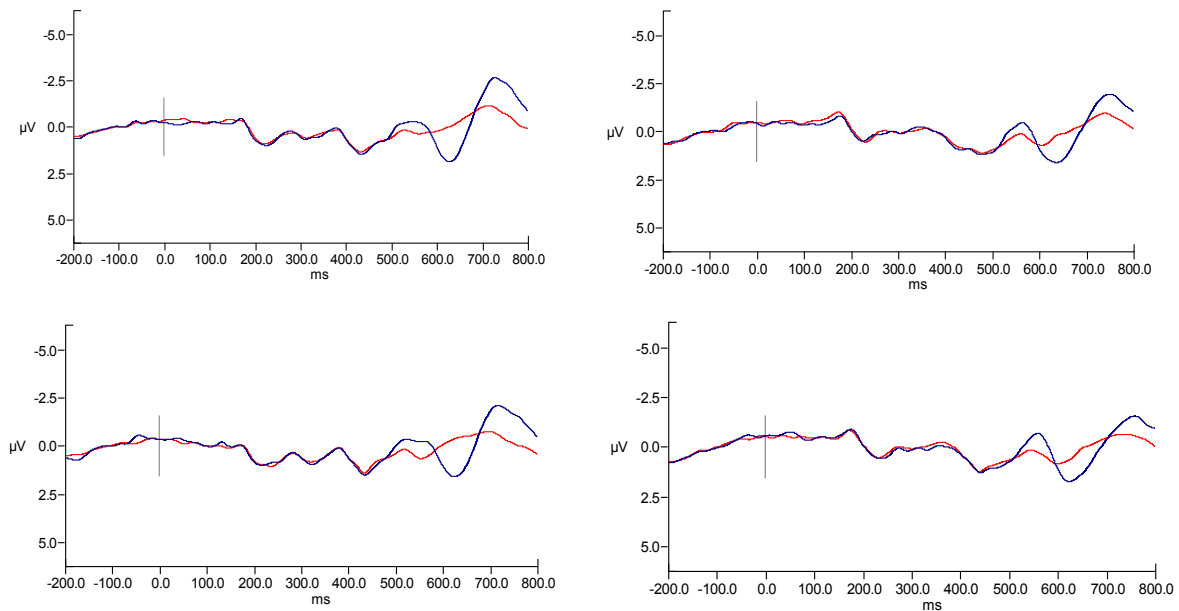
Figure 7.32. Baseline grand-average ERPs of 11 NS (left) and 11 S (right) at baseline (top) and follow-up (bottom) at CZ elicited during the Go/NoGo task, showing Go (red) and NoGo (navy) stimuli. Vertical grey line marks stimulus onset (i.e., 0 ms).

Figure 7.33. Baseline grand-average ERPs of 11 NS (left) and 11 S (right) at baseline (top) and follow-up (bottom) at C1 elicited during the Go/NoGo task, showing Go (red) and NoGo (navy) stimuli. Vertical grey line marks stimulus onset (i.e., 0 ms).
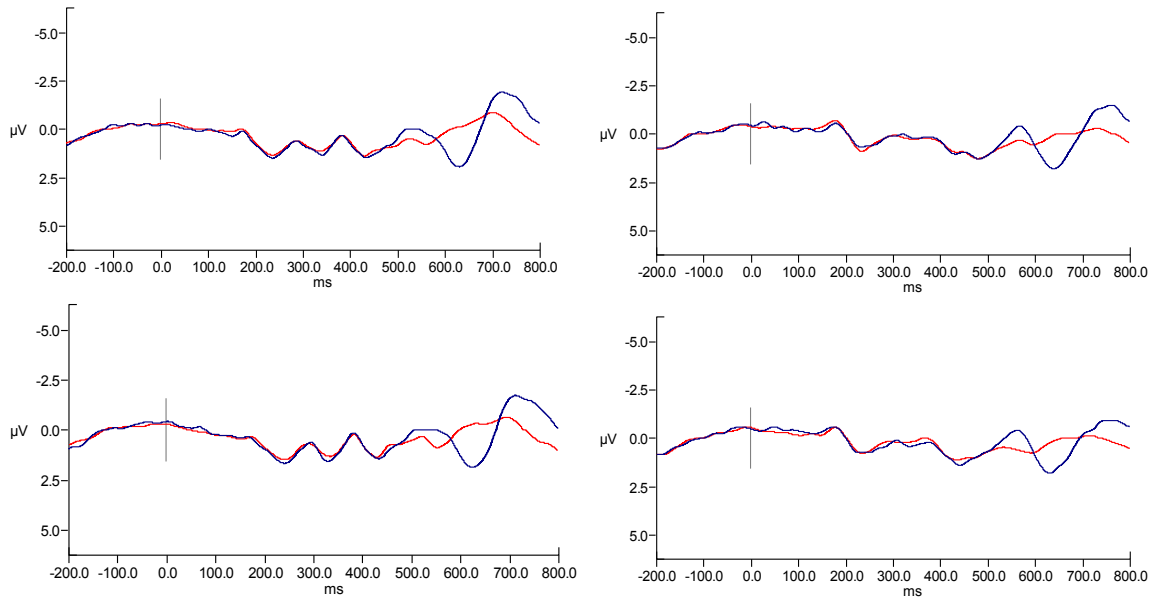
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Figure 7.34. Baseline grand-average ERPs of 11 NS (left) and 11 S (right) at baseline (top) and follow-up (bottom) at C2 elicited during the Go/NoGo task, showing Go (red) and NoGo (navy) stimuli. Vertical grey line marks stimulus onset (i.e., 0 ms).
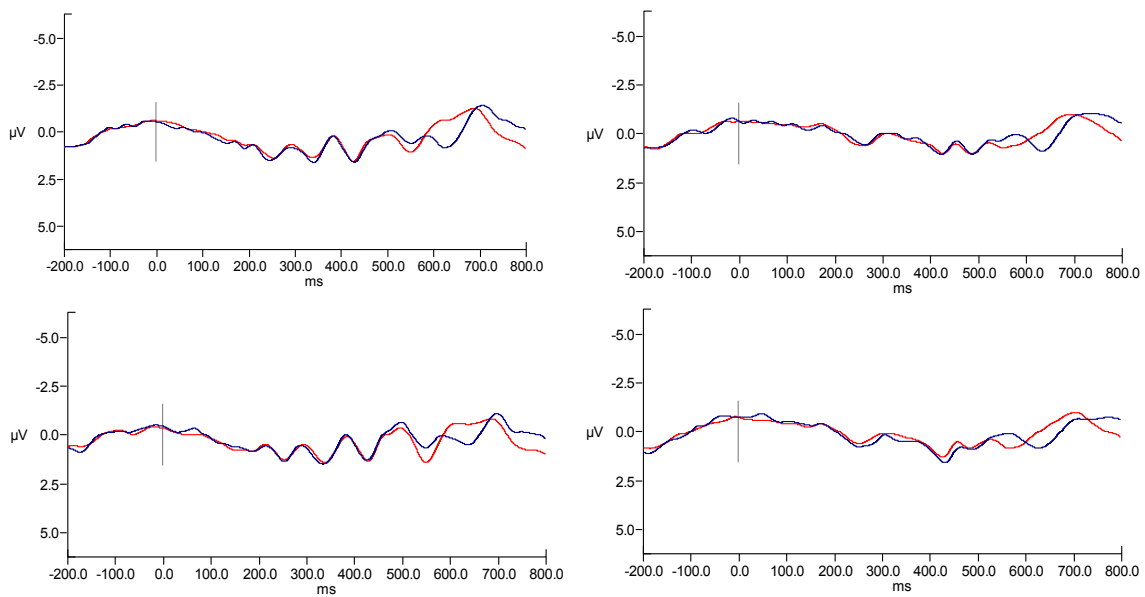

Figure 7.35. Baseline grand-average ERPs of 11 NS (left) and 11 S (right) at baseline (top) and follow-up (bottom) at CPZ elicited during the Go/NoGo task, showing Go (red) and NoGo (navy) stimuli. Vertical grey line marks stimulus onset (i.e., 0 ms).