COGNITIVE PROCESSES IN CIGARETTE SMOKING CESSATION:

A FIELD INVESTIGATION

by

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> The LORD is my strength and my shield; my heart trusts in Him, and He helps me. My heart leaps for joy, and with my song I praise Him.
>
> - Psalms 28:7

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DEDICATION

To my beloved grandmother and father who passed during the proposal and final dissertation defense phases of this project. Because of you, I have witnessed love that is transforming and persevering in spite of adversities.

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ABSTRACT

Cognitive Processes in Cigarette Smoking Cessation: A Field Investigation:

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Cigarette smoking continues to be the nation's leading preventable cause of death. Recent research has examined the cognitive processes underlying smoking and relapse to smoking in the hope of finding novel treatment approaches for smoking cessation. The dual process model suggests that both executive processes (e.g., sustained attention and impulsivity) and automatic processes (e.g., attentional bias) are involved in smoking relapse. Few studies have tested this idea in smoking addiction. Specifically, sustained attention abilities may be both an independent predictor of smoking outcomes as well as a moderator of the impact of automatic processes on smoking outcomes. Moreover, most studies of cognitive processes in smoking have been conducted in a laboratory setting. The current study used ecological momentary assessment to assess cognitions and smoking in the field.

This dissertation examined smokers (N=22) who were willing to cut down or quit smoking for one week. During the two-week study, participants completed Rapid Visual Information Processing (RVIP) assessments on a PDA at home each morning. During

Week 1, participants were instructed to complete the assessments while abstinent on three mornings and after smoking on another three mornings. Participants were instructed to try to cut down or quit during the second week of the study. During Week 2 smoking was assessed each day with a smoking diary and with a breath carbon monoxide monitor each evening. Specific Aim 1 assessed the feasibility of assessing sustained attention (RVIP performance) in the field. Specific Aim 2 examined the role of the RVIP as a predictor variable and Specific Aim 3 examined RVIP performance as a moderator variable.

Half of the 22 participants who enrolled in the study completed the study. Among study completers, smoking rates were lower in Week 2 than Week 1. Participants exhibited reasonable compliance to individual components of the protocol, but they generated a lower number of days/observations per subject for analyses than expected. During Week 1, morning RVIP hit rate at home after smoking was better than hit rate before smoking. Hit rate during morning assessments in Week 2 predicted subsequent CO levels later that day. An unexpected finding was that a higher false alarm rate during abstinence was also generally associated with increased smoking during Week 2. Lastly, there was no evidence that RVIP performance moderated the associations between attentional bias and subsequent smoking during Week 2.

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Chapter 1: General Introduction

CIGARETTE SMOKING

Cigarette smoking is pervasive (c.f., World Health Organization, 2011; Centers for Disease Control and Prevention, 2012; Substance Abuse and Mental Health Services Administration, 2012). Although overall there is a declining trend of cigarette use (see Substance Abuse and Mental Health Services Administration, 2012), smoking still constitutes the leading preventable cause of morbidity and mortality (Centers for Disease Control and Prevention, 2002, 2004, 2010). Adverse health effects include pulmonary and vascular diseases as well as various cancers (Centers for Disease Control and Prevention, 2004, 2008). Cigarette smoking also has economic costs to the person and society. These financial costs are due to healthcare expenditure (Warner, Hodgson, & Carroll, 1999; Centers for Disease Control and Prevention, 2008) and productivity losses (Centers for Disease Control and Prevention, 2008).

The health benefits of smoking cessation include increased quality (Nusselder, Looman, Marang-van de Mheen, van de Mheen, & Mackenbach, 2000; Parrott & Godfrey, 2004; Piper, Kenford, Fiore, & Baker, 2012) and quantity of life (Nusselder et al., 2000; Parrott & Godfrey, 2004; Taylor, Hasselblad, Henley, Thun, & Sloan, 2002; U.S. Public Health Service, 1990; Van Meijgaard & Fielding, 2012). There are also direct and indirect financial benefits to cessation, such as decreased healthcare expenditure on smoking-related treatment (Parrott & Godfrey, 2004) and reduced absences from work (Lightwood & Glantz, 1997; Parrott & Godfrey, 2004), respectively.

Relapse to Smoking

Despite the availability of efficacious smoking cessation interventions, the proportion of smokers who express interest in quitting and who are motivated to quit far exceeds the proportion who are able to quit (Centers for Disease Control and Prevention, 2012; Borland, Partos, Yong, Cummings, & Hyland, 2012; Centers for Disease Control and Prevention, 2010). It is well established that the most common outcome of a quit attempt is relapse to smoking (Borland, Partos, Yong, Cummings, & Hyland, 2012; Centers for Disease Control and Prevention, 2010). However, the psychological processes that cause relapse are unclear. Many researchers have focused on negative affect (e.g., Baker, Piper, McCarthy, Majeskie, & Fiore, 2004), and some relapses to smoking are preceded by acute increases in negative affect (e.g., Shiffman & Waters, 2004). However, many relapses occur when participants are in a neutral or good mood (Shiffman, Paty, Gnys, Kassel, & Hickcox, 1996; Shiffman, West, & Gilbert, 2004). An improved understanding of the psychological processes underlying relapse to smoking may lead to more efficacious interventions.

Cognitive Processes in Smoking

Recently, researchers have scrutinized the role of cognitive processes in addiction and relapse (e.g., Sofuoglu, DeVito, Waters, & Carroll, 2013; Tiffany, 1990; Wiers et al., 2013; Wiers & Stacy, 2006) to try to identify cognitive targets for interventions. Contemporary cognitive models conceptualize addiction as a "battle" between "automatic" (or "implicit") processes, which increase the risk of drug taking/relapse, and "controlled" (or "explicit") processes, which attempt to inhibit automatic processes or their output (see review in Wiers et al., 2013). If automatic processes prevail, drug use/relapse will occur.

If controlled processes prevail, abstinence will be maintained. This conceptualization is referred to as dual-process theory because of the emphasis on two qualitatively distinct processes: automatic (or "implicit") and controlled (or "explicit") (e.g., Kahneman, 2011; Wiers et al., 2013). Automatic cognitive processes are characterized by quick, parallel processing without effort and without requiring conscious evaluations of input. In contrast, controlled processes are characterized by slow, serial processing requiring deliberate effort, driven by conscious evaluations of input (Kahneman 2011). Although dual process theories can be criticized (e.g., see Wiers et al., 2013), this conceptualization is useful for understanding the hypotheses in this study. Dual process theory will be elaborated in a later section.

Researchers have examined cognitive processes that may contribute to smoking relapse, including implicit (e.g., attentional bias, defined later; Waters, Shiffman, Sayette et al., 2003) and explicit (e.g., executive functions; Ashare, Falcone, & Lerman, 2013) processes. The remainder of this chapter will be organized as follows. First, a broad overview of neurocognitive processing as it relates to smoking will be presented. Second, a more detailed examination of smoking and executive functioning, specifically sustained attention and impulsivity, will be presented. This is because sustained attention, in particular, is a primary focus of the current study. The concepts of sustained attention and inhibitory control will be described in this section. Third, a focused review of the role of attentional bias and craving in smoking behavior will be presented. Fourth, the dual process theory, introduced above, will be described in further detail. Last, a description of the study methodology will be provided.

A Note on Terminology

The large number of terms used to describe cognitive processes warrants a brief overview. For the purposes of this dissertation, an automatic process is considered synonymous with an implicit process, and a controlled process is considered synonymous with an explicit process. As noted later, in the decision making literature, Kahneman (2011) and other researchers have referred to automatic/implicit processes as "system 1" (or type 1) processes and controlled/explicit processes as "system 2" (or type 2) processes.

A subdivision of "cognitive processes" that is pertinent to this dissertation are "neurocognitive functions" (or "neurocognitive processes") that primarily assess controlled processes. Tasks that assess "executive functions", such as sustained attention and inhibitory control (to be described later) fall within this category.

Cognitive processes are assessed using cognitive tasks. However, an individual cognitive task is unlikely to be "process-pure" and likely taps a range of processes. Tasks such as the modified smoking Stroop task (described later) and the Implicit Association Test are used to assess automatic/implicit processes, although researchers are aware that controlled processes also play a role in task performance on these "implicit tasks" (Wiers et al., 2013).

NICOTINE ADDICTION

Reducing cigarette consumption is difficult because of the addictive properties of nicotine, the primary psychoactive ingredient in tobacco (USDHHS, 1988). The pharmacological actions of nicotine have been well-studied. Nicotine is an alkaloid that acts on nicotinic acetylcholine receptors (nAChRs) distributed throughout the central nervous system and the peripheral nervous system (Markou, 2008). A detailed review of

the neurobiology of nicotine's effect is beyond the scope of this dissertation. However, it is worth noting at the outset that nicotine increases dopamine release in a number of brain areas including the nucleus accumbens, corpus striatum, and the prefrontal cortex. These actions underlie nicotine's addictiveness and may underlie its acute effect on cognitive performance (as described in more detail later). However, the neurobiological mechanisms underlying nicotine's effects are complex because nicotine also influences the release of other neurotransmitters such as norepinephrine (noradrenaline), vasopressin, acetylcholine, and serotonin.

Nicotine withdrawal is another feature of nicotine addiction (Hatsukami & Pickens, 1985). When chronic smokers are deprived of nicotine, they experience withdrawal symptoms, consisting of subjective, physiological, and cognitive changes (Hatsukami & Pickens, 1985; Hughes, Keenan, & Yellin, 1989; Hughes, 2007). These withdrawal symptoms are thought to be the result of neuroadaptations in nAChRs which occur as a result of chronic smoking.

Most important for the current study, abstinence from nicotine impairs cognitive performance as documented by decrements in performance on tasks of sustained attention (Hughes, Keenan, & Yellin, 1989; Leventhal et al., 2010). Therefore, to understand the effects of nicotine on cognitive performance, one needs to take into account the smoking status of the subject (e.g., smoker, former-smoker, never-smoker) as well as their state at the time of test (nicotine-deprived vs. non-deprived). In this proposal, the word "deprived" has the same meaning as "abstinent." For example, a positive acute effect of nicotine in overnight deprived smokers may reflect relief of the effect of withdrawal rather than an absolute enhancement. One also needs to consider the acute effects of

nicotine (e.g., single dose, cigarette smoking in a laboratory setting, etc.) separately from the chronic effects (effects of repeated smoking over years or decades). The foregoing review of nicotine's effects on human cognitive performance will therefore consider smoking status when the information is available. Furthermore, the effects of acute and chronic nicotine, as well as deprivation effects (i.e., withdrawal) will be highlighted as appropriate. Unless otherwise specified, the reviewed studies examined non-clinical (i.e., healthy) adults. A review of the animal literature on the acute and chronic effects of nicotine is beyond the scope of this dissertation.

Cognitive Effects of Nicotine/Smoking

Experimental and observational studies have investigated the impact of acute and chronic effects of nicotine or smoking on cognitive functioning in humans. This section will review this literature.

Acute Effects of Nicotine/Smoking

In an experimental laboratory study of habitual smokers, the acute effects of nicotine administered transdermally via patches revealed that relative to the placebo condition, nicotine improved sustained attention (decreased response time and its variability on a continuous performance task [CPT]), but not for inhibition (assessed with the stop signal task) (Bekker, Bocker, Van Hunsel, Van den Berg, & Kenemans, 2005). In another laboratory study, nicotine was administered acutely using nicotine gum in smokers, former smokers, and never-smokers (Ernst, Heishman, Spurgeon, & London, 2001). Acute nicotine improved response speed on an attention task (2-Letter Search) in the smoking as well as both non-smoking (never- and former-smokers) groups. This suggests that, at least for the 2-Letter Search task, acute nicotine imparts a true positive

effect on attention that is not due to withdrawal relief. However, there was an absence of significant findings for working memory (assessed with a variant of the N-back task) and verbal information processing (measured with the Logical Reasoning task).

In a meta-analysis of rigorous placebo-controlled double-blind empirical studies, improvements in motor functioning were found (reflecting small effects), and enhancements in attention, working memory, and short term memory (the remainder indicated medium-sized effects; Heishman, Kleykamp, & Singleton, 2010) after nicotine administration. Furthermore, studies of non-smokers and smokers who were minimally deprived (at most), were only included in this study. This enables the interpretation of absolute nicotine improvements and precludes the possibility that the observed was due to relief of withdrawal effects. Similarly, other studies reported enhancements in motor abilities (Durazzo, Meyerhoff, & Nixon, 2010), attention (Swan & Lessov-Schlaggar, 2007; Newhouse, Potter, & Singh, 2004; Durazzo et al., 2010), working memory (Durazzo et al., 2010; Swan & Lessov-Schlaggar, 2007), memory (Durazzo et al., 2010), and executive functions (Swan & Lessov-Schlaggar, 2007).

Collectively, the acute effects of nicotine are associated with attention improvements and some evidence for working memory, motor functioning, short-term memory, and executive function enhancements. The improvements are often reflected as shorter response speed and, less consistently, in increased accuracy rates. These effects appear to be absolute enhancements, found in both smoking and non-smoking groups, and not simply due to withdrawal relief (as never-smokers were included).

Effects of Acute Abstinence

This section will be limited to studies evaluating abstinence-induced neurocognitive decrements.

A review by Sherwood (1993) of the earlier literature reported that abstinence generally impairs performance on cognitive tasks. In more recent studies assessing overnight deprivation, significant decrements were found on general cognitive functioning (Schlienz, Hawk, & Rosch, 2013) and verbal working memory (Sweet et al., 2010). After 12-hr. abstinence, one study found that declines in verbal learning returned to pre-abstinence levels (Soar, Dawkins, Begum, & Parrott, 2008). One study investigated the impact of 24-hr abstinence on neurocognitive function in male subjects. Results revealed that abstinence-induced dysfunction was found for different aspects of attention (including vigilance), episodic verbal memory, and verbal recognition, but working memory was intact (Wesnes, Edgar, Kezic, Salih, & de Boer, 2013).

Chronic Effects of Nicotine/Smoking

The chronic effects of nicotine/smoking are more difficult to study in humans than the acute effects. This is because it is not possible to randomize subjects to either "smoke" or "not smoke" for a prolonged period of time (chronically). Accordingly, researchers have compared the cognitive performance of chronic smokers and never-smokers. However, interpretation should take into account the fact that smokers are self-selected. Therefore individuals with poor cognitive performance, or who exhibit poorer cognitive performance over time, may be more likely (and perhaps more motivated) to initiate and continue to smoke than those with good cognitive performance. Another

complication is that cigarette smoke contains many compounds other than nicotine, which makes it difficult to determine the chronic effect of nicotine from these studies.

Overall, this is a complex literature. Some studies found chronic nicotine did lead to improvements in attention and memory (e.g., Levin, McClernon, & Rezvani, 2006; Rezvani & Levin, 2001). However, a majority of studies found that chronic smoking was associated with decrements in performance across neurocognitive domains.

A review of the effects of chronic smoking reported that smoking was associated with an increased risk for clinical levels of cognitive dysfunction (including deficits in verbal memory, executive processes, and information processing rate) (Swan & Lessov-Schlaggar, 2007). In a population-based case-controlled study of healthy subjects (aged 18-65), regular smokers exhibited deficits in visual attention and impulsivity, relative to their never-smoking counterparts (Wagner et al., 2013). The between-group differences had small effect sizes and were not attributable to psychiatric histories including ADHD, alcohol misuse, or age. Cognitive functions that were not different (between smokers and never-smokers) included verbal fluency, verbal memory, verbal working memory, and EF. However, years smoked was unrelated to cognitive function, suggesting that the cognitive deficits in smokers might reflect pre-smoking levels.

Cognitive deficits with chronic smoking have been found even in young adults (aged 18-29; Chamberlain, Odlaug, Schreiber, & Grant, 2012). Relative to never-smokers, current smokers exhibited impairments in sustained attention, spatial working memory, executive planning, and risky decision making strategies that had moderate effect sizes. However, response inhibition and reaction time, in general, were not different between smokers and never-smokers. A study of working memory revealed that

never-smokers performed best, then ex-smokers, while current smokers performed the worst on a working memory task (Ernst et al., 2001). However, there was no effect of group on a verbal information processing task.

In a prospective study of middle-aged smokers (mean age = 46 years), current habitual smokers displayed worse response time performance, fine motor abilities, learning (verbal and visuospatial), visuospatial memory, executive function, and IQ compared to their non-smoking counterparts (who reported smoking less than 20 cigarettes ever in their lifetime) (Durazzo, Meyerhoff, & Nixon, 2012). These differences had moderate to large effect sizes and were not due to potential confounds including age, educational level, occupation, or alcohol use. Furthermore, this study found that years smoked was associated with worse performance in general information processing speed and visuospatial abilities. In another prospective study of middle-aged adults (mean age of 55 years during one phase of the study), current smokers, compared to never-smokers, had an increased risk of clinical levels of memory deficits and displayed decrements in reasoning abilities (Sabia, Marmot, Dufouil, & Singh-Manoux, 2008). In this study, ex-smokers had a reduced risk of decrements in verbal performance.

In the later stages of life, chronic smoking is associated with memory deficits (Reitz, Luchsinger, Tang, & Mayeux, 2005), global cognitive decline (Whalley, Fox, Deary, & Starr, 2005; Anstey, von Sanden, Salim, & O'Kearney, 2007; Ott et al., 2004), and increased risk for Alzheimer's disease (Anstey et al., 2007), all of which were not attributable to aging.

In sum, a majority of studies found detrimental effects of chronic smoking. Overall, decrements in a variety of neurocognitive domains were found that are

independent of educational level or psychiatric conditions including alcohol misuse. Generally, decrements were found in information processing, fine motor abilities, attention, working memory, learning, memory, and executive functions such as impulsivity, reasoning, judgment, and planning (e.g., Wagner et al., 2013).

However, it should be re-emphasized that is not possible to draw strong causal inferences from these cross-sectional and prospective observational studies. It is unclear whether the neurocognitive decrements in chronic smokers are pre-existing conditions (i.e., would be observed even if they never smoked) or a consequences of smoking. Some studies suggested that they may be pre-existing (Wagner et al., 2013), and some suggested they were at least in part as a consequence of smoking (Durazzo et al., 2012). As noted earlier, another complication is that cigarette smoke contains a variety of compounds other than nicotine. It remains possible that nicotine itself has a positive chronic effect but other agents in cigarette smoke damage vasculature (or have some other negative effect) that leads to an overall negative effect of smoking on cognition. Overall, further research is needed to clarify the relationship between smoking and cognition.

Effects of Chronic Abstinence

Few studies have examined the effect of chronic abstinence from smoking over time. Studies have also found that successful cessation, even after two years, can improve cognitive functioning (Almeida et al., 2011) and even reverse the detrimental effects (Fried et al., 2006).

Smoking and IQ

Some studies assessing IQ have used this variable as a dependent variable, examining whether smokers and never-smokers differ in IQ.

IQ is typically poorer in smokers than never-smokers and there is evidence of global declines in cognitive functioning as well as an increased risk for Alzheimer's disease that is not due to aging (e.g., Anstey et al., 2007; Durazzo et al., 2012). Broadly, data suggest that low pre-smoking IQ is related to smoking initiation and severity (e.g., Corley, Gow, Starr, & Deary, 2012; Menon, Jahn, Mauer, & O'Bryant, 2013), however more research needs to be conducted.

Other studies have used IQ as a covariate (rather than a dependent variable). When doing so, between-group differences in attention and executive functions (between smokers and never-smokers) disappeared (Wing, Bacher, Sacco, & George, 2011), while global cognitive decrements remained, even when holding IQ constant (Durazzo et al., 2010). However, treating IQ as a covariate is problematic. Covarying a factor that is naturally inherent in a population is unsuitable (Dennis et al., 2009; Miller & Chapman, 2001) nor does IQ meet the requirements of a covariate (Dennis et al., 2009). Also, removing the effects of IQ may remove any significant effects on cognitive performance if they are correlated (e.g., Miller & Chapman, 2001).

Few studies have examined IQ as an independent variable. In this study, we explored whether IQ predicted smoking outcomes.

SUSTAINED ATTENTION AND INHIBITION

Until now the current manuscript has provided a broad review of neurocognitive functions influenced by nicotine use. This section will focus on executive functioning,

specifically sustained attention and inhibitory control. Executive functioning is one aspect of neurocognitive functioning. There are several cognitive domains that fall under this umbrella term, such as attention, working memory, inhibition, planning, set shifting, and problem solving (e.g., Chan, Shum, Toulopoulou, & Chen, 2008; Elliott, 2003; Gilbert & Burgess, 2008). Accordingly, there are numerous definitions that reflect this variation. Generally, however, executive function encompasses cognitive processes involved in complex higher order processing (Elliott, 2003; Gilbert & Burgess, 2008). Similarly, there are a number of theories of executive function, one of which is Norman and Shallice's model of action, which includes the supervisory attentional system (SAS) (Chan et al., 2008; Gilbert & Burgess, 2008; Shallice & Burgess, 1996).

Norman and Shallice's model of action (1996) described two separate processes that operate to determine behavior: automatic and willed control (Shallice & Burgess, 1996). The automatic system is guided by external stimuli from the environment as well as by internal drives. It functions without our conscious awareness and encompasses habits and routines. The notion of an automatic processing system is germane to the current study. As such, this concept will be revisited and discussed further later. The willed control system operates more complex tasks that require explicit processing; otherwise it engages when automatic processing is insufficient. It operates via the SAS, which coordinates and monitors schemas to determine behavior. Schemas are learned thoughts and actions, such as rules and scripts that facilitate navigating through situations. The SAS holds executive roles and manages complex problem-solving and subsequent behaviors. It also suppresses irrelevant information. In this manner, the SAS is

comparable to top down inhibitory control and requires sustained attention, among other executive functions.

The remainder of this section will focus on sustained attention and inhibitory control. Sustained attention has been defined as the ability to maintain alertness for a prolonged period of time on a task (Sarter, Givens, & Bruno, 2001). There are numerous conceptualizations of the psychological concept of inhibition (or inhibitory control). Generally, inhibitory control reflects the ability to suppress prepotent responses or inhibit distractions from preventing task accomplishment (e.g., Bari & Robbins, 2013; Nigg, 2000).

Inhibition is often characterized as an umbrella term that can be fractionated into different subtypes, including behavioral and decision-making, among others (c.f., Bari & Robbins, 2013; Nigg, 2000). From this perspective, behavioral inhibition includes response inhibition (or "impulsivity" to indicate the absence of this ability), which can be assessed with a Go/No-go task. Delayed discounting is an example of the decision-making form of inhibition. The former (response inhibition) will be the main type of inhibitory control that is relevant for this dissertation. Again, impulsivity is essentially the absence of, or reduced, inhibitory control. In other words, impulsivity reflects impairment in suppressing dominant responses (Logan, Schachar, & Tannock, 1997).

Limited Capacity

Attention and inhibition are thought to have limited capacities (e.g., Head & Helton, 2012; Helton & Warm, 2008; Muraven & Baumeister, 2000). Sustained attention is viewed as a limited resource (Sarter et al., 2001; Head & Helton, 2012; Helton & Warm, 2008) and its continued use without breaks would lead to reduced effectiveness

(Head & Helton, 2012; Helton & Warm, 2008). Other investigators have described attention as a finite capacity and that different sources can call on these reserves, including bottom-up and top-down processes (Pessoa, Kastner, & Ungerleider, 2002).

Likewise, researchers have proposed a similar idea for inhibition. A paper that conceptualized self-control to include sustained attention and inhibition summarized that these neurocognitive abilities are limited resources and that with continued operation will eventually falter (Muraven & Baumeister, 2000). The authors further proposed that this decline in performance is not due to effort, negative mood, or learned helplessness.

Summary

Collectively, these studies of executive function imply that individuals with decreased cognitive resources may be at a disadvantage. Indeed, substance-addicted individuals who exhibited greater executive function difficulties relative to control subjects, experienced performance decrements with increasing cognitive load (e.g., Hester & Garavan, 2004).

Individuals with reduced executive function may have a particularly difficult time maintaining cessation and executive function deficits may be used as a marker to identify high-risk groups. For example, individuals with sustained attention difficulties may not be able to use problem-solving strategies effectively to prepare for a quit attempt. Moreover they may not be able to use effective coping strategies if resources are limited. They may also be less able to inhibit prepotent responses when confronted with a tempting smoking cue. This latter point is elaborated on later.

Brain Mechanisms Underlying Sustained Attention

Sustained attention is thought to be mediated by the fronto-parietal network (e.g., Bartes-Serrallonga et al., 2014; Coull, 1998; Coull et al. 1996; Coull, Frackowiak, and Frith, 1998; Sarter et al., 2001) with the thalamus found to be implicated in some studies, and the reticular activating system also involved (Coull, 1998; Oken et al., 2006). On the RVIP task (described below), neuroimaging studies have found that the frontal, parietal, occipital, thalamic, and cerebellar brain structures are activated (Lawrence et al., 2003). One study reported that the right fronto-parietal areas mediated sustained attention while the left fronto-parietal cortical structures mediated working memory (Coull et al., 1996).

With respect to neurotransmitters, sustained attention is thought to be modulated by dopamine, acetylcholine, and noradrenaline. The noradrenergic neurotransmitter system is associated with the maintenance of alertness while the dopamine system is associated more with executive aspects of attention, including working memory (Coull, 1998). Further, cholinergic transmissions in the prefrontal and parietal cortex are considered to be involved in sustained attention (Himmelheber et al., 2000; Klinkenberg, et al., 2011).

Effect of Nicotine on Brain Mechanisms Underlying Sustained Attention

As noted earlier, nicotine is an agonist for the nicotinic acetylcholine receptor, increasing cholinergic activity when it binds to it (Jasinska, Zorick, Brody, & Stein, 2014). As noted earlier, acetylcholine transmission in the fronto-parietal-thalamic network is required for sustained attention. Nicotine also increases dopamine release in a number of brain areas, including the prefrontal cortex, which may partially underlie nicotine's effects on sustained attention and working memory (c.f., Jasinska, Zorick,

Brody, & Stein, 2014). Both dopamine and norepinephrine have actions on prefrontal cortical function. Indeed several studies support the notion that nicotine improves sustained attention by way of fronto-parietal-cingulate-thalamic attention network activation (e.g., Hong et al., 2011; Lawrence et al., 2002). An fMRI study assessing the neural mechanisms of nicotine on the RVIP task found that nicotine administration in smokers increased brain activation in bilateral parietal cortex, thalamus, and caudate with less activation in the frontal brain area, which may be more associated with working memory (Lawrence et al., 2002).

Sustained Attention and Nicotine

Studies using the Rapid Visual Information Processing Task (RVIP), the most extensively used Continuous Performance Task (CPT) in the smoking literature, will be reviewed here (summarized in Table 1). The RVIP is of particular interest in this study because it will be assessed in the field. A variety of names have been used to refer to essentially the same task, including Rapid Information Processing Task (RIPT) and Rapid Visual Performance (RVP) task. This manuscript employs the task name used in the respective journal articles. In general, on this computerized task, digits from 2 to 9 are presented serially on the screen. Subjects are instructed to press a key when they see a pre-prescribed 3-digit target. Working memory is required for this task because the set targets are to be kept in their mind as they attend to the stimuli (see sample task instructions in Appendix D). Outcome variables include number of correct hits, mean response time on correct hits, and number of false alarms.

Overall, as described in detail below, studies have generally revealed that the RVIP task is sensitive to the effects of nicotine and nicotine deprivation. As noted in

Table 1, different studies have used varied methodological designs in moderate to heavy habitual smokers and never-smokers, varied nicotine doses, and a number of administration routes (e.g., Lawrence, Ross, & Stein, 2002; Leventhal, Waters, Moolchan, Heishman, & Pickworth, 2010; Rusted & Alvares, 2008; Wesnes & Warburton, 1983).

Acute Effects of Nicotine/Smoking on RVIP

The effect of nicotine on attention can be investigated by acutely administering nicotine (vs. placebo). The seminal 1983 study by Wesnes and Warburton (Wesnes & Warburton, 1983), using a sample of habitual college-aged smokers, found that acute nicotine improved RIPT performance. In this study, improvements on response time and correct hits were exhibited in smokers who acutely received nicotine compared to their 24-hour deprived baseline levels (Wesnes & Warburton, 1983) while similar enhancements were found by delivering nicotine via a transdermal patch (Lawrence et al., 2002). Moreover, these improvements were not attributable to a trade-off between the RIPT indices (Wesnes & Warburton, 1983). A dose-response relationship was also revealed wherein the greatest improvements occurred with the highest nicotine-delivering cigarettes (Wesnes & Warburton, 1983). Furthermore, performance on the RIPT diminished over time, parallel to reductions in nicotine levels.

These findings were replicated using a comparable methodological design, this time implementing a 12-hr deprivation period prior to smoking (Edwards, Wesnes, Warburton, & Gale, 1985). In this study, the RVIP task was administered immediately after the experimental smoking session, when nicotine concentrations were the highest. However, not all studies have found improvements with correct detections. For example, Petrie and Deary (1989) found improvements on response latency only.

Kelemen and Fulton (2008) found that improvements in sustained attention did not generalize to higher order cognitive processes, such as memory, in moderate smoking college students. Furthermore, a dose expectancy effect for false alarms and subjective concentration was found (Juliano, Fucito, & Harrell, 2011). That is, participants' commission errors (false alarms) and reported concentration problems worsened when expecting to smoke a placebo cigarette.

Although a majority of the literature has found improvements on the RVIP with acute nicotine (Table 1), a number of studies revealed negative findings. Some studies reported that acute nicotine did not improve RVIP performance in habitual smokers (Herbert, Foulds, & Fife-Schaw, 2001; Nesic, Rusted, Duka, & Jackson, 2011; Poltavski & Petros, 2005) and never-smokers (File, Fluck, & Leahy, 2001; Poltavski & Petros, 2005). Herbert and colleagues (Herbert et al., 2001) posited that the lack of a training period conducted prior to the actual trials might have introduced noise to the data. Nesic and colleagues (2011) utilized a sample with a range of light to heavy smokers and a 5-minute abbreviated RVIP task. The authors posited that the null findings might be attributable to practice effects. Despite the absence of effects in this study, the more severe nicotine dependent participants exhibited less improvement on RVIP indices relative to the less severely dependent subjects. This result suggests an effect of nicotine was only observed in high dependent subjects. In Poltavski and Petros (2005), the absence of nicotine-induced effects was found using a 6-hour deprivation period and with the acute delivery of nicotine via a transdermal patch. The authors proposed that the 5-minute practice period (and 5-minute actual trials) may not have been sufficient time to establish optimal performance.

Of particular interest, in Poltavski and Petros (2005), Herbert et al. (2001), and Nesic et al. (2011) the deprivation period prior to acute nicotine administration was unclear, and the deprivation period was generally shorter than the studies that found nicotine-induced effects. The vast majority of studies that found positive effects utilized at least eight hours of deprivation (c.f., Edwards et al., 1985; Foulds et al., 1996; Kelemen & Fulton, 2008; Leventhal et al., 2010; Parrott & Craig, 1992; Petrie & Deary, 1989; Wesnes & Warburton, 1983), with a single exception of Juliano and colleagues (2011) who employed a three-hour abstinence period.

To elucidate whether improvements in attention are attributable to absolute nicotine effects or simply the relief of nicotine withdrawal, never-smokers were used as study participants. Using acute nicotine subcutaneous injections, Foulds and colleagues (1996) found differential improvements on the RVIP task. With the administration of acute nicotine, nicotine-deprived smokers demonstrated increased correct hits and reduced response latencies, while never-smokers exhibited reduced response latencies. Comparably, a study of never smokers employing a nasal spray for nicotine delivery revealed that nicotine improved RVIP response time compared to the placebo condition (Rusted & Alvares, 2008). No effects on number of correct hits or false alarms were found.

The positive findings in never-smokers provide support that nicotine can have effects on cognitive performance that are not due to withdrawal relief. Nevertheless, one study of never-smokers found that acute nicotine did not impact RVIP performance (File et al., 2001). However, all subjects were never-smoking medical students and no comparison or control group was included. Furthermore, these results need to be

considered in light of the fact that never-smokers may be inherently different than regular smokers.

To summarize, the literature on acute nicotine administration has generally found improvements in performance on the RVIP task that, at least in never-smokers, is not due to withdrawal relief. These positive findings are consistent across varied designs and nicotine administration routes.

Effects of Acute Abstinence on RVIP

The effect of nicotine abstinence on RVIP performance has been investigated by manipulating nicotine abstinence (nicotine deprivation) as an independent variable (comparing non-abstinent vs. abstinent smokers). Leventhal and colleagues (2010) recruited moderate to heavy habitual smokers not attempting to quit. In this within-subject study design, participants were instructed either to smoke as usual or abstain from nicotine for at least 12 hours prior to completing the RIPT. Abstinence-induced decrements were found on RIPT performance, reflected by increased response latency and decreased correct detections. Additional analyses on the same dataset suggested there were no gender differences (Leventhal et al., 2007). A second study found similar results. Hendricks and colleagues (2006) randomly assigned smokers to either smoke as usual or abstain from smoking. Abstainers exhibited slower reaction times relative to their closely matched smoking counterparts. Further, these decrements were found within 30 minutes of not smoking. Comparably, Kelemen & Fulton (2008) found decreased hit rates and increased response times using moderate smoking college students not trying to quit. Participants abstained from nicotine for at least 8 hours in this

study. In summary, results from studies inducing acute nicotine deprivation reveal that acute abstinence impairs performance on the RVIP.

Summary of Nicotine and RVIP Studies

Taken as a whole, these studies provide consistent support that the RVIP task is sensitive to the effects of acute nicotine and nicotine abstinence (see Table 1). From a broader perspective, impaired attention can be a barrier to successful cessation efforts and this information may provide some insight on factors underlying successful versus unsuccessful quit attempts.

To the author's knowledge, there are no studies evaluating RVIP performance and smoking cessation outcomes (other than Kang (2013), described later). However, a section on abstinence-induced attention declines (assessed using CPTs other than the RVIP) as it relates to smoking cessation outcomes will follow in the section entitled Abstinence-induced Neurocognitive Declines and Smoking Cessation Outcomes.

Impulsivity and Nicotine

In de Wit's review, impulsivity can lead to drug use and drug use can lead to impulsivity (c.f., de Wit, 2009). She highlights the key role of impulsivity in drug addiction. For instance, premorbid impulsivity can lead to the initiation of drug use, function to maintain drug use, and/or contribute to relapse. Another paper argues that impulsivity is a major contributor in the different phases of drug addiction and dependence (Perry & Carroll, 2008) and the risk of drug use (Crews & Boettiger, 2009). Where available, studies utilizing a Go/No-go task will be reviewed.

A review evaluated studies that measured impulsivity and its association with smoking. Findings using the Go/No-go task revealed that smokers on the whole were

more impulsive than non-smokers (former- and never-smokers; Mitchell, 2004). The authors proposed three possible mechanisms for this link: impulsivity is premorbid which leads to smoking, impulsivity is associated with the positive and/or negative reinforcement of smoking, or that smoking causes neuroadaptations that lead to increased impulsivity. In another study, relative to ex- and never-smokers, current smokers performed worse on the Go/No-go task, manifest as increased commission errors. This difference was not attributable to an inability to complete the task or due to erratic quick responses (Nestor et al., 2011).

There is a paucity of studies using the Go/No-go task to evaluate the effects of abstinence on inhibitory control. As such, where possible, studies utilizing the Go/No-go task are reviewed, otherwise, studies using other measures of inhibition are considered. One study used both subjective and objective measures of impulsivity in a within subject design to examine the effects of three different states of deprivation (non-deprivation, five-hour, and 17-hr deprivation; Harrison, Coppola, & McKee, 2009). Findings revealed that at five hours of deprivation, only the Cued Go/No-go task revealed performance decrements, while at the 17-hour deprivation period, performance deterioration was exhibited on both the Go/No-go and Connor's CPT. As alluded to above, the Connor's CPT is another task commonly used to measure impulsivity, largely by commission errors.

A study evaluated the effects of 12-hr deprivation using an antisaccade task to assess response inhibition in smokers and found that abstinence-induced declines in response inhibition improved with smoking resumption at a three month follow-up, but no improvements using the CPT was found (Dawkins, Powell, Pickering, Powell, & West,

2009). This study provides insight on the recovery of task-specific withdrawal symptoms across three months. Likewise, smokers during overnight abstinence exhibited impairments in response inhibition, as assessed with an occulomotor task (Powell, Dawkins, & Davis, 2002). Further, using a different task of impulsivity, smokers exhibited increased levels of delayed discounting during abstinence (minimum of 13 hours) relative to when they were smoking as usual (Field, Santarcangelo, Sumnall, Goudie, & Cole, 2006). Overall, evidence suggests that among neurocognitive domains, impulsivity (including sustained attention and working memory) is the most consistently influenced during withdrawal (Ashare et al., 2013).

Impulsivity and Smoking Cessation Outcomes

This section provides an overview of studies evaluating impulsivity and smoking cessation outcomes. A section on withdrawal-induced impulsivity difficulties as it relates to smoking cessation outcomes will follow thereafter.

In a retrospective correlational study of a community sample, general executive dysfunction, and specific behavioral disinhibition, predicted unsuccessful smoking cessation that was independent of poor general cognitive function (Brega, Grigsby, Kooken, Hamman, & Baxter, 2008). A few studies examined adolescent smokers and adults with schizophrenia. Under usual smoking conditions, adolescents were administered both subjective and objective measures of impulsivity (Krishnan-Sarin et al., 2007). Findings revealed that while there were no significant differences between abstainers and relapsers on self-reported measures of impulsivity (post-treatment), relapsers performed worse on the objective measures of impulsivity.

In another smoking cessation treatment study, adults with schizophrenia who exhibited worse baseline neurocognitive deficits were less likely to successfully quit (Dolan et al., 2004). This pattern was not due to depression or antipsychotic medications and indicated a medium to large effect (Dolan et al., 2004). Of interest, the healthy controls in the Dolan et al. study did not exhibit the same patterns. That is, neurocognitive deficits did not predict outcomes in the healthy controls. Generally, the control subjects performed better than the schizophrenia subjects; it may be the case that the tasks that had acceptable sample sizes were not sensitive to detect subtle neurocognitive deficits.

Similarly, in a prospective double-blind placebo controlled study of habitual smokers willing to make a quit attempt, subsequent relapsers exhibited greater nicotine induced improvements in response inhibition prior to the quit attempt (Powell, Pickering, Dawkins, West, & Powell, 2004).

In another smoking cessation study, trait impulsivity predicted faster relapse, independent of other known relapse predictors including affect (positive and negative), craving, nicotine dependence and age (Doran, Spring, McChargue, Pergadia, & Richmond, 2004). Similarly, in a study of a heavy smoking lower socioeconomic status smokers, baseline levels of impulsive decision-making and self-reported cognitive impulsivity predicted relapse, even after undergoing evidence-supported smoking cessation treatment (Sheffer et al., 2012). In this study, although the Go/No-go task was utilized, it was not a significant predictor of smoking outcomes. In a study of non-treatment seeking smokers, self-reported trait impulsivity did not predict relapse in a smoking cessation attempt (Powell, Dawkins, West, Powell, & Pickering, 2010).

To summarize, there are some inconsistencies in the literature regarding baseline levels of impulsivity as a predictor of smoking outcomes. Insufficient power to detect significant findings or limited variability in the types of assessments may contribute to some of this discrepancy.

Abstinence-induced Neurocognitive Declines and Smoking Cessation Outcomes

This section will review studies that investigated the role of abstinence-induced attention problems and impulsivity in predicting smoking cessation outcomes. Understanding the role of abstinence-induced neurocognitive declines in smoking cessation outcomes is important given the clinical implications. Understanding and identifying high-risk populations may provide valuable insight toward developing more effective cessation interventions, when they are most needed. That is, identifying who might be most in need, what types of interventions are most beneficial, and when is the critical time to deploy these interventions to initiate and/or maintain smoking cessation may be worthwhile.

Abstinence-induced Attention Problems and Impulsivity Predict Smoking Relapse

In a smoking cessation treatment study, self-reported inattention and impulsivity during the first week of a quit attempt predicted relapse eight weeks later when subjects were taking nicotine replacement therapy (NRT; Rukstalis, Jepson, Patterson, & Lerman, 2005). This study suggests that the first week after a quit attempt may be a critical time period for future effective interventions.

One study mimicked a cessation attempt and found that abstinence-induced working memory deficits predicted shorter time to relapse in self-quitters, however sustained attention, as assessed with a CPT task, did not; this study controlled for

baseline task abilities (Patterson et al., 2010). These positive findings were exhibited for the most cognitively demanding trials of the working memory task; it may be the case that the CPT variant used for this study was not sensitive enough to detect differences. Another prospective study examined non-treatment seeking smokers trying to quit smoking. Using three objective measures of impulsivity assessed during 24 hrs. of abstinence, response inhibition and motor impulsivity predicted relapse at one-week post quit while motor impulsivity predicted relapse at 1- and 3- months post quit (Powell et al., 2010). Using a delay discounting task as a measure of impulsivity, greater dysfunction during a three-hour deprivation period was associated with increased smoking (Dallery & Raiff, 2007).

There are few studies investigating abstinence-induced declines in sustained attention and smoking outcomes, and to the author's knowledge, none that utilized the RVIP task (with the exception of Kang, 2013, described later).

ATTENTIONAL BIAS AND CRAVING

The next section focuses on attentional bias which can be defined as the tendency to automatically attend to drug-related cues and to maintain attention on those cues (Field & Cox, 2008).

Attentional Bias

Attentional bias is an automatic psychological process that is thought to increase the risk of relapse if controlled processes do not prevent this from occurring (Wiers et al., 2013). Other automatic processes include "approach bias" (the tendency to automatically approach drug-related cues) and stimulus-response "habits" (Wiers et al., 2013). However, this manuscript will focus only on attentional bias.

Attentional bias is a measure of implicit processing (Field & Cox, 2008; Stacy & Wiers, 2010) and is used to assess the hyper-salience of drug cues (Goldstein & Volkow, 2002). It is observed in individuals with alcohol dependence (Loeber et al., 2009; Noel et al., 2007) as well as non-dependent heavy drinkers (Townshend & Duka, 2001), smokers (Evans, Craig, Oliver, & Drobes, 2011; Leventhal et al., 2008; Waters, Shiffman, Bradley, & Mogg, 2003), users of opiate (including heroin; Constantinou et al., 2010; Marissen et al., 2006), methamphetamine (Hester, Lee, Pennay, Nielsen, & Ferris, 2010), cocaine (Liu et al., 2011), as well as polysubstance users (Noel et al., 2005). Additionally, research findings suggest this phenomenon is not attributable to confounds such as a general slowing of response times (Hester, Dixon, & Garavan, 2006). Furthermore, heavier drug use or dependence is associated with stronger attentional bias (Stacy & Wiers, 2010). Importantly, attentional bias has been found to strengthen as the duration of abstinence increases (Cox, Hogan, Kristian, & Race, 2002) and to predict poor addiction outcomes such as relapse (Cox et al., 2002; Hester et al., 2010). However, one study found that attentional bias was not necessary for drug seeking behavior (Hogarth, Dickinson, Janowski, Nikitina, & Duka, 2008). The authors proposed that had their measurement of drug seeking behavior not been at ceiling levels, they may have been able to detect an effect of attentional bias on drug use. Attentional bias has also been shown to strengthen the appetitive effect of drug cues through expectancies, thereby increasing craving and thus leading to substance use (Field & Cox, 2008).

Attentional bias can be assessed using a variety of reaction time tasks and eye movements. In the current study, the modified Smoking Stroop task was employed.

Stroop Task

The traditional Stroop assessment is a reaction time task in which words are written in color and the subject is to name the color of the words (Stroop, 1935). This task requires that the subject ignore the meaning of the words and instead focus on the color in which the words are written. Trials include neutral items (e.g., YYY written in blue), and/or distractor items (e.g., BLUE written in red). This interference manifests as longer reaction times and is called the Stroop effect. It takes longer to name the color of the word when it is written in an inconsistent color (e.g., BLUE written in red) than it is to name the color when it is consistent with the word (e.g., BLUE written in blue).

A modified emotional Stroop task can be used to assess attentional bias to salient drug cues and has been shown to predict substance misuse outcomes (e.g., Cox et al., 2002; Hester et al., 2010). In the addiction Stroop task, the trials include neutral words (e.g., desk) and drug cues (e.g., ashtray). The longer latency to name the colors of drug words (vs. neutral words) suggests that attention has been focused on the drug cues thereby slowing responses on the color-naming task. As such, the interference captured by the addiction Stroop is an index of attentional bias to drug cues. Detailed information about the smoking Stroop that was assessed in the field setting is provided in the Measures section.

Attentional Bias and Cigarette Smoking

Attentional bias has been examined in the smoking literature. Using an emotional variant of the Stroop task, attentional bias increased in light to moderate smokers during a 24-hr withdrawal period (Waters & Feyerabend, 2000). Furthermore, the authors found that the greater the attentional bias, the sooner smokers smoked their first cigarette of the

day. Similarly, using the modified emotional Stroop, this time in heavy treatment seeking smokers, attentional bias toward smoking cues was found during acute abstinence (on quit day) and predicted smoking outcomes (Waters, Shiffman, Sayette et al., 2003). Specifically, the smokers with greater attentional bias were at an increased likelihood of lapsing faster than their counterparts who exhibited less attentional bias to smoking cues. Furthermore, attentional bias to smoking after overnight abstinence was associated with smoking relapse (Powell et al., 2010).

Attentional bias has also been shown in non-deprived smokers (Littel & Franken, 2011) and heavy smokers using the visual probe task, although it did not predict smoking outcomes in one study (Waters, Shiffman, Bradley et al., 2003). In a smoking cessation trial, attentional bias to smoking cues (assessed with the emotional Stroop) when smoking ad libitum was associated with post quit smoking outcomes (Janes et al., 2010). That is, smokers who subsequently relapsed exhibited higher pre-quit attentional bias relative to smokers who did not relapse.

Overall, it appears that attentional bias is an important construct to consider in substance misuse.

Craving

Craving, or the urge to smoke, is a widespread experience for smokers as well as successful quitters, even years after cessation (e.g., Hughes, 2010). Craving is often reported as a distressing experience (Shadel, Niaura, Brown, Hutchison, & Abrams, 2001). Further, craving is experienced soon after abstinence (post-quit craving) (Tiffany, Cox, & Elash, 2000) and increases over the first six hours (Brown et al., 2013) with the greatest levels of craving occurring within two days of quitting (Wray, Gass, & Tiffany,

2013). Moreover, nicotine administration reduces craving (Carter et al., 2008; Tiffany et al., 2000; Toll, Schepis, O'Malley, McKee, & Krishnan-Sarin, 2007; West & Shiffman, 2001). Indeed, increased craving often precedes smoking (pre-quit craving; Carter et al., 2008; Dunbar, Scharf, Kirchner, & Shiffman, 2010), suggesting its role in the maintenance of smoking (Bickel, Yi, Landes, Hill, & Baxter, 2011; Ferguson & Shiffman, 2009; Shiffman, West, & Gilbert, 2004) and as a predictor of relapse or barrier to cessation efforts (Allen, Bade, Hatsukami, & Center, 2008; Ferguson & Shiffman, 2009; Shiffman et al., 2004). A recent systematic review summarized that post-quit craving is a stronger predictor of cessation outcomes than pre-quit craving (Wray et al., 2013). In light of this, the anticipation of craving is associated with actually experiencing it and both are linked to negative past quit experiences, such as the inability to quit smoking (Erblich & Montgomery, 2012).

It is important to recognize that although craving is associated with smoking, this association is not large in magnitude (Wray et al., 2013). In particular, there are many coping strategies that can be employed to reduce the risk of smoking even under high craving. Given that the enactment of coping strategies likely use executive processes (e.g., planning, sustained attention and inhibitory control), it is hypothesized that craving is associated with smoking more strongly in individuals with poorer executive processes.

Questionnaire for Smoking Urges

Craving can be assessed using self-report measures such as the Questionnaire of Smoking Urges (QSU). The abbreviated version, QSU-Brief, is a 10-item questionnaire, yielding two factor scores: intention to smoke and relief from negative feelings with the urgency to smoke (Cox, Tiffany, & Christen, 2001; Toll, Katulak, & McKee, 2006). It is

sensitive to the effects of smoking cue exposures and abstinence (Morgan, Davies, & Willner, 1999). Detailed information about the QSU is provided in the Measures section.

ELABORATION OF THE DUAL PROCESS MODEL

This section will be an elaboration of the dual process model that was introduced earlier. Although there is evidence that neurocognitive decrements and attentional bias are independently associated with smoking initiation, maintenance, and relapse, it is likely that these two types of processes interact to impact substance misuse. The dual process model of addiction is one such model to conceptualize the interrelationship between these implicit and explicit processes. Unless otherwise stated, implicit processing will refer to attentional bias whereas explicit processing will refer to executive function and cognitive control.

To review, the dual process model asserts that prepotent salient drug cues precipitate drug use while executive control processes work to inhibit this automatic responding (see pathway 2 in Figure 1). A more extensive and detailed description of this conceptualization will follow. This will be followed by a review of the empirical literature on the dual process model as it relates generally to substance misuse then specifically to smoking.

Theoretical Frameworks Underlying Dual Process Models

A number of dual process models have been proposed. As noted earlier, Norman and Shallice's model of action (1996) described two separate types of process that operate to determine behavior: automatic and willed control (Shallice & Burgess, 1996). To review, the automatic system is guided by sensorimotor data from the environment as well as by internal drives. It functions without our conscious awareness and encompasses

habits and routines. Alternatively, the willed control system operates for more complex tasks that require explicit processing. It operates via the supervisory activating system (SAS), which coordinates and monitors schemas to determine behavior.

Dual process theories have also been applied in research on judgment and decision making (Evans, 2003; Kahneman, 2011). Some theories have referred to automatic/implicit processes as type 1 processes (or system 1 processing) and to controlled/explicit processes as type 2 processes (or system 2 processing). The unconscious, implicit, automatic processing associated with system 1 is rapid and parallel whereas the conscious, explicit, controlled processing associated with system 2 is slow and serial.

While not all authors use the term "dual process," an evaluation of their description of addiction is essentially in line with it. Tiffany applied this idea to the addictions and proposed that automatic processes drive drug use and that controlled processes either inhibit or support automatic schemas via urges (Tiffany, 1990; Tiffany & Conklin, 2000). Bechara describes separate "reflective" and "impulsive" systems and advocates that an imbalance can lead to addiction (Bechara, 2005). The prefrontal cortex plays a large role in the reflective system (i.e., heavily constituting executive functioning) while the impulsive system is largely mediated by neuronal circuitry involving the amygdala (i.e., emotional processing). He further proposes that a hyperactive impulsive system (much akin to attentional bias) can overwhelm the reflective system.

Dual Process Applied to Substance Use

A number of studies have examined the idea that the effect of implicit processing on drug use is moderated by executive function (pathway 2 in Figure 1). Specifically, the

idea is that when executive function is intact, implicit processing does not predict drug use, however when executive function is compromised, implicit processing is not inhibited by explicit processing and therefore predicts drug use (e.g., Stacy & Wiers, 2010). One study tested this hypothesis in adolescents. Results revealed that adolescents with intact executive control as opposed to impaired abilities (including impatience and impulsivity) were better able to resist using substances (Wills, Pokhrel, Morehouse, & Fenster, 2011). Executive function capacity moderated the relationship between implicit word associations and smoking and alcohol use, such that adolescents with smaller working memory capabilities exhibited stronger implicit processes that predicted drug use while the same was not true for individuals with larger working memory capacities. In smokers who also drink, working memory moderated the relationship between implicit associations and drug use. Specifically, for individuals with low working memory capacities, drug-related associations in memory predicted drug use more strongly than for individuals with high working memory (Grenard et al., 2008).

Furthermore, studies of adolescents, who have underdeveloped executive functioning abilities, could provide an additional perspective. A review paper incorporated the relationship between implicit and explicit processes in contributing to alcohol misuse in adolescents and summarized the findings by proposing that addiction is due to the imbalance of hyper-salient drug cues and poor executive control, specifying that executive function work to reduce drug use (Wiers et al., 2007).

One study of heavy alcohol drinkers found that when response inhibition was poor, alcohol intake increased, quite possibly due to inability to inhibit prepotent drug cues (Houben, Nederkoorn, Wiers, & Jansen, 2011). When the subjects were not trained

to inhibit their response to alcohol cues, there was a trend toward significance of positive implicit perceptions of alcohol and a corresponding increase in alcohol intake. However, when the subjects were trained to improve response inhibition, this resulted in less alcohol intake and increased negative perceptions of alcohol.

Studies have also examined the effect of executive function on implicit processes (not drug use; pathway 3 in Figure 1) by manipulating working memory as an independent variable and observing the effect on attentional bias. Evans et al. (2011) reported that as difficulty on a working memory task increased (thus taxing the cognitive load), accuracy in detecting smoking words decreased, suggesting that working memory capacity may be required for the effective control of attentional bias. In a similar vein, a review paper proposed that individuals with poor executive function abilities would have greater attentional bias (Field & Cox, 2008). Similarly, another review yielded evidence suggesting that impaired executive functions, specifically impulse control, increased the risk of substance use, suggesting that an unregulated limbic system takes over (Crews & Boettiger, 2009). We are not aware of any studies that have manipulated attentional bias as an independent variable and observed the effect on executive function.

Finally, brain imaging techniques have been used to study implicit and explicit processes (e.g., Littel & Franken, 2011; Nestor et al., 2011). A smoking cessation study found that smokers deemed high-risk of relapse exhibited poor top down control over their emotional response to smoking cues (as assessed with neuroimaging techniques), implying dual processing operation (Janes et al., 2010). An fMRI study comparing smokers and ex-smokers revealed that there was an increase in brain activity in the prefrontal cortex in ex-smokers when compared to current smokers. Current smokers also

exhibited increased subcortical activity, consistent with an exaggerated attentional bias (Nestor et al., 2011).

Summary of Dual Process Applied to Substance Use

In sum, the dual process model has generated an interesting prediction that has been tested in the addictions literature. The main idea is that the impact of automatic processes on drug use should be weaker in individuals with stronger executive function. Few studies have tested this idea in smoking using sustained attention and/or impulsivity measures. In the current study we tested predictions derived from the dual process model to smoking behavior.

Assessments in the Field

The vast majority of researchers have assessed cognitive performance in a laboratory setting. The laboratory remains the "gold-standard" setting for cognitive assessment. As noted in Table 2, in the laboratory performance can be monitored under controlled conditions and experimental manipulations can be conducted using standardized conditions. In addition, the conditions under which an assessment takes place can be described in detail and replicated by other researchers.

These strengths notwithstanding, there is always the concern that performance in the laboratory may not accurately capture cognitive performance in naturalistic settings. In addition, for practical reasons, it is difficult to collect detailed data on cognitive performance over time in laboratory studies because subjects would need to attend multiple laboratory sessions.

Ecological Momentary Assessment

Ecological momentary assessment (EMA) is a complimentary methodology that occurs in near real-time ("momentary") and in the real-world ("ecological"). This approach has been utilized to capture cognitive, emotional, and behavioral data in various fields of research, including clinical and cognitive psychology (e.g., Newman, Szkodny, Llera, & Przeworski, 2011; Waters, Shiffman, Bradley et al., 2003; see Table 2). Data collection can employ diverse sampling procedures such as random- or event-based (Shiffman, Stone, & Hufford, 2008). Mobile devices, such as cell phones, PDAs, and smartphones, are subsequently used to deliver the EMA paradigm.

Advantages of an EMA paradigm include the ability to collect data close in time to the variable or event of interest, collection of detailed dynamic information, the ability for repeated assessments, the capacity to bypass biases inherent in retrospective recall (for subjective measures), the potential to reduce random error variability (by way of multiple assessments), and improved external validity (Moskowitz & Young, 2006; Shiffman et al., 2008). Many studies have shown that it is possible to administer cognitive assessments using EMA (e.g., Shiffman et al., 1995, Waters & Li, 2008, Waters et al., 2012, Waters et al., 2013). In the current study we assessed cognitive performance in the field.

Use of Mobile Technology

As noted above, EMA studies typically use mobile devices such as smartphones. With the expansion of the information and digital age, there is a parallel burgeoning of using technological tools in health care, including in smoking research and cessation interventions. Examples include recruitment for internet-based smoking cessation

programs (e.g., Heffner, Wyszynski, Comstock, Mercer, & Bricker, 2013) as well as the delivery and remote biochemical verification of self-reported abstinence (e.g., Dallery & Glenn, 2005; Etter, 2006; Stoops et al., 2009), and SMS text messaging (e.g., Free et al., 2011; Sutton et al., 2013).

In light of the costs associated with technology and its use, there may be concerns as to whether the use of mobile devices in EMA studies influences recruitment and subsequent generalizability of study findings. For example, despite the growth and development of technology one may wonder whether there are differences in access due to variables such as age, gender, and educational level (e.g., Jensen, King, Davis, & Guntzviller, 2010) and race (Lopez, Green, Tan-McGrory, King, & Betancourt, 2011). There may also be segments of the population who are particularly disadvantaged with respect technology use (e.g., chronic homeless individuals).

However, research has found that technological access and use is generally widespread (Brodie et al., 2000; Kennedy, Smith, Wells, & Wellman, 2008), even in low SES populations (Brodie et al., 2000). This gap continues to narrow (see Brodie et al., 2000; Lopez et al., 2011) such that low SES populations manage to have high rates of technology use, including the use of the internet and computers (Brodie et al., 2000). Studies have also found that lower income groups are able to navigate and utilize technology-based health services (e.g., Gustafson et al., 2011; Shaw et al., 2008). Furthermore, studies have reported that individuals expressed ease of its use despite having some difficulties with the device (Zarghom, Di Fonzo, & Leung, 2013). Even low SES individuals with limited technological skill either owned or had access to mobile

phones and computers, although they did not appear to regularly use them (Jensen et al., 2010).

Taken as a whole, while some disparities may exist for lower income groups with regards to technological use, such disparities are diminishing over time and many individuals nevertheless are able to acquire mobile devices, and when they do, they are able to navigate them successfully.

Remote Biochemical Verification

In the current study, we assessed not only cognitive performance in the field, but we also biochemically verified smoking status using expired air carbon monoxide (CO) (described in more detail later). There are numerous advantages of remote biochemical verification of self-reported smoking status. In a research setting, physical, financial, and time burden is alleviated for researchers and subjects (Jacobsen, Sprenger, Andersson, & Krogstad, 2003). These can all translate to lowered costs associated with study participation. Accessibility is also increased for individuals with limited transportation, who live in remote areas, or who simply have busy schedules (c.f., Dallery & Raiff, 2011; Gustafson et al., 2011; McDaniel & Stratton, 2006). Altogether, reducing burdens on the subjects could not only increase study enrollment, but also decrease study dropout rates (e.g., McDaniel & Stratton, 2006). Although there are potential disadvantages to employing this method, such as concerns about confidentiality and security of personal information (e.g., Dallery & Raiff, 2011; McDaniel & Stratton, 2006), procedures could be employed to reduce or counteract these concerns, such as using identification codes, data encryption, and video recordings (e.g., Dallery & Glenn, 2005; Stoops et al., 2009).

To biochemically verify smoking status remotely, smoking studies have utilized strategies such as mail-in saliva samples (e.g., Etter, Le Houezec, & Perneger, 2003) and breath CO recordings that are supplemented with video recording email transmissions (e.g., Dallery & Glenn, 2005; Stoops et al., 2009). However, to the author's knowledge, there are no studies that have yet employed a portable USB-enabled expired air CO monitor, the COmpact™ USB Smokerlyzer® by Bedfont Scientific. The advantage of utilizing this CO monitor over other portable monitors currently used in the field is the USB connection. This feature permits CO recordings to be uploaded directly to a computer as a non-modifiable electronic file that is date and time stamped. Another advantage is the facilitation of easy electronic data transfer, thereby obviating the need to return for a laboratory visit to submit a biochemical sample. Despite these advantages, no studies have yet tested this novel device's feasibility and utility in the field. The current study assessed the feasibility of using this device in the field.

SMOKING CESSATION: IMPORTANCE OF FIRST WEEK

A large proportion of individuals who are motivated to quit and who seek treatment for smoking cessation relapse within one week of quitting (Powell et al., 2004; Hughes, Keely, & Naud, 2004; Garvey, Bliss, Hitchcock, Heinold, & Rosner, 1992; Hughes et al., 1992). Furthermore, the figures are worse for self-quitters (quitters not seeking cessation treatment) and individuals contemplating cessation (relative to committed quitters), with the vast majority of uncommitted quitters relapsing within one week of a quit attempt (Hughes et al., 2004). Specifically, estimates for relapse rates during the first week of a cessation attempt range from 50% (Garvey et al., 1992) to

approximately 80% (Hughes et al., 1992). Furthermore, lapses during week one or two of a quit attempt predicted future relapse (Kenford et al., 1994).

Moreover, withdrawal symptoms are at their highest early in a quit attempt and they subsequently decrease over time (Alessi, Badger, & Higgins, 2004). One study found that the ability to remain abstinent on the first day of a quit attempt predicted abstinence at six months (Westman, Behm, Simel, & Rose, 1997). Withdrawal symptoms and craving during the first week of abstinence also predicted smoking outcomes (Piper et al., 2008). Moreover, there is evidence that intact executive control predicts successful smoking cessation, at least in a community sample (Brega et al., 2008).

These findings highlight the importance of assessing psychological processes in the first week of smoking cessation. For this reason, the current study will examine cognitive processes during the first week of an attempt to quit or cut down smoking.

CHAPTER 2: Introduction to the Current Study

PRELIMINARY STUDY

Kang (2013) investigated the association between abstinence-induced attention difficulties and subsequent smoking in treatment-seeking smokers attempting to quit (*N*=193). Participants were assessed over a six-week period, from two weeks prior to quit day through four weeks post quit. On one session before quit day, participants smoked as usual ("non-abstinent session") and on another pre-quit session participants were instructed to remain abstinent for at least 12 hours ("abstinent session"). Participants completed the RVIP task (CANTAB® version; see Figure 3) at both sessions. Abstinence from smoking was assessed for four weeks after quit day, and the primary outcome variable was point prevalence smoking status at the end of the study (4 weeks post-quit).

As expected, and consistent with Leventhal et al. (2010), abstinence-induced decrements in performance were obtained for number of hits and mean reaction times on hits. Number of false alarms was not affected by abstinence. Individuals who subsequently relapsed (defined by smoking during the final week of the study) exhibited abstinence-induced declines in performance (at the pre-quit sessions). Individuals who were abstinent during the final week of the study did not exhibit abstinence-induced declines in performance. When standardizing the predictor variables, and using hierarchical logistic regression, abstinence-induced decrements in RVIP RT (OR = 1.55; 95% confidence interval [CI] = 1.03-2.34; $p < .05$) predicted subsequent relapse. As abstinence-induced RT deteriorated by one standard deviation, there was a 55% increase in the probability of relapse four weeks later, respectively. Overall, abstinence-induced

attention decrements in attention assessed using the RVIP were associated with worse cessation outcomes. This study therefore suggests that attention difficulties may interfere with the ability to quit smoking.

RATIONALE FOR CURRENT STUDY

Despite the best available cessation interventions and treatments, the number of smokers who express interest in quitting smoking far exceeds the number of successful quitters. A better understanding of the psychological processes underlying smoking relapse to smoking is required to develop more effective interventions. As described in Chapter 1 and above, recent research has examined the cognitive processes underlying smoking relapse. The dual process model suggests that both executive processes (e.g., sustained attention and impulsivity) and automatic processes (e.g., attentional bias) are involved. While the dual process model has been applied in the addictions literature, few studies tested this framework in smoking addiction. Sustained attention abilities may be both a predictor of smoking outcomes as well as a moderator of the impact of automatic processes on smoking outcomes.

Interestingly, most smoking cessation studies, such as those that examine the effect of pharmacotherapies and smoking cessation counseling, are targeted at smokers who are preparing to quit and who are seeking treatment for smoking cessation. However, it is also known that most smokers quit on own without any pharmacacological assistance (Chapman et al., 2010). The current dissertation examined non-treatment-seeking smokers who were willing to make an attempt to cut down or quit smoking for one week. Therefore the sample should be broadly representative of non-treatment seeking smokers who are interested in quitting.

Accordingly, the primary objective of this dissertation was to further examine the role of RVIP performance, as both a predictor variable and as a moderator variable, in non-treatment seeking smokers who attempted to cut down or quit for at least one week. The dissertation study examined RVIP performance assessed in the field using EMA over the course of two weeks. We assessed the feasibility of assessing RVIP performance in the field, as well as the role of the RVIP as both a predictor and moderator variable. The primary independent variable was RVIP performance (assessed both during Week 1 and on each morning during Week 2) and the primary dependent variable was smoking behavior (number of cigarettes smoked daily and CO levels) during an attempt to cut down or quit smoking (during Week 2 of the study).

SPECIFIC STUDY AIMS AND HYPOTHESES

Specific Aim 1: To examine the feasibility, reliability, and validity of assessing RVIP performance in an EMA paradigm.

Hypothesis 1.1: It will be feasible to assess RVIP performance on a PDA in the field. Feasibility will be determined by percent of completed and usable: RAs, morning RVIP data in the field, breath CO readings, and video recordings. Qualitative data on subjects' experience (ease of use, feasibility) of study procedures was also collected, specifically the field tasks on PDA, USB CO monitor, video recording, and email transmission of CO readings.

Internal reliability of RVIP performance was assessed using split-half correlation coefficients. In a large sample (N=203) Leventhal et al. (2010) reported good internal reliability (using the Spearman Brown formula, all r's >.8) for RVIP Hits and RT in a 10-minute laboratory RVIP task. The current RVIP task was briefer (4-mins) and was

administered in the field; therefore internal reliability above 0.6 was considered acceptable.

Hypothesis 1.2: Acute smoking will improve RVIP performance in overnight-deprived smokers assessed in the field. Given that acute smoking improves RVIP performance in overnight-deprived smokers in the lab, this is a test of the validity of the study measures in the field.

Specific Aim 2: To examine whether RVIP performance assessed in the field is associated with smoking behavior in smokers trying to cut down or quit (i.e., to test RVIP performance in the field as a predictor variable). Smokers with better RVIP performance during abstinence will be more successful in cutting down or quitting smoking.

Hypothesis 2.1: Better mean RVIP performance during abstinence (Week 1) will be associated with a reduced smoking behavior during a cut down period or quit attempt (Week 2).

Hypothesis 2.2: Better mean RVIP performance after overnight abstinence (morning pre-smoking) in Week 2 will be associated with reduced smoking behavior that day (i.e., better RVIP performance will be associated with less smoking on the same day).

Specific Aim 3: To examine whether RVIP performance assessed in the field moderates the relationship between craving/attentional bias and smoking behavior (i.e., to test RVIP performance in the field as a moderator variable). We expected better RVIP performance to weaken the relationship between craving/attentional bias and smoking behavior.

Hypothesis 3.1: Mean RVIP performance during abstinence (Week 1) moderates the association between morning craving and daily smoking behavior during Week 2 (i.e.,

the association between craving and smoking will be weaker in individuals with better RVIP performance).

Hypothesis 3.2: Mean RVIP performance during abstinence (Week 1) moderates the association between morning attentional bias and daily smoking behavior during Week 2 (i.e., the association between attentional bias and smoking will be weaker in individuals with better RVIP performance).

In exploratory analyses, we also evaluated the association between intelligence and neurocognitive function (as assessed with the Shipley and the NIH Toolbox, Cognition Battery) and Week 2 smoking outcomes (daily smoking rate and evening CO levels). We expected smokers with higher IQ (as assessed by the Shipley) to have more success in cutting down/quitting. We expected smokers with better neurocognitive performance (as assessed by the NIH Toolbox, Cognition Battery) to have more success in cutting down/quitting. We also examined the association between performance on the Go/No-go task and smoking outcomes. Finally, for comparisons purposes, we also examined whether measures of smoking and tobacco dependence were associated with smoking outcomes.

CHAPTER 3: Methods

PARTICIPANTS

Twenty-two non-treatment seeking smokers enrolled in the study and completed Visit 1 (Table 5; Figure 12). Subjects were recruited via media channels including newspaper advertisements, Craigslist, and from an internal laboratory study registry of previous subjects who expressed interest in participating in future studies.

Compensation procedures are shown in Table 4. Briefly, non-federal civilians received compensation up to a maximum of $201 for study participation. Per current laws, federal employees were not compensated for study participation.

All study procedures were approved by the Institutional Review Board of the Uniformed Services University of the Health Sciences (USUHS).

INCLUSION AND EXCLUSION CRITERIA

Prospective subjects were screened via telephone. If they met initial criteria, they were invited to an in-person laboratory session (Visit 1), where they underwent additional screening procedures that were not feasible over the telephone.

Study sample selection was based on the following inclusion and exclusion criteria. Inclusion criteria were: 1) between the ages of 18 to 65; 2) current regular smoker (minimum of ten cigarettes daily for the past year); 3) interest in cutting down or quitting; 4) access to a laptop or computer and internet (if not, we loaned lab-owned laptops when available); 5) functioning video recording device (otherwise, we loaned video recording devices); 6) legitimate home address and functioning telephone number; 7) able to speak, read, and write English at an 8th grade literacy level. Exclusion criteria included: 1) regular use of tobacco products other than cigarettes, including smokeless

tobacco, cigars, pipes, and nicotine replacement products, and/or varenicline or bupropion; 2) expired air carbon monoxide (CO) reading less than 10 parts per million to ensure regular cigarette use (SRNT Subcommittee on Biochemical Verification, 2002); 3) pregnant or breast feeding; 4) unstabilized neurological disease (including stroke, epilepsy, and Huntington's disease); 5) current post-concussive symptoms or past concussion with loss of consciousness greater than 30 mins; 6) past DSM-IV and current symptoms of substance use disorder, including alcohol; 7) serious mental illness (particularly, depression with active suicidal ideation).

STUDY PROCEDURES

Table 4 and Figure 4 provide an overview of the study procedures. To facilitate adherence to study procedures, whenever possible, subjects received e-mail reminders and/or phone calls with pertinent study instructions.

Telephone Screening

Preliminary eligibility screening occurred over the telephone by the research staff. Eligible and interested subjects were subsequently scheduled for the first laboratory visit (Visit 1).

Laboratory Visit 1

During Visit 1, further screening that was not possible over the telephone was conducted. A detailed description of the study was provided, any questions answered, and signed written informed consent was obtained (see Appendix A). If participants declined to participate in the study, they were compensated for the visit and received smoking cessation resources if they were interested. If they signed the informed consent,

laboratory visit one procedures proceeded. Subjects' saliva and breath samples were collected; the latter was used to determine eligibility. An expired air CO level less than 10 ppm rendered them ineligible for the study (SRNT Subcommittee on Biochemical Verification, 2002).

Week one experimental condition order (order of completion of Acute Nicotine and Acute Abstinence conditions) was determined during Visit 1. The week one experimental condition cross-over date (i.e., the date the subject switched experimental condition procedures) was also established. The experimental condition order was counterbalanced and stratified by sex to reduce order effects and ensure approximately equal numbers of males and females for each condition. The participants who signed the informed consent were assigned to the experimental conditions as follows: six females and six males were assigned to complete the Acute Nicotine condition first, while seven females and five males were assigned to complete the Acute Abstinence first.

Subjects completed a demographic questionnaire and responded to a brief medical and psychiatric interview which included questions about current psychiatric conditions, history of neurological conditions, past and current alcohol use disorders, ADHD diagnosis (history and current), psychotropic and stimulant medication use, caffeine use, and vision problems (refer to Appendix B). Subjects also completed a smoking history questionnaire, the Fagerstrom Test for Nicotine Dependence (FTND), Wisconsin Smoking Withdrawal Scale (WSWS), Questionnaire for Smoking Urges-Brief (QSU-B), and the Smoking Abstinence Self-Efficacy Questionnaire (SASEQ; refer to Appendix B). The SASEQ assesses confidence to refrain from smoking under smoke-promoting situations and overall self-efficacy ratings on cutting down as well as quitting. Because

self-efficacy is known to predict future lapse and relapse (e.g., Gwaltney, Metrik, Kahler, & Shiffman, 2009; Shiffman, 2005), pre-quit ratings were obtained during this visit (see Appendix B). Data from the SASEQ are not presented in the dissertation.

At Visit 1, the following cognitive assessments were administered on the PDA: RVIP, smoking Stroop, and the Go/No-go task. The NIH Toolbox-Cognition Battery, and the Shipley IQ were also administered (see Measures section below).

Subjects were then trained to use the PDA and COmpact™USB, which were loaned. Starting on Day 1, and throughout the course of the study, subjects were instructed to record the number of cigarettes smoked nightly on their Smoking Diary (refer to Appendix B for a sample).

Participants left Visit 1 with two PDAs, a "home PDA" and a "field PDA." They were instructed to complete the morning PDA assessments on the home PDA (subject-initiated assessment). They were instructed to leave the home PDA at home and not to carry it around with them. They were instructed to carry the second PDA (the field PDA) around with them and were instructed to complete up to 4 RAs per day on it (see below).

Week 1 Field Procedures

During Week 1, as noted, subjects performed subject-initiated assessments on the home PDA and RAs on the field PDA (see measures section for details on these tasks). Subjects were asked to refrain from ingesting any caffeinated substances (e.g., coffee, tea) before the subject-initiated morning assessments on the home PDA. Subjects were instructed to video-record themselves providing the CO measures (see Experimental Conditions section) to provide additional assurance that the intended source provided the CO readings. Mini-tripods were loaned to participants to assist with video recording.

Video recordings of CO readings have been employed in previous studies (e.g., Dallery & Glenn, 2005; Stoops et al., 2009). Subjects were asked to save the videos on their recording device and bring it into the following lab visit (Visit 2) with the appropriate cables to ensure that the date and timestamp were preserved after data transfer.

A COmpact™USB was loaned to each subject. The CO output report was non-modifiable and date and time stamped. The CO output was designed to be emailed directly from the software interface once a reading was obtained. As such, CO output reports were submitted after each reading. Instructions for and demonstrations of the CO and video recordings were reviewed at Visit 1. Additionally, the user-friendly CO software provided real-time written and visual instructions on how to take a CO reading to facilitate the procedures while in the field (see Figure 6).

Experimental Conditions

The experimental conditions applied to days two through seven. In this within-subject study design, the subjects underwent each of the conditions (Acute Nicotine and Acute Abstinence) for three days (per condition). In other words, subjects assigned to the Acute Nicotine condition before the Acute Abstinence condition followed the Acute Nicotine condition procedures for three days (study days 2, 3, and 4) followed by the Acute Abstinence condition procedures during the next three days (study days 5, 6, and 7) and vice versa for the subjects assigned to the Acute Abstinence before the Acute Nicotine condition (see Figure 5).

Acute Nicotine Condition

During this condition, procedures were as follows: 15mins after awakening, subjects: 1) provided a time-stamped CO reading (CO1; to verify overnight abstinence);

2) smoked their first cigarette of the day; 3) waited 5-10 mins before taking another time-stamped CO reading to verify smoking (CO2; see recommendations on obtaining a more accurate CO reading in [Woodman, Wintoniuk, Taylor, & Clarke, 1987]); and 4) completed a subject-initiated assessment on the home PDA (that includes the RVIP task; see Figure 10). The subjects were asked to make a single video recording of these procedures or video recordings of the two CO readings.

Acute Abstinence Condition

After overnight abstinence, procedures were as follows. Fifteen minutes after awakening, subjects: 1) provided a time-stamped CO reading (CO1; to verify overnight abstinence); 2) completed a subject-initiated time-stamped PDA assessment (that includes the RVIP task); 3) completed another time-stamped CO reading (CO2; to minimize systematic differences between experimental conditions); 4) smoked their first cigarette of the day (refer to Figure 5). Again, subjects were asked to make a single video recording of these procedures or two CO reading recordings.

Laboratory Visit 2

During Visit 2, biochemical markers to verify smoking status were collected (saliva sample for the cotinine assay and a CO reading). The Go/No-go task was re-administered during this visit. Week 1 PDA data (subject-initiated assessments and RAs) were downloaded.

The subjects were loaned a home PDA that presented both the RVIP and Stroop tasks. Subsequently, the week two study procedures (cut down/quit attempt) were described and overall self-efficacy to quit ratings were assessed. Regardless of cut down/quit status, subjects were instructed to complete subject-initiated PDA assessments

after overnight abstinence on the home PDA. For instance, even if a subject smoked on Day 9, they were to complete PDA assessments before smoking their first cigarette of the day for Day 10 (see Figure 7).

Participants left Visit 2 with two PDAs, a "home PDA" and a "field PDA." They were instructed to complete the morning PDA assessment on the home PDA (subject-initiated assessment). The home PDA administered both the RVIP and Stroop tasks. As in Week 1, they were instructed to leave the home PDA at home and not to carry it around with them. They were instructed to carry the second PDA (the field PDA) around with them. As with Week 1, they were instructed to complete up to 4 RAs per day on it.

Week 2 Field Procedures

The start of Week 2 (Day 9) served as the onset of the cut-down and/or quit period. As noted above, during Week 2, subjects completed subject-initiated assessments every morning after overnight abstinence, regardless of smoking status (as we anticipated a majority of the sample to smoke during this week [c.f., Hughes et al., 1992]). As in Week 1, subjects were instructed to complete the morning subject-initiated PDA assessments 15 mins after awakening and to refrain from ingesting any caffeinated substances (e.g., coffee, tea) before these assessments. Subjects provided a CO sample after completing the assessment. In contrast to Week 1, during Week 2 only one CO reading was taken each morning. In addition to the daily morning CO recordings, subjects provided CO readings every evening to determine degree of smoking (Figure 7). As in the Week 1 field procedures, subjects video recorded themselves taking CO readings (both morning and evening readings) and delivered the video recordings at Visit

3. The subjects were instructed to transmit the CO report upon its acquisition (twice per day). Four daily RAs continued to prompt the subjects during Week 2.

Laboratory Visit 3

At Visit 3, biochemical samples (expired air and saliva) were collected to verify smoking status. The Go/No-go task was re-administered and overall post-quit self-efficacy re-assessed (given that both pre- and post-quit self-efficacy are important in smoking outcomes [Gwaltney et al., 2009; Shiffman, 2005]). Loaned equipment was collected and PDA data were downloaded from both the home PDA and field PDA.

Subjects then underwent a post-experimental interview on their experience with the study procedures. Specifically, they were questioned on their sense of the ease and feasibility of completing the PDA assessments, use of the COmpact™USB device and software, as well as video recording (see Appendix C for the post-experimental interview questions). Final study compensation was determined and mailed to participants.

LABORATORY MEASURES

Appendix B contains the following self-report questionnaires: Demographics, Smoking History, SASEQ and overall self-efficacy ratings, FTND, WSWS, and QSU-B. Table 4 indicates the visits at which each assessment was administered.

Demographic and Smoking Questionnaires

Subjects answered basic demographic questions such as age, education, and income as well as handedness. They responded to questions about their smoking history, completed the FTND, WSWS, QSU-B, and the SASEQ (Spek et al., 2013). The SASEQ is a brief questionnaire that was adapted to reflect ones' ability to cut-down in addition to

quit smoking. For Visits 2 and 3, an abbreviated unidimensional measure (i.e., overall confidence rating as opposed to different situations) was utilized.

Fagerstrom Test for Nicotine Dependence

The Fagerstrom Test for Nicotine Dependence (FTND) is a 6-item self-report measure employing a 10-point rating scale used to assess nicotine dependence and to quantify dependence severity (see Appendix B; Heatherton et al., 1991).

Questionnaire of Smoking Urges - Brief

The Questionnaire of Smoking Urges - Brief (QSU-Brief) is a multidimensional 10-item self-report measure of craving (Cox et al., 2001; Toll et al., 2006). See Appendix B. The questionnaire yields two factor scores: 1) intention and desire to smoke as well as anticipated pleasure from smoking; 2) expected relief from negative affect and associated withdrawal symptoms along with the urgency to smoke (Cox et al., 2001; Toll et al., 2006). A total score is computed by summing all of the items, which indicates an overall rating of craving. Psychometric properties are strong, demonstrating good internal reliability (Toll et al., 2006) and reliability in different samples and settings (Cox et al., 2001). In the present study, the QSU-B was administered at Visit 1.

Wisconsin Smoking Withdrawal Scale

The Wisconsin Smoking Withdrawal Scale (WSWS; Welsch, Smith, Wetter, Jorenby, Fiore, & Baker, 1999) is a 28-item self-report questionnaire using a 5-point rating scale that assesses nicotine withdrawal symptoms (refer to Appendix B). Higher scores indicate worse withdrawal symptoms. Subscales include Concentration Difficulty and Anger. The instrument has shown strong psychometric properties. It has been

reported to have good reliability and validity, has shown high sensitivity to withdrawal, and has been used to predict cessation outcomes (Welsch, Smith, Wetter, Jorenby, Fiore, & Baker, 1999; West, Ussher, Evans, & Rashid, 2006).

In the current study, the WSWS was administered at Visit 1.

Health History

During Visit 1, general psychiatric history, including alcohol use and misuse (current and history), ADHD diagnosis (past and current), and current use of psychotropic and stimulant medication was assessed (see Appendix B). Current caffeine use was also recorded. Any history and current neurological condition or brain insults were also assessed.

Neuropsychological Battery

Shipley Institute in Living Scale

Subjects were also administered the Shipley Institute in Living Scale (Shipley; Shipley, 1940) to estimate intellectual functioning. The Shipley Institute in Living Scale (SILS) is a 60-item test that measures intellectual ability and cognitive impairment (Shipley, 1940). It takes approximately 15-20 minutes to administer. Two subtests constitute the SILS: Vocabulary and Abstract Thinking. In the Vocabulary subtest, subjects select a word (out of four options) that is most similar to the target word. In the Abstract subtest, subjects fill in the blank to complete a pattern. A composite score yields an estimate of IQ. Psychometric properties are sound. Reliability coefficients above .80 demonstrate good reliability (Shipley, 1940). Predictive validity with other well-established measures of intelligence is also good (Schear & Harrison, 1988).

NIH Toolbox, Cognition Battery

The Cognition battery of the NIH Toolbox was also administered. Participants completed this battery on the web-based Assessment Center. Data were securely collected over the internet using this platform. The NIH Toolbox, Cognition battery is a standardized set of brief computerized neuropsychological assessments, with a total approximate 30-min duration. The subtests ranged in duration from three to ten minutes. The battery was developed to create a standard set of assessments, to supplement other extensive test measures that can be used across studies to facilitate communication and interpretation (Weintraub et al., 2013). The Cognition battery has been validated and normed on individuals aged 3-85, and normative data are available. Some of the subtests employ computer adaptive testing (CAT), a method of test administration wherein item execution is determined based on performance level. As such, the subtest is tailored to each individual. This method has been shown to reduce test duration while preserving precision (see http://www.nihtoolbox.org/Resources/Pages/Lists,descriptions-of-measures.aspx).

The six neurocognitive domains: attention, working memory, episodic memory, language, processing speed, and EF were selected due to their importance in functional outcomes (Weintraub et al., 2013). While all of the subtests are computerized, some are self-administered (S) and the remaining are proctor-administered (P). The seven subtests with administration type, domains, and outcome measures in parentheses are as follows: 1) Flanker Inhibitory Control and Attention Test (S; attention and EF; Hits and RT); 2) Dimensional Change Card Sort (S; EF; Hits and RT); 3) List Sorting Working Memory (P; WM; Hits); 4) Picture Sequence Memory (P; episodic memory; Hits); 5) Oral Reading Recognition (P; language; CAT administered); 6) Picture Vocabulary (S;

language; CAT administered); and 7) Pattern Comparison Processing Speed (S; processing speed; Hits). In addition to the abovementioned individual measure outcomes, three composite scores are also computed: 1) Cognitive Function (akin to a "full scale" score, includes all of the measures); 2) Fluid Cognition (DCCS, Flanker, Picture Sequence Memory, List Sorting, Pattern Comparison measures); 3) Crystallized Cognition (Picture Vocabulary and Reading Recognition measures).

The battery has good psychometric properties. Test-retest reliability is good and results from convergent and discriminant construct validity analyses suggest that the NIH Cognition tests are measuring what is intended and not measuring constructs that are not intended, respectively (Weintraub et al., 2013).

BIOCHEMICAL MARKERS

Salivary cotinine was collected at laboratory visits and expired air CO readings were taken in the field and at the laboratory visits. Saliva samples were collected and mailed to an external assay company to determine cotinine levels (Salimetrics LLC, State College, PA). Cotinine is a major metabolite of nicotine that can be measured in urine, plasma, and saliva (Etzel, 1990). Given its high sensitivity and specificity, cotinine is considered the gold standard in the smoking literature for detecting nicotine exposure (Jarvis et al., 2008; SRNT Subcommittee on Biochemical Verification, 2002). While it is generally detectable up to one week, ideal detection is within three days because of the reduced reliability with time.

To verify recent smoking (up to a maximum of 48 hours), expired air CO was recorded using a novel commercially available CO monitor (COmpact™USB; Bedfont Scientific Ltd., UK). The COmpact™USB is a portable device equipped with a USB

port to enable connection to a computer or laptop, which makes it ideal for remote biochemical verification (see Figure 11). Carbon monoxide levels are immediately displayed on the computer. This output report is non-modifiable by the user and can be saved and electronically transmitted. Expired air CO is an indirect measure of carboxyhemoglobin (%COHb) in the blood. Carboxyhemoglobin is formed in the blood when CO enters the circulation system. The amount of nicotine absorbed is related to the uptake of CO in the body. Therefore, breath CO is an indirect measure of CO in the blood, which can be used to index recent smoking. A standard cut-off value of less than or equal to 10ppm was used to determine abstinence (c.f., SRNT Subcommittee on Biochemical Verification, 2002).

The rationale for using taking breath CO levels in the field rather than saliva samples (for assessment of cotinine) is as follows. The half-life of breath CO is shorter than salivary cotinine (6-8 hrs. vs. 18 hrs.) and CO is therefore a better biochemical marker to verify overnight abstinence and to assess daily smoking. At a practical level, CO is cheaper and easier to assess than cotinine in saliva which would require subjects to refrigerate saliva samples.

When participants provided CO assessments at home (both Week 1 and Week 2), there were three sources of CO data: the emailed report of the CO reading (if available), the CO reading as it appeared on the participant's video (if available), and the participant's self-report of the CO reading. These three reading types were highly correlated (r's > .9). Therefore, an average of the available CO readings was used as the CO reading from home assessments. In cases where there was a significant difference in

CO reading between two or more of the sources (> 10 ppm), the research staff made an agreed determination of the appropriate value.

To check the validity of the data from the COmpact™ USB, for 21 assessments in the laboratory, we also assessed CO using a "standard" CO monitor (Micro+ Smokerlyzer, Bedfont Scientific Ltd., UK) that was calibrated against a known concentration of CO.

The following CO cut-off level was applied every morning in the field during Week 1. For the Acute Nicotine condition, CO readings were utilized to validate overnight abstinence. Carbon monoxide readings less than or equal to 10 ppm were expected for the first reading. Similarly for the Acute Abstinence condition, CO readings were utilized to verify overnight abstinence, immediately before and after the PDA cognitive tasks. These procedures are elaborated in the Experimental Condition section. During Week 2, CO readings were taken every morning and evening. Again, CO less than or equal to 10 ppm was used to index abstinence in the morning. The evening CO level assessed amount of smoking during the day..

SMOKING DIARY

Participants recorded their daily cigarette use with a smoking diary throughout the course of the study (see Appendix B). Self reported daily number of cigarettes smoked was used as an outcome variable (along with evening CO levels during Week 2).

PDA COGNITIVE TASKS

Go/No-go Task

The Go/No-go task was administered at each laboratory visit on a PDA to assess response inhibition (Mitchell, 2004). Stimuli were presented serially on the screen. The

"Go" stimuli were consonants and the "No-go" stimuli were the letter E. The "Go" stimuli were presented more frequently (88.9% of trials) than the "No-go" stimuli (in order to train a dominant "Go" response). Subjects were instructed to press any hard key on the PDA as quickly and accurately as possible when they saw a consonant letter ("Go" trials) and were to withhold the dominant (incorrect) response when they saw an E ("No-go" trials). Accuracy on Go and No-go trials, and reaction time for correct responses on Go trials were computed. The task has demonstrated strong reliability (Weafer, Baggott, & de Wit, 2013) and it (or variations) has been widely used in cognitive psychopathology research, including neurodevelopmental disorders (e.g., Tye et al., 2013) and substance addictions (Weafer et al., 2013), including cigarette smoking (Luijten, Littel, & Franken, 2011; Sofuoglu, Herman, Li, & Waters, 2012).

Rapid Visual Information Processing Task

The Rapid Visual Information Processing (RVIP) task was a PDA-adapted version of the CANTAB® desktop RVIP task (Cambridge Cognition Ltd., Cambridge, UK; see Figure 3) to assess visual sustained attention, which also has a working memory component (refer to Figure 10). Each PDA was loaded with a list of stimuli that was randomized to the following specifications. Each list contained 400 digits (from 2 to 9) that were presented at 600 ms (100 digits/min). Each list resulted in approximately 32 target sequences with nearly equal representation of even and odd targets. This translated to approximately 8 targets per minute. A minimum of 5 digits occurred between targets. The target sequences in the PDA version were any even and odd triad. This instruction set is consistent with the majority of studies that have demonstrated RVIP's sensitivity and reliability to the effects of nicotine (e.g., Wesnes & Warburton, 1983; Leventhal et

al., 2010; Juliano et al., 2011). To the author's knowledge, there are no studies in the smoking literature that assessed RVIP in the field.

The outcome variables included: the number of correct hits (measured in counts), mean reaction time of correct hits (milliseconds), and number of false alarms (measured in counts). Number of false alarms can be interpreted as a measure of impulsivity, with more false alarms indicating greater impulsivity. In the present study, subjects completed the RVIP at Visit 1 as well as on both the home and field PDAs, as described later (see Table 4).

Smoking Stroop Task

The Smoking Stroop task was administered on a PDA to assess attentional bias to smoking cues. Subjects were instructed to indicate the color of individual words presented on the PDA screen by pressing one of three buttons on the PDA. The buttons corresponded to the three colors (red, green, blue) used in the study. At each assessment, the PDA program randomly chose a list from 24 lists. Each list contained a block of 33 smoking words and a block of 33 neutral words. The neutral words preceded the smoking words on half the lists, and vice versa for the other lists. At each assessment, participants also completed a practice block (33 trials) that involved indicating the colors of letter strings. The positions of the color buttons changed from assessment to assessment. The Smoking Stroop task has been administered in the field in previous studies, (e.g., Waters & Li, 2008; Waters et al., 2014).

The relevant outcome variable is the Stroop interference scores (smoking Stroop effect). This is computed by taking the difference in response times on smoking and neutral words. The Stroop interference score indexes attention capture by smoking cues

In the present study, subjects completed the Smoking Stroop during Visit 1 and during Week 2 each morning after overnight abstinence (on the home PDA).

FIELD ASSESSMENTS

PDA Subject-Initiated Assessments (Home PDA)

Subject-initiated assessments could be completed at any time on the home PDA (refer to Figure 9). Subjects were instructed to start an assessment every morning during both weeks of the study by pressing an "Assessment" button on the PDA. During Week 1 (Days 2-7), subjects completed the RVIP (and self-report items) after overnight abstinence and after acute nicotine (3 days each). During Week 2 (Days 9-14), subjects completed the RVIP (and self-report items) and Smoking Stroop task after overnight abstinence.

Subjects responded to the following questions using a 7-point Likert scale (1 = Strongly Disagree, 7 = Strongly Agree) or selected from a list of options tailored to the question. The items were presented in the following order: 1) adapted Minnesota Nicotine Withdrawal Scale (MNWS; 8 items on 1-7 scales assessing: irritability, restlessness, insomnia, anxiety, depression, increased appetite, difficulty concentrating, and craving); 2) smoking so far that day (Yes, No); 3) recency of the last cigarette smoked (i.e., when the last cigarette was smoked: just smoked or smoking now, 5-30 mins ago, between 30 mins and 2 hrs, or ≥ 2hrs ago); 4) a single-item attentional capture to smoking-related cues ("Since the last assessment, I found myself staring at cigarettes", 1-7 scale); 6) craving for cigarette (1-7 scale); 7) caffeine intake and consumption recency (source: tea, coffee, soda, energy drink, other; when consumed: within 1hr, between 1 and 2hrs ago, between 2 and 3hrs ago, or ≥ 4hrs ago); 8) substance use and

recency (type: alcohol, other depressant[s], stimulant[s], prescription medication, other [a list of potential substances for each category was provided to the subjects on Orientation Day]); 9) single-item mood (1-7 scale); 10) general physiological state (fatigue, alertness, stress, hunger, pain) (1-7 scales); 11) two items assessing context: company (whether alone or with others) and setting (home, work, commuting/traveling, or elsewhere).

As noted above, a single item was used for the assessment of craving: "Right now, I feel a craving to smoke" (7-point scale from Strongly Disagree to Strongly Agree). Studies have found that shorter craving measures were comparable to longer measures in terms of sensitivity to abstinence and reliability. Specifically, one study revealed that a single-item craving question performed comparably with the QSU-B and this was stable over time (West & Ussher, 2010). Most pertinent to the current dissertation Shiffman et al. (1997) were able to predict daily smoking lapses in smokers who recently quit using a single-item measure of craving administered each morning. Although a multi-item craving measure may more thoroughly assess craving (but see West & Usher, 2010) we opted to use a single item to decrease participant burden. Other EMA studies have used single-item measures of craving (e.g., Waters et al, 2014).

After participants completed the items above, the instructions for the RVIP task were presented, followed by the RVIP task. A practice trial was presented only on the first RVIP assessment, which was completed in the laboratory. Due to the repeated nature of testing, practice trials were not presented thereafter.

Upon conclusion of the RVIP task, subjects were asked to report frequency of interruptions during task completion (response options: No times, 1 time, 2 times, 3 times, 4+ times). This item was administered so that data could be potentially be analyzed

while excluding assessments with a large number of interruptions. Lastly, boredom ("I was bored during this task"; 1-7 scale from Strongly Disagree to Strongly Agree) and effort ("I put in my best effort during this task"; 1-7 scale from Strongly Disagree to Strongly Agree) were assessed. These items were used to determine whether participants became increasingly bored with the task over time, and to determine whether they reported putting in high levels of effort on the task.

PDA Random Assessments (Field PDA)

Participants carried the field PDA with them throughout the day. During both weeks of the study, the field PDA prompted the subject at four random times each day during the subject-specified wake hours. Subjects set their "wake-up" and "bed" times on the field PDA. Based on these times, the program divided the wake-day into four approximately equal intervals and one RA was randomly scheduled during each interval.

When an RA was presented, the subject had the option to delay it by five minutes, up to four times. However, if the subject did not respond to an RA, it timed out, forfeiting the chance to contribute data for that RA. A Suspend function enabled the subjects to stop the field PDA from presenting RAs for up to 120 mins. The subject was able to cancel the Suspend at any time.

The same items that were presented in the subject-initiated assessments were presented in the RAs. In addition, the RVIP task was assessed at every RA. The Stroop task was <u>not</u> administered on the field PDA.

PDA HARDWARE AND SOFTWARE

The Hewlett Packard iPAQ, which runs on the Microsoft Windows Pocket PC 2003 operating system, was used. Terminal C, a Houston-based programming company,

completed software programming. Only the study program was able to run on the PDA; all other PDA functions were locked.

As mentioned above, training was provided on how to use the PDA during Visit 1. The subject could interact with the touchscreen-enabled PDA using their fingers or stylus. In addition, the hard button keys were used for the RVIP and Go/No-go tasks.

MANIPULATION CHECKS FOR WEEK 1 EXPERIMENTAL CONDITIONS

Acute Abstinence Condition

The manipulation check for the Acute Abstinence condition (Week 1) was initially conceived as follows: 1) The participant had to report they had not smoked so far that day on the PDA item that assessed smoking so far that day; 2) The first CO reading (CO1) should be comparable to the second CO reading (CO2) and both should indicate deprivation levels (CO $\leq$ 10 ppm); 3) The CO1 timestamp should precede the RVIP task timestamp; 4) The RVIP task timestamp should occur before the CO2 timestamp; 5) Dates for all of these events should be the same.

However, on days in which participants did not complete procedures as instructed (e.g., if they failed to provide two CO readings, or if, contrary to instructions, they completed multiple assessments on the home PDA) the above criteria could not be applied. On these days, two research staff members evaluated the available data and determined whether any PDA assessment entered on that day was usable based on the data available. At a minimum, PDA data could only be included if 1) participants reported on the PDA that they had <u>not smoked</u> so far that day; 2) the time of the first CO recording occurred earlier than the start time of the PDA assessment, and 3) the time of the second CO recording, if available, needed to occur later than the start time of the

PDA assessment. Moreover, as described later, the requirement that CO1 levels needed to be ≤ 10 ppm was removed for the primary analyses.

Acute Nicotine Condition

For the Acute Nicotine condition (Week 1), the manipulation check was initially conceived as follows: 1) The participant had to report they had smoked within 30 minutes, based on the response to the PDA item assessing recency of smoking; 2) CO1 should be no greater than CO2, and CO1 should be ≤ 10 ppm; 3) The timestamps of both CO readings should precede the RVIP task timestamp; 4) The RVIP task timestamp should be within 30 minutes of the CO2 reading; 5) Dates for all of these events should be the same.

As in the AA condition, on days in which participants did not complete the procedures as instructed, the above criteria could not be applied. On these days, two research staff members evaluated the available data and determined whether any PDA assessment entered on that day was usable based on the data available. At a minimum, PDA data could only be included if 1) participants reported on the home PDA that they had smoked within 30 minutes of the assessment; 2) the start time of the home PDA assessment occurred after the time of the second CO recording and within 30 minutes of that recording. If, contrary to instructions, the subject completed multiple assessments on the home PDA on a given day, then the first assessment completed on the day was included except in two cases, when a later assessment was selected (based on the criteria above). Moreover, as with the AA condition, the requirement that CO1 levels needed to be ≤ 10 ppm was removed for the primary analyses.

ANALYTIC PLAN

Descriptive statistics (means, standard deviations, percentages) for variables obtained at baseline for the sample were examined.

General Analytic Plan

For analysis of EMA data, we used Linear Mixed Models (PROC MIXED in SAS). These analyses allowed for missing data (i.e., subjects differed in the number of observations available for analysis) and took into account the clustering of data by subjects. For all models, Day in study (a within-subject variable) was included. For all models we used a random (subject-specific) intercept and an autoregressive model of order 1 for the residuals within subjects. Within-subject variables (e.g., Day) were treated as a random effect in the model if the *p*-value for the covariance parameter estimate was less than .1 (Fitzmaurice, Laird & Ware, 2011). Similar methods were used in Waters et al. (2014).

Specific Aim 1: To examine the feasibility, reliability, and validity of assessing RVIP performance in an EMA paradigm, the following analyses were conducted.

Hypothesis 1.1: To assess the feasibility of employing the RVIP task on a PDA in the field and remote CO monitoring, we computed the proportion of complete and usable RAs, RVIP indices, CO recordings, and video recordings. Qualitative data on subjects' experience (ease of use, feasibility) of study procedures were also collected. Specifically, the field tasks involving the PDA, USB CO monitor, and video recordings were of interest.

Internal reliability of RVIP performance was assessed using split-half correlation coefficients. Pearson's correlation coefficients, adjusted using the Spearman Brown

formula (2r/(1 + r)), were computed using SAS. In a large sample (*N*=203) Leventhal et al. (2010) reported good internal reliability (using the Spearman Brown formula, all *r*'s >.8) for RVIP Hits and RT in a 10-minute laboratory RVIP task. The current RVIP task was briefer (4 mins.) and was administered in the field; therefore internal reliability above 0.6 was considered acceptable.

Hypothesis 1.2: To test the validity of utilizing RVIP in an EMA paradigm, we tested whether acute smoking improves RVIP performance in overnight-deprived smokers using LMM. In addition to Day (a within-subject variable with 3 levels: 1, 2 and 3, corresponding to the three days in the abstinence and smoke conditions), State (a within-subject variable with 2 levels, Acute Abstinence and Acute Nicotine) was entered into the model. The dependent variables were RVIP indices (Number of Hits, mean RT, Number of False Alarms). A significant parameter estimate for State would reveal that performance differs in the two conditions.

Specific Aim 2: To examine whether RVIP performance assessed in the field is associated with smoking behavior in smokers trying to cut down or quit smoking (i.e., to test RVIP performance in the field as a predictor variable). We expected smokers with better RVIP performance during abstinence to be more successful in cutting down or quitting smoking than smokers with poorer RVIP.

Hypothesis 2.1: Better mean RVIP performance during abstinence (Week 1) will be associated with a lower smoking rate during a cut down period or quit attempt (Week 2).

To examine the effect of RVIP scores (Week 1) on smoking behavior during Week 2, we used LMM. RVIP scores in abstinence during Week 1 were the primary

independent variables and smoking behavior assessed by smoking diaries (the daily number of cigarettes smoked) and CO level during Week 2 were the dependent variables. A significant parameter estimate for RVIP scores during abstinence would indicate that this variable influences smoking behavior. We examined whether any significant associations persisted when including FTND scores as a covariate. To examine whether any association was specific to abstinence, we also included mean RVIP performance during Week 1 ad libitum smoking as a covariate (from random assessments). To compute this variable, we only included RAs in which participants reported that they had smoked so far that day.

Hypothesis 2.2: Better RVIP performance after overnight abstinence (morning pre-smoking) in Week 2 will be associated with reduced smoking behavior that day (i.e., better RVIP performance will be associated with less smoking on the same day).

To examine the effect of morning RVIP scores in Week 2 on smoking later that day during Week 2 we used LMM. RVIP scores in abstinence during Week 2 was the primary independent variable and smoking behavior assessed by smoking diaries (the daily number of cigarettes smoked) and CO levels during Week 2 were the dependent variables. A significant parameter estimate for morning RVIP scores would indicate that this variable influences smoking behavior. For this hypothesis, the parameter estimate reflects the influence of between- and within-subject associations (Hedeker et al., 2009; Waters et al., 2014). As for hypothesis 2.1, covariates included FTND scores and RVIP performance during Week 1 ad libitum smoking (from random assessments).

Specific Aim 3: To examine whether RVIP performance assessed in the field moderates the relationship between craving/attentional bias and smoking behavior (i.e., to

test RVIP performance in the field as a moderator variable). We expect better RVIP performance to weaken the relationship between craving/attentional bias and smoking behavior.

Hypothesis 3.1: Mean RVIP performance during abstinence (Week 1) moderates the association between morning craving and daily smoking behavior during Week 2 (i.e., the association between craving and smoking will be weaker in individuals with better RVIP performance).

As with Specific Aim 3, we used LMM to test this hypothesis. However, we specifically tested the interaction term between mean RVIP scores (Week 1) and morning craving (Week 2). A significant parameter estimate for the interaction term would reveal that the association between craving and smoking is moderated by RVIP scores.

Hypothesis 3.2: Mean RVIP performance during abstinence (Week 1) moderates the association between attentional bias and daily smoking behavior during Week 2 (i.e., the association between attentional bias and smoking will be weaker in individuals with better RVIP performance).

Using LMM, we specifically tested the interaction term between morning RVIP scores (Week 1) and morning attentional bias (Week 2). A significant parameter estimate for the interaction term would reveal that the association between morning attentional bias and smoking is moderated by RVIP scores.

In exploratory analyses, we also evaluated the relationship between intelligence and neurocognitive function (as assessed with the Shipley and the NIH Toolbox, Cognition Battery) and Week 2 smoking outcomes (daily smoking rate and evening CO levels). We expected smokers with higher IQ (as assessed by the Shipley) to have greater

success in cutting down/quitting. Further, we expected smokers with better neurocognitive performance (as assessed by the NIH Toolbox, Cognition Battery) to have better smoking outcomes. We also examined the association between performance on the Go/No-go task and smoking outcomes. Finally, for comparison purposes, we also examined whether measures of smoking and tobacco dependence were associated with smoking outcomes.

Power Analysis

All power analyses assumed alpha = .05 and a 2-tailed test. For Hypothesis 1.2, if 16 subjects (out of the subjects who signed the informed consent form and completed Visit 1) provided data, they can potentially complete in total 96 EMA assessments (6 assessments each: 3 in the Acute Abstinence condition and 3 in the Acute Nicotine condition). To be conservative we assumed subjects would complete 2 assessments in each condition. We used the 2-within subject factorial ANOVA procedure in PASS version 12 (Hintze, 2013) to estimate power for the LMM. This power analysis requires an estimate for the correlation of RVIP variables over different assessments. We estimated that the correlation in the population, rho, for RVIP Hits and RT to be .6. Assuming each participant completes two assessments in each condition, and rho = .6, we have power = .80 to detect differences between means of 0.48 *SD*s. This is a larger difference between means than that reported in Kang (2013). However, the current study uses a stronger manipulation in that RVIP performance is compared in abstinence, just following the first cigarette of the day. In Kang (2013), performance in abstinence was compared against a condition in which participants had smoked on average about 15

minutes earlier, meaning that blood nicotine levels would have declined considerably over time.

For hypothesis 2.1, the power to detect a between-subject association between a level 2 variable and a level 1 variable depends on what is termed the "effective sample size" for the analysis. The larger the effective sample size, the greater the power. To compute the effective sample size, the VIF (Variance Inflation Factor) is computed (VIF = 1+((average number of observations per person) -1)*ICC). Then the total number of assessments (i.e., average number of observations per person multiplied by the number of study subjects) is divided by VIF. The ICC is the intraclass correlation coefficient for the dependent variable. Using data from Ruscio (2013), we estimated the ICC of smoking behavior collected on diaries over a 2-week period to be 0.6. Assuming the ICC = 0.6, and assuming perfect compliance with the smoking diaries, and 15 participants completed the entire study, the VIF = 1 + (7-1)*ICC = 3.5, so the effective sample size = 105/4.6 = 23. Note that because the data are highly correlated, the effective sample size is only modestly larger than the number of subjects. Using G*Power 3.1.2, assuming an effective sample size of 23, we have estimated power = .80 to detect a correlation, rho, of .55 (a large effect size) between RVIP scores and smoking behavior.

For hypothesis 2.2, under the assumption that 15 subjects complete Week 2 and provide data, and that there will be 80% compliance with EMA assessments, we have an estimated 84 assessments (15 subjects x 0.8 x 7 days) available for analysis. The estimated power to detect an association is the same as that noted above for hypothesis 2.1, and in this case will reflect the influence of between- and within-subject associations.

Power analyses for Specific Aim 3 are not provided given that we know of no procedures, other than simulations, that allow their estimation. However, given the small samples sizes, it is clear that we will only have good power to detect very large effect sizes in the population for interaction effects.

CO validity check

As noted above, for 21 assessments in the laboratory we assessed expired CO with both the COmpact™USB and using a "gold-standard" CO monitor (Micro+ Smokerlyzer) that was calibrated against a known concentration of CO. There was a high correlation between the CO assessed from the COmpact™USB and the CO assessed with the gold-standard, $r(19) = .91$, $p < .001$. Despite this high correlation, it was noted that the COmpact™USB produced higher readings ($M = 20.84$ ppm, $SD = 10.94$) than the Micro+ Smokerlyzer ($M = 9.90$ ppm, $SD = 6.28$). A linear regression revealed that the predicted CO readings on the Micro+ Smokerlyzer (the gold standard) were as follows: Predicted CO readings on Micro+ Smokerlyzer = -0.963 + (0.521 x COmpact™USB readings). Thus, a two-unit change on the COmpact™USB device corresponded to about a 1-unit change on the gold standard. This suggested a problem of calibration on the COmpact™USB device. Therefore, to compute appropriately "calibrated" CO readings from the data from the COmpact™USB device, the regression equation above was used to derive predicted CO readings on the Micro+ Smokerlyzer. The predicted CO scores are used and presented in this dissertation.

Processing Home PDA Data

Week 1

For Week 1, in the AA condition home PDA data were included if 1) participants reported on the home PDA that they had not smoked so far that day and 2) the time of the first CO recording occurred earlier than the start time of the home PDA assessment and 3) the time of the second CO recording, if available, occurred later than the start time of the home PDA assessment. This is because participants were instructed to complete the home PDA assessment between the two CO recordings in the AA condition.

In the AN condition PDA data were included if 1) participants reported on the home PDA that they had smoked so far that day within 30 minutes of initiating the assessment, and 2) the start time of the home PDA assessment occurred after the time of the second CO recording and within 30 minutes of that recording. This is because participants were instructed to complete the home PDA assessment after smoking and after completing the second CO recording. If, contrary to instructions, the participant completed multiple assessments on the home PDA on a given day, then the first assessment completed on the day was included except in two cases (subject 1, day 3, subject 7, day 6), where the assessment most proximal to the second CO reading was selected.

Using the above criteria, of the 15 participants who completed Week 1, 12 participants provided PDA data on 38 days. No usable data were available for subjects 19, 21 and 23. One subject (23) did not complete any home PDA assessments. Two subjects completed at least one home PDA assessment but the assessments did not meet the inclusion criteria noted above.

The first CO level (which was always scheduled to occur before smoking in both the AA and AN conditions) was >10 ppm for 15 (out of 38) days. The "high" first CO assessments were included in some analyses but excluded in other analyses, as described later.

Week 2

For Week 2, home PDA data were included if participants reported on the PDA that they had not smoked so far that day. If, contrary to instructions, the participant completed multiple home PDA assessments on a given day, then only the first assessment completed on that day was used. Data from the Stroop task were excluded if it was initiated more than an hour later than the RVIP task. The mean lag between the initiation of the RVIP and Stroop assessments was 6.6 minutes, and the maximum lag was 22.2 mins.

Based on the criteria above, 7 participants provided home PDA data on 38 days in Week 2. The average time of day for these 38 assessments was 8:04 AM. For 37 of these assessments morning CO data were available (no CO readings were available for subject 1021, day 9. Most (33) morning CO readings were "timely" (i.e., occurred within 30 minutes of the home PDA assessment) but in 4 cases (subject 10, day 13; subject 21, day 10; subject 21, day 11; subject 21, day 14) they occurred more than an hour after the initiation of the home PDA assessment. Morning CO levels were > 10 ppm for 10 (out of 33) days on which timely morning CO data were available. The primary analyses using home PDA data from Week 2 use the 23 days on which timely CO $\leq$ 10 ppm.

Evening CO levels were available on 34 days, and data on self-reported cigarette smoking was available on all 38 days.

CHAPTER 4: Results

SAMPLE CHARACTERISTICS

Subject demographic and smoking variables are reported in Table 5. As shown in Fig. 12 (and Table 5), of the 22 participants who enrolled in the study, 11 provided data at all three study visits. We compared the characteristics of the 11 participants who completed the study with those who did not (Table 5). There were no significant differences on demographic variables, smoking variables, RVIP indices, or the Shipley Test. On the NIH test battery, completers performed better than non-completers on the Cognitive Picture Vocabulary test, but worse on the Cognitive Processing Speed measure. On all other measures, there were no significant differences between completers and non-completers.

SMOKING BEHAVIOR

Participants were instructed to smoke as usual during the first week of the study, and to cut down or quit during the second week. For the 11 participants who completed the study, we therefore examined whether participants smoked less during the second week than the first. On the smoking log, participants reported smoking an average of 13.30 (SD = 7.49) cigarettes per day during Week 1 and 8.36 (SD = 8.37) cigarettes per day during Week 2. Using LMM, reported smoking was lower during Week 2 (vs. Week 1), $F(1, 10) = 10.76$, $p = .008$.

Table 7 reports CO and cotinine levels in saliva at each lab visit (see also Figure 13). Using LMM, CO levels at Visit 3 were lower than CO levels at earlier visits, $F(1, 21) = 9.80$, $p = .005$. There was no difference in CO levels between Visit 1 and Visit 2, $F(1, 10) = 0.00$, $p = .96$. Similarly, cotinine levels in saliva at Visit 3 were lower than

cotinine levels at earlier visits, $F(1, 20) = 6.12$, $p = .02$. There was no difference in cotinine levels between Visit 1 and Visit 2, $F(1, 10) = 1.03$, $p = .33$.

Regarding abstinence, no participant reported that they abstained from smoking entirely from Days 9 through 14. Two participants had CO levels below 10 ppm and cotinine levels below 15 ng/ml at Visit 3. One of these participants reported that they had not smoked any cigarettes from days 11 through the end of the study and the other reported that they had not smoked any cigarettes from days 12 through the end of the study.

Overall, among the 11 study completers there was good evidence that smoking rates were lower in Week 2 than Week 1, although no participant achieved continuous abstinence during Week 2. In addition, there was no evidence for a decline in smoking between Visit 1 and Visit 2.

SPECIFIC AIM 1

To examine the feasibility, reliability, and validity of assessing RVIP performance in an EMA paradigm.

The following is a report of the number of subjects who rated the "ease" and "practicality" of the field procedures as "acceptable" as indicated by their responses to the Visit 3 interview. Ease of use of the devices was defined as how easy or difficult it was to operate the devices: PDA, CO monitor, and video recording device. Practicality refers to the feasibility of using each of the devices in light of the competing internal or external demands (e.g., time constraints).

At the end of visit 3 interview participants were asked to rate on a five-point scale the ease of use and practicality of use (response options: adverse; unacceptable; neutral;

acceptable; favorable). We computed the number of responses that there were "acceptable" or "favorable." With regards to "ease of use" of the PDA, 8 out of 11 subjects reported it was acceptable (or favorable), for the CO readings 10 out of 10 subjects reported it was acceptable (or favorable), for the video recordings 9 out of 10 subjects reported it was acceptable (or favorable), and for the video recording procedures 9 out of 9 subjects reported it was acceptable (or favorable). With regards to the "practicality" of the field procedures, 9 out of 11 subjects rated the PDA as acceptable (or favorable), for the CO readings 10 out of 10 subjects, for the video recordings 8 out of 10 subjects, and for the video recording procedures 9 out of 9 subjects.

However, these global judgments may be inflated by social desirability and participant biases. For instance, one subject described the "likes" and "dislikes" of the practicality of the video recordings, but overall reported it favorably, "Practical because I understood why it needed to be done. Doing the morning and evening procedures weren't that practical because I had to squeeze it into my normal routine. It would be easier to do it at night versus morning because there is more time in the evening (because I don't have to be somewhere at night). Overall, was acceptable."

Four subjects described disliking the PDA assessment. Subjects' statements included the following. "Overall, unacceptable because problems with the RVIP task being too difficult." "RVIP task was impractical." "I disliked the RVIP task, it was confusing." "The task was good at capturing sustained attention but it was very annoying." "Disliked PDAs, (particularly) the RVIP task because I hate numbers and I thought it was too long." "By the second week I was starting to feel burned out and I

didn't want to complete the assessments." "It was impractical, because it was long, repetitive, and I wouldn't do it again."

Two subjects disclosed not being able to comply with the morning abstinence instructions. Specifically, subjects stated the following. "It's hard not to smoke and (drink) caffeine and overall it was unacceptable." "The first week I did sometimes smoke before doing the morning procedures." "I felt guilty to email (the CO) result if I cheated and smoked when I should not have smoked."

The morning procedures were described as burdensome due to time constraints and because it prevented them from smoking their first cigarette of the day. "Within minutes of awakening, I did the video procedures because I'm a busy person and wanted to get them out of the way." "Slightly stressful when I had to do the steps before the first cigarette because I'm used to smoking very shortly after awaking." "It's hard not to smoke and (use) caffeine." "The first week I did sometimes smoke before doing the morning procedures." "Week 2 procedures got easier because the process wasn't as involved in the morning."

Table 6 reports a number of compliance measures. As noted earlier, of the 22 participants who enrolled in the study, 15 completed Visit 2, and 11 completed the study.

During Week 1, the 15 participants (who attended Visit 2) completed a home PDA assessment on 70.00% of days during Week 1. However, only 38 assessments (42.22% of days) during Week 1 contained a usable home PDA assessment (as defined earlier) and of those, only 23 assessments (25.56%) occurred on days in which the first CO level was $\leq$ 10 ppm.

During Week 2, the 11 participants who attended Visit 3 completed a home PDA assessment on 75.76% of days during Week 2. Thirty-eight assessments (57.58%) of days contained a valid home PDA assessment (as defined earlier) although only 23 assessments (34.85%) occurred following a timely CO reading of ≤ 10 ppm.

We also examined the feasibility of the experimental manipulation of smoking during Week 1. In the AN condition CO levels should increase from the first reading to the second (because participants are instructed to smoke between the two readings). In the AA condition, CO levels should not increase (because participants are instructed not to smoke between the two readings).

Summary statistics on CO levels are shown in Table 8. As expected, CO levels at the first reading in the AA condition were not significantly different from CO readings in the AN condition, $F(1, 23) = 0.24$, $p = .63$. As expected, in the AN condition CO levels were significantly higher at Reading 2 (post-smoking) than at Reading 1 (pre-smoking), $t(9) = 3.21$, $p = .01$. In the AA condition, CO levels were not significantly higher at Reading 2 than at Reading 1, $t(9) = 0.45$, $p = .66$. The effect of Condition (AA vs. AN) on change in CO levels was significant, $F(1, 24) = 8.14$, $p = .008$. The effect remained significant when subsetting analyses to the 23 assessments where the first CO reading ≤ 10 ppm ($p = .02$).

We also examined the feasibility of assessing smoking through self-report and evening breath CO during Week 2. As expected, CO levels were significantly higher in the evening than in the morning, $t(6) = 4.94$, $p = .004$. For the 7 participants who provided usable home PDA data, the correlation across days between reported cigarettes smoked on each day and CO level at the evening assessment was $r = .85$.

Internal Reliability of RVIP

The internal reliability of RVIP indices was computed for home PDA data during Week 1, field PDA data during Week 1, and home PDA data during Week 2. The internal reliability was computed as described earlier using the Spearman-Brown correction. The internal reliability for number of hits was r = .80 on the home PDA during Week 1, r = .94 on the field PDA during Week 1, and r = .78 on the home PDA during Week 2. The internal reliability for mean RT was r = .28 on the home PDA during Week 1, r = .53 on the field PDA during Week 1, and r = .45 on the home PDA during Week 2. The internal reliability for number of false alarms was r = .79 on the home PDA during Week 1, r = .97 on the field PDA during Week 1, and r = .84 on the home PDA during Week 2. Overall, internal reliability for number of hits and number of false alarms was good. However, internal reliability for mean RT was weaker.

Hypothesis 1.2: Acute smoking will improve RVIP performance in overnight-deprived smokers assessed at home.

Table 10 shows that, as expected, the number of hits was significantly higher in the AN condition (see Figure 14). As expected, reported craving was also higher in the AA condition (i.e., prior to smoking) than in the AN condition (after smoking). No other effects were significant.

The aforementioned analyses used data from the 38 usable home PDA assessments, as defined earlier. In supplementary analyses we also examined whether any effects of Condition on RVIP performance persisted when subsetting to assessments (n = 23) where the first CO level was ≤ 10 ppm. The results were generally similar to those reported in Table 10, although the effect of Condition on Hits was reduced to a

trend, *PE* = 4.02, *SE* = 2.23, *p* = .09. We also examined whether any effects of Condition were moderated by CO level at the first assessment. There was no evidence for moderation (*p*'s > .05).

SPECIFIC AIM 2

To examine whether RVIP performance assessed at home is associated with smoking rate in smokers trying to cut down or quit.

Hypothesis 2.1: Better mean RVIP performance during abstinence (Week 1) will be associated with a lower smoking rate during a cut down period or quit attempt (Week 2).

Results of LMMs testing hypothesis 2.1 are shown in Table 11. The analyses used home PDA data from the AA condition where the first CO reading ≤ 10 ppm. In general, Week 1 RVIP performance during abstinence (AA condition) was not strongly associated with Week 2 smoking (either cigarettes smoked per day or evening CO levels).

The only significant association was for false alarms (see Figure 15). Number of false alarms was associated with reported cigarettes smoked during Week 2 such that more false alarms exhibited during the Week 1 abstinent days were associated with more reported cigarettes smoked during Week 2. When mean number of false alarms from RAs in Week 1 was included as a covariate, the association was marginally significant, *PE* = 0.35, *SE* = 0.19, *p* = .08. Mean number of false alarms from RAs in Week 1 did not itself predict Week 2 reported cigarettes smoked per day for these subjects, *PE* = 0.05, *SE* = 0.07, *p* = .51. When FTND was included as a covariate, the association between false alarms during Week 1 and cigarettes smoked during Week 2 became non-significant (*p* = .24).

Hypothesis 2.2: Better RVIP performance after overnight abstinence (morning pre-smoking) in Week 2 will be associated with less smoking that day.

Results of LMMs testing hypothesis 2.2 are shown in Table 11. The analyses use data from the home PDA where timely CO readings were ≤ 10 ppm. Number of hits was associated with higher CO levels during Week 2 such that a greater number of hits was associated with lower CO readings (Fig. 16). This effect persisted when controlling mean number of hits from RAs in Week 1, *PE* = -0.74, *SE* = 0.31, *p* = .03. Mean number of hits from RAs in Week 1 did not itself predict Week 2 evening CO levels, *PE* = -0.43, *SE* = 0.31, *p* = .17. The association between number of hits and CO levels also persisted when controlling for FTND, *PE* = -0.57, *SE* = 0.24, *p* = .03.

More false alarms during Week 2 home PDA assessments were associated with more reported smoking and higher CO levels during Week 2 (Table 11, Fig. 17). The effect on cigarettes smoked per day was marginally significant when controlling for mean number of false alarms from RAs in Week 1, *PE* = 0.40, *SE* = 0.19, *p* = .052, and retained significance when controlling for FTND, *PE* = 0.42, *SE* = 0.19, *p* = .04. Number of false alarms on RAs during Week 1 did not in itself predict cigarettes smoked per day during Week 2, *PE* = 0.44, *SE* = 0.44, *p* = .39, or evening CO levels, *PE* = 0.46, *SE* = 0.26, *p* = .10.

The association between number of false alarms and evening CO levels persisted when controlling for mean number of false alarms from RAs in Week 1, *PE* = 0.45, *SE* = 0.20, *p* = .04, and when controlling for FTND, *PE* = 0.50, *SE* = 0.21, *p* = .03. In this dataset, FTND did not itself predict cigarettes smoked, *PE* = -0.27, *SE* = 1.84, *p* = .89, or Week 2 evening CO levels, *PE* = -0.79, *SE* = 1.12, *p* = .49.

SPECIFIC AIM 3

Specific Aim 3: To examine whether RVIP performance moderates the relationship between craving/attentional bias and smoking behavior (i.e., to test RVIP performance as a moderator variable)

Hypothesis 3.1: Mean RVIP performance during abstinence (Week 1) will moderate the association between craving and daily smoking during Week 2.

Results of LMMs testing hypothesis 3.1 are shown in Table 11. For cigarettes smoked, there were no significant RVIP x Craving interactions. For evening CO level, the False Alarm x Craving interaction was significant. The sign of the interaction revealed that as the number of false alarms increased, the association between craving during Week 1 and CO level during Week 2 became stronger. The mean RT x Craving interaction was also significant. The sign of the interaction revealed that as mean RT increased (i.e., performance became slower), the association between craving during Week 1 and CO level during Week 2 became stronger. These findings are consistent with hypotheses but should be treated with caution given that only three participants contributed data to this analysis.

Hypothesis 3.2: Mean RVIP performance during abstinence (Week 1) will moderate the association between attentional bias and daily smoking during Week 2.

Results of LMMs testing hypothesis 3.2 are shown in Table 11. There were no significant RVIP x Stroop interactions. For mean RT and number of false alarms, there were near significant interactions (p's < .06). These interactions were in the opposite direction to that predicted (i.e., as RVIP performance became worse the association between the attentional bias and smoking became weaker).

Exploratory Analyses

As reported in Table 12, there was no evidence that Shipley IQ scores predicted cigarettes smoked during Week 2 or evening CO levels during Week 2. Likewise, there was no evidence that errors on the Go No-Go task (on No-Go or Go trials), or RT on Go trials, predicted cigarettes smoked during Week 2 or evening CO levels during Week 2. Cotinine levels in saliva at Visit 1 did predict cigarettes smoked during Week 2.

We also examined self-reports of "boredom" ("I was bored during this task" rated on a 1-7 scale from Strongly Disagree to Strongly Agree) and "effort" ("I put in my best effort during this task" rated on a 1-7 scale from Strongly Disagree to Strongly Agree) on the RVIP task collected after task completion. For participants who provided data at both Week 1 and Week 2, the average boredom rating at morning RVIP assessments during Week 1 was 4.45 (*SD* = 2.05) and during Week 2 it was 4.69 (*SD* = 2.39). This difference was not significant ($p = .76$), meaning that study completers did not report that the task became more boring over time.

For participants who provided data at both Week 1 and Week 2, the average effort rating at morning RVIP assessments during Week 1 was 6.25 (*SD* = 1.30) and during Week 2 was 6.49 (*SD* = 0.92). These participants therefore gave generally high effort ratings. Ratings of effort were higher during Week 2 (vs. Week 1) though this difference was not significant ($p = .35$).

Participants who provided data at Week 1 but not Week 2 reported higher ratings of boredom ($p = .04$) during Week 1 ($M = 6.86$, $SD = 0.36$) and lower ratings on effort ($M = 4.90$, $SD = 1.26$; $p = .006$) than those provided data for both Week 1 and Week 2.

CHAPTER 5: Discussion

This study examined the assessment of RVIP performance in the field as smokers attempted to cut down or quit smoking. The main findings of the study were as follows. First, with regards to the feasibility of study procedures, there were mixed findings. Half of the participants who enrolled in the study completed the study. Study completers, as a group, smoked as usual during Week 1 and smoked less during Week 2. During both Weeks 1 and 2, participants exhibited reasonable compliance to individual components of the protocol, but they generated a lower than expected number of days/observations per subject for analyses. Nonetheless, as predicted, morning RVIP performance (number of hits at home after smoking) in Week 1 was better than RVIP performance before smoking.

Second, there was limited evidence that RVIP hit rate or RT was associated with subsequent smoking, although hit rate during morning assessments in Week 2 predicted subsequent CO levels later that day. An unexpected finding was that a higher false alarm rate during abstinence was also generally associated with increased smoking during Week 2. Lastly, there was limited evidence that RVIP performance moderated the associations between craving/attentional bias and subsequent smoking during Week 2. Each finding will be discussed in turn.

REDUCTION IN SMOKING

The eleven participants who completed the study appeared to comply with instructions to quit or cut down during Week 2. This demonstrated that study completers were sufficiently engaged in the study to follow this instruction and were motivated to cut down smoking, although no participant was able to attain abstinence for the entire Week 2. Additionally, we appear to have captured a non-treatment sample that was motivated

to cut down or quit. Indeed, 55% of the sample reported that they were in the preparation stage while 45% were in the contemplation phase of change (c.f., Prochaska & Norcross, 2001). This compares to the general population of smokers where 20% report being in the preparation phase and 40% in the contemplation phase (and 40% in pre-contemplation; Velicer et al., 1995). This study contributes information on non-treatment seeking smokers who are considering quitting. Previous studies have mainly focused on smokers who are ready to quit and are seeking treatment.

AIM 1: STUDY FEASIBILITY, RELIABILITY, AND VALIDITY

As noted earlier, feasibility has a number of components. The eleven participants who completed the study exhibited reasonable compliance on individual components. However, they provided usable data for a relatively low proportion of days. For example, during Week 1, participants completed home PDA assessments on 63 days (70.00% of days). However, usable data were only available from 38 days (60.32% of the 63 days), and of those 38 days, CO levels were less than 10 ppm on 23 days (36.51% of the 63 days). This suggests that participants struggled to follow the experimental protocol during Week 1.

In particular, participants deviated from protocol in a number of ways. First, participants did not provide the first CO reading during Week 1 on 21 days (23.33% of the 90 days). In addition, in the Acute Nicotine condition, contrary to instructions, on 9 days the RVIP timestamp occurred before the second CO reading timestamp or greater than 30 mins. after the second CO reading timestamp. In the Acute Abstinence condition, contrary to instructions, subjects appeared to smoke between the two CO readings.

Indeed, during the Visit 3 post-study interview, some participants noted that it was challenging to adhere to study instructions regarding when to smoke their first cigarette of the day (see Results section). These participants reported that they wanted to smoke soon after awakening. Other participants stated that completing the experimental condition instructions in the morning was demanding in light of being pressed for time to go to work. The participants who remained in the study reported that the Week 2 study procedures were relatively more feasible and easier to follow and complete relative to Week 1. This pattern was consistent with the data. For Week 2, participants provided home PDA data on 50 out of 66 days (75.76%) and data on 38 days were usable (76.00% of the 50 days).

With regards to RVIP administrations in the field, there was evidence that subjects were unsatisfied with its frequency, as abovementioned. During an interview at the final study visit, some subjects described the RVIP task as difficult, annoying, and that it became progressively boring. Exploratory analyses of boredom ratings revealed that subjects who dropped out before Week 2 reported higher boredom ratings during Week 1 and reported less effort than those who completed the study. Thus, the repeat administration of a boring task may deter some subjects from completing the protocol. Future researchers may consider toggling between different sustained attention tasks to circumvent this issue. Research may also benefit from investigating RVIP duration to determine the briefest task that yields useful information.

Internal reliability of the RVIP task was good (r's > .78) for RVIP Hits and False Alarms but was not acceptable for RTs (r < .6). This is in contrast with Leventhal et al. (2010) who used a 10-minute RVIP task in a laboratory setting and found strong internal

reliability (*r*'s > .8) for all RVIP indices. The internal reliability for mean RT may be much lower in this study (vs. Leventhal et al., 2010) because we had fewer hits and therefore fewer RTs on which to compute a mean RT. There were fewer RTs in the current study for two reasons. First, the task was briefer (4 minutes vs. 10 minutes in Leventhal et al., 2010). Second, the hit rate was somewhat lower in the current study. Although the number of hits was 16.30 in the acute nicotine condition during Week 1 (approximately 50% and comparable to the data in Leventhal et al., 2010), hit rate in the acute abstinence condition (Week1) and during the morning home PDA assessments during Week 2 was low, (10.89 and 9.68 respectively, an approximate 31% hit rate). Therefore mean RT was computed from a relatively small number of hits, which presumably reduced the internal reliability.

A technical issue that was encountered involved whether all hits (correct button presses on targets) were correctly recorded by the program on all PDAs. If some correct button presses were unrecorded then this would also have reduced the number of hits (and therefore number of RTs from which to compute a mean RT). However, this is unlikely to have been a major problem as one participant recorded a hit rate of about 80% during Week 1 with one assessment recording 29 hits (i.e., near ceiling). The same participants also recorded a hit rate of about 75% during Week 2 with one assessment recording 28 hits.

Depending on the underlying cause of the low hit rate, several strategies could be implemented to bolster hit rate. If hit rate is low due to low motivation or lack of effort, greater incentives could be provided to increase motivation and effort. However, this strategy may change the nature of the task and may complicate interpretation of data. If

interruptions interfere with task performance, then assessments with multiple interruptions could be excluded. The task could also include a greater density of targets (e.g., 12 per minute, rather than 8) to increase the number of hits. Of course, it will also be important to further verify that all correct hits are validly recorded.

As predicted, smoking improved RVIP hit rate relative to overnight abstinence. This improvement in hit rate is consistent with the results of Kang (2013) and Leventhal et al., 2010 that were obtained in a laboratory setting. The current study is the first to report an effect of smoking on RVIP performance assessed in the natural environment. Consistent with Kang (2013) and Leventhal et al., (2010), smoking did not significantly influence false alarms. Contrary to Kang (2013) and Leventhal et al., (2010), smoking did not significantly decrease mean RT on targets, although there was a non-significant tendency in this direction (see Fig. 14). The absence of an effect of smoking on mean RT may be due to a number of factors, including the small sample size and the lower reliability of mean RT observed in this dataset (as noted earlier).

Another consideration is that these results were obtained when using all assessments regardless of CO levels on the first reading in the morning. Supplemental analyses showed that CO levels (on the first reading) did not moderate the effect of smoking on RVIP performance. However, when analyses are subset to the 23 assessments where the CO levels on the first reading in the morning were below 10 ppm, the outcome trended toward significance ($p = .09$). Overall, although these results are consistent with prediction, they should be treated cautiously pending replication.

AIM 2: RVIP AS A PREDICTOR VARIABLE

Overall, there was limited evidence that RVIP performance assessed during Week 1 predicted smoking during Week 2 (Hypothesis 2.1). The exception was that mean RVIP False Alarms during Week 1 abstinence predicted self-reported cigarettes smoked during Week 2. This indicates that greater impulsivity during abstinence was associated with greater smoking during a subsequent cut down/quit attempt. Confidence in this finding is diminished somewhat by the observation that it was obtained only on reported cigarettes smoked (this was not found for evening CO levels). However, it is important to note that there were fewer data points for analysis for CO levels than for reported smoking. Specifically, there was a sample size of 30 days for self-reported cigarettes smoked compared to 23 days for CO data. The non-significant CO findings may be attributable to the smaller number of observations for those analyses.

False alarms assessed during Week 1 random assessments in the field (when participants had reported smoking) were not associated with Week 2 smoking. This indicates that it is important to assess performance during abstinence. Similarly, Kang (2013) reported that the abstinence-induced decline in hit rate and mean RT was associated with subsequent relapse in smoking cessation. However, the current results are different from Kang (2013) because an association was observed with the false alarm rate in the current study but not in Kang (2013). It is not clear why this would be, although the dependent variable in the current study is different from that in Kang (2013) (reduced smoking in non-treatment smokers vs. abstinence at 4 weeks of a quit attempt, respectively).

As abovementioned, the task in the current study also had greater working memory demands which may have exerted an influence on performance. Having a

greater number of potential targets (i.e., any odd or even triad versus 3 fixed triads) while not having the target sequences displayed on the screen requires greater working memory functioning, and taxes cognitive capacity overall. Additionally, overall RVIP performance was worse in this study (compared to Kang, 2013). This more difficult RVIP task may have produced more false alarms, which made it easier to detect associations between number of false alarms and the outcome variable.

Additionally, there were several methodological differences that could contribute to the different pattern of data in Kang (2013) and the current study. The task used here was briefer in duration, was assessed on multiple occasions, and was administered in the field. As noted above, multiple administrations may have increased subjects' annoyance and boredom with the task. This more difficult version of the task combined with multiple administrations may have elicited frustration or distress. Indeed, it is plausible that this version captures, at least in part, task persistence or the ability to remain steadfast under duress. Alternatively, other non-neurocognitive psychological factors such as level of motivation or perhaps personality characteristics such as obsessive-compulsive traits could also impact performance on the task used in the current study and can complicate interpretation. Although these extraneous "non-cognitive" variables can influence sustained attention, one could argue that without intact (or "functional") sustained attention, one may not be able to perform the task well even if motivation were high and there was no task frustration. However, it is difficult to disentangle the role of non-cognitive factors such as frustration or task motivation in the current study.

Moreover, different smoking populations may also explain the difference in findings. Kang (2013) recruited treatment-seeking smokers who reported being fully

committed to quit smoking. Kang (2013) was advertised as a cessation study. However, the current study recruited non-treatment seeking smokers who expressed readiness to attempt a quit attempt, and some of the participants were in the contemplation stage (as opposed to the preparation stage). There may be differences between the smokers recruited by Kang (2013) and the current sample. It would be interesting to examine whether there are neurocognitive differences between individuals in the different stages of change.

With regards to Hypothesis 2.2 (prediction of Week 2 smoking from daily measures during Week 2), the finding that abstinence-induced RVIP decrements (during Week 2) predicted smoking later that same day is of particular interest. Specifically, low hit rate and high number of false alarms were associated with greater CO levels later that day. At the time of writing, the author is unaware of any other studies that have examined whether abstinence-induced performance predicts later smoking on the same day.

The methodology used in the current study is advantageous for two reasons. First there is relatively little duration between the RVIP assessment (the independent variable) and smoking (the dependent variable). For instance, Kang (2013) investigated the relationship between RVIP performance and smoking cessation, and in Kang (2013) there was six weeks duration between assessment of RVIP and smoking cessation outcome. One would expect a stronger relationship between cognition and smoking when assessments occur closer in time. For example, there may be a variety of extraneous variables that could influence smoking behaviors within a one-week timeframe, such as acute psychosocial stressors or changes in psychiatric and/or medical condition(s).

Second, in the current (dissertation) study the assessment of RVIP occurred during an actual attempt to quit or cut down. Therefore performance should reflect cognitive performance under these conditions. In contrast, Kang (2013) assessed RVIP performance after overnight abstinence but not during a quit attempt. Thus, the current study has greater ecological validity because it assessed cognition during an actual attempt to reduce smoking.

Additionally, RVIP performance assessed during random assessments (when participants had reported smoking so far that day) was not a significant predictor of one's ability to reduce smoking. That is, it is RVIP performance assessed during abstinence that is most strongly linked to smoking. This finding is similar to that reported in Kang (2013). In Kang (2013), abstinence-induced decrements in RVIP were associated with outcome. Overall, it seems that RVIP performance in abstinence (versus non-abstinence) is most strongly associated with smoking.

While RVIP false alarms were predictive of smoking, baseline impulsivity, as assessed with the Go-No-Go task, was not associated with smoking. It is important to note that impulsivity is multidimensional (c.f., Stevens et al., 2014; Pitts & Leventhal, 2012). It may be the case that false alarms on the RVIP and performance on Go No-go tasks are tapping into different aspects of impulsivity. False alarms (commission errors) on the RVIP task are determined by pressing the button on a non-target stimulus (irrespective of having a dominant response) while on the Go No-go task, commission errors are determined by pressing the button on a non-dominant response (i.e., difficulty withholding a dominant response). One may suspect that the RVIP commission errors reflect difficulty with modulating anticipation and acting prematurely, which is a subtle

difference from the Go No-Go task. Another difference between the RVIP and the Go No-Go task is that the former was administered both during abstinence and when smoking, and the latter was only assessed in the lab (i.e., not during abstinence). Future studies may consider investigating what facets of impulsivity are most pertinent to successful smoking cessation when assessed daily in the field.

AIM 3: RVIP AS A MODERATOR VARIABLE

There was evidence that the number of false alarms and mean RT moderated the association between craving and smoking. Specifically, for subjects who committed more abstinence-induced false alarms, the association between craving and CO levels was stronger. Similarly, as processing speed during abstinence worsened (i.e. mean RT got longer), the association between craving and CO levels during the quit attempt became stronger. These findings are consistent with hypotheses but should be treated with caution given that only three participants contributed data (14 data points) to these analyses (refer to Table 11). That is, only three subjects presented with data on contributing variables (i.e., RVIP during abstinence in Week 1 as well as craving and CO data during Week 2). There were no significant moderation effects for attentional bias or other RVIP indices. The small sample size reduced the power and ability to detect significant moderation effects as well as confidence in the findings. More research is needed to investigate the moderation hypotheses.

LIMITATIONS

The study had a number of limitations. The main limitation was the high attrition rate. The high attrition rate has a number of consequences. First, it reduces the generalizability of findings. It is not certain that the current results generalize to the

broader population of smokers targeted in this study, given that analyses were conducted on a self-selecting sample of subjects who were able to tolerate and follow the study procedures. This is particularly true for analyses involving Week 2 data because only 50% of participants provided that data. With that said, the study did not find significant differences in baseline demographics, smoking characteristics, and general neurocognitive functioning between completers and non-completers, suggesting that the final sample was not markedly different from the initial recruitment group. The study results may also not generalize beyond individuals who are contemplating or preparing for a future quit attempt.

Second, the high attrition rate, together with incomplete daily data, reduced the power of analyses, and increased the probability of type II errors. This may have particularly impacted the power to detect significant interactions. At a minimum, the study had less power than anticipated to test study hypotheses. The fact that there were significant findings appears to mitigate this concern to some degree. However, the study tested many hypotheses, and there was no correction for multiple testing. In addition, low power remains a significant concern, even if significant results are obtained (Button et al., 2013). For example, Button et al. (2013) argued that in research domains in which studies were underpowered, under some conditions the majority of reported positive findings constitute false positives (rather than true positives).

Third, one may question whether the parameter estimates and p-values produced by linear mixed models are valid with such small sample sizes. Simulation studies have been used to test the robustness of linear mixed models employed on small sample sizes. Maas and Hox (2005) found that when the true effect was a medium effect size,

regression coefficients and their standard errors were relatively robust when 10 level-2 units (in this case subjects) were used, with 5 observations for each subject (i.e., 50 data points in total). Although reassuring, some analyses in the current study had fewer level-2 units, and so the robustness of the procedures with datasets smaller than 50 observations is not known. Maas and Hox (2005) note that bootstrapping approaches may be useful in small samples (Yung and Chan, 1999). Future research could use these small sample approaches for data analysis to confirm the findings presented in this dissertation study. Bootstrapping approaches would be particularly useful for analyses of data involving false alarms because the distribution of number of false alarms appeared to be positively skewed.

Fourth, in common with all linear mixed model analyses, parameter estimates may be biased if the missing data are not missing at random (NMAR). Stated another way, the models only provide unbiased parameter estimates if the missing data are completely missing at random (MCAR), or else if missingness is accounted for by the independent variables (known formally as "missing at random", MAR). If missingness is related to the value of the dependent variable, then parameter estimates may be biased. Therefore the current data, and especially the p-values, should be considered preliminary and treated with caution, pending replication in larger datasets.

Fifth, the study also had some limitations of a technical nature. There was an apparent calibration problem with the mobile CO monitor. Although the true CO levels could be estimated with the regression procedure, there is some uncertainty regarding the accuracy of the cut-off values used. However, it is important to note that the readings

from the mobile CO monitor correlated highly with the CO readings from the "gold-standard" laboratory CO monitor.

Participants also received feedback on their CO levels at each CO assessment. Although this may have clinical utility, the information (CO level) provided may influence target behavior (smoking), potentially reducing the generalizability of study findings. In future studies, CO could be assessed without participants knowing the level.

Finally, as abovementioned, the study had interpretative limitations. The study investigated associations between cognition and smoking in the field. However, it is possible that given the boring and frustrating, and repetitive, nature of the study protocol, RVIP performance not only captures cognitive performance, but also motivational factors, task persistence, or frustration tolerance. Previous research has shown that task persistence or distress tolerance is associated with substance treatment outcomes. Specifically, opioid drug users with a greater ability to tolerate frustration were shown to have better treatment outcomes (Strong et al., 2012). Similarly, cigarette smokers who were more persistent were able to maintain sustained abstinence, and this effect was independent of other relevant factors including nicotine dependence (Brandon, Herzog, Juliano, Irvin, Lazev, Simmons, 2003). Future research will be required to disentangle these alternatives.

One possible approach to further examine the reliability and validity of RVIP performance would be to compute a subject-specific measure of internal reliability for each RVIP index. For example, data from participants who exhibit adequate internal reliability on mean RT could be analyzed separately from those who did not exhibit adequate reliability on mean RT. It would be interesting to examine if the RT data from

participants with more reliable data exhibits stronger relationships with outcome variables than the RT data from participants with lower reliability. Another possibility is to examine the impact of RT variability; participants with less variable data may provide more reliable data.

STRENGTHS

The study also had a number of strengths. It is the first study to deploy the RVIP task in the field. This enabled assessing RVIP performance before and during an actual cut down/quit period. That is, assessing sustained attention on a daily basis during the cut down/quit period was novel. The relatively brief two-week study also reduced the potential for extraneous factors (e.g., changes in psychiatric and/or medical conditions) influencing sustained attention or smoking.

Further, the study may have captured an ecologically valid measure of sustained attention and perhaps introduced an avenue for a more comprehensive understanding of the relationship between sustained attention and smoking. First, the study assessed sustained attention as individuals were actually trying to quit or cut down. Second, there are several factors competing for one's attention in a naturalistic setting, and therefore assessment in a real-world context may be more ecologically valid than a laboratory setting. Additionally, although our findings on false alarms are different from those reported in Kang (2013), an association between impulsivity and smoking has been found using other measures of impulsivity (e.g., Bold, Yoon, Chapman, & McCarthy, 2013; Powell et al., 2010; Dallery & Raiff, 2007; Rukstalis, Jepson, Patterson, & Lerman, 2005).

This study was also the first to use a mobile CO monitor to assess daily smoking during EMA. This novel approach permitted subjects to submit CO readings in their

natural environment without returning to the laboratory, and therefore provided more detailed data on daily smoke exposure than is typically obtained.

IMPLICATIONS AND FUTURE DIRECTIONS

There are several clinical implications and future research directions that could be explored.

Assessment of Sustained Attention in the Field

Valid assessment of sustained attention in the field may be valuable. Investigating when someone is most at risk for a lapse or relapse would inform when (and what type) of interventions are most in need. In light of the novel pattern of RVIP performance, including the findings regarding false alarms, replication of these findings is critical. More research using this abbreviated version of the RVIP task with a larger sample sizes is warranted.

As mentioned earlier, research may benefit from determining the shortest task duration that yields useful information. However, one should bear in mind that although an RVIP task of brief duration may be useful, it may not assess "sustained attention" in the same way that a longer task does. It would also be useful to examine the optimal daily number of assessments. For example, one could manipulate the number of daily assessments as an independent variable and examine the relative utility of RVIP measures under different conditions. Moreover, in future research it would be useful to investigate the associations between reported interruptions (and task effort) and RVIP performance. For example, it is possible that associations between RVIP performance and smoking are most robust on assessments where participants reported high effort or few or no interruptions. The effects of caffeine use and withdrawal on RVIP performance could

also be investigated. Similarly, the effect of reported sleep and fatigue could be examined. Also, the effect of number of assessments on RVIP performance could be examined to examine changes in performance over time. Similarly, within-assessment changes in RVIP performance may provide useful information about the robustness of sustained attention over a 4-minute period that may be related to smoking. For example, smokers whose sustained attention is robust over 4 minutes may be better able to resist temptations to smoke. It would also be interesting to manipulate financial incentives for RVIP performance to determine the effect and utility of providing financial or other rewards for good performance.

Future analyses may separate out the between- and within-subject associations present in the multilevel data from hypotheses 2.1 and 2.2 (Hedeker et al., 2009). Given the small sample sizes, this was considered beyond the scope of the current dissertation. Additionally, analyses for future studies may examine data from the RVIP tasks administered during random assessments (in both weeks 1 and 2) in more detail. For example, one could examine the association between RVIP performance and self-reported cigarettes smoked (on the PDA). Future studies may consider assessing CO at every assessment and examining RVIP performance as a function of smoking.

As noted earlier, the RVIP task assesses sustained attention but also has a working memory component. It would be instructive in future studies to examine the relative contributions of the sustained attention and working memory components. For example, one could manipulate the working memory demands of the task (e.g., by manipulating the number of digits to be retained in short-term memory) separately from the sustained

attention component. Alternatively, separate tasks assessing working memory and sustained attention could be used.

Assessment of CO in the Field

The mobile USB CO monitor used in the field simplified the process of obtaining CO readings daily that fit well with the EMA paradigm. We were able to capture CO readings in the subjects' natural environment daily with relative ease and subjects did not need to attend the laboratory for these assessments. Additionally, the clinical utility of this monitoring is evident. For example, mobile assessment of CO could be used to validate abstinence in contingency management interventions (Bold, Yoon, Chapman, & McCarthy, 2013). Future studies using larger samples and smokers motivated to quit (rather than cut-down or quit for a week) can examine associations between sustained attention and daily abstinence. As noted earlier, qualitative data were collected on participants' perceptions the RVIP task and CO monitor. Additional analyses of these interview data, (e.g., using thematic analyses) may be useful in determining the potential utility of CO feedback.

Future research efforts could be devoted toward investigating smartphone-based CO monitor applications. This would further facilitate the process of obtaining CO readings and enable the opportunity to collect these readings anywhere and at any time they are able to use their smartphones. One research group has tested a prototype of a smart-phone based breath CO monitor (Meredith et al, 2014). They reported that it was acceptable to study participants and found that it reliably and accurately distinguished between smokers and non-smokers. Indeed this is a burgeoning area of interest. There is

now a commercially available expired air carbon monoxide monitor (iCO™) for use with smartphones or tablets (Bedfont Scientific Ltd., UK).

Real-world assessment of CO will be useful in both research and clinical contexts. In a research context, the CO data may provide a more sensitive index of smoking behavior than self-report. This will be useful both for testing theory as well as for testing the efficacy of interventions. For example, mobile CO monitors may be able to test the theory that people smoke more intensely when experiencing negative affect. Clinically, mobile CO monitors may be used to confirm abstinence in contingency management programs.

Table 1. Summary of studies examining RVIP performance in nicotine addiction.

Study	Population	Nicotine Conditions	Blinding	Acute Nicotine vs. Acute Abstinence	Administration Route	Primary Independent Variables (Task[s])	Primary Outcome Variables (Task[s])	RVIP Findings	Notes
Wesnes & Warburton (1983)	Experiment 1: *N*=24 male undergrad smokers. Experiment 2: *N*=12 male and female undergrad smokers	Exp1: cigarettes 0.28 (Con), 0.71, 1.65 mg nicotine. Exp2: nicotine-free (Con), 0.60, & 1.84 mg nicotine	Unspecified	Acute nicotine	Cigarette	Condition; Time	RIPT (Hits, RT, Omission errors)	**Nicotine improved RIPT performance** (decreased RT & increased Hits), relative to baseline. Exp1: greatest improvements with highest nicotine and tar cig. Exp2: performance worse over time with no to less nicotine.	Two Experiments (only males in expt1 and both sexes in epxt2)
Edwards et al. (1985)	*N*=19 male undergrad smokers	No smoking, 0.9, 1.5mg nicotine cig	Unspecified	Acute nicotine	Cigarette	Condition	RVIP (Hits, RT, Omission errors)	**Acute nicotine improved RVIP** performance (increased Hits & decreased RT), relative to baseline smoking and 12-hr deprivation; no trade-offs b/w RT and Hits.	ERP recording
Petrie & Deary (1989)	*N*=12 smokers	Smoking vs. No-smoking	Unblind	Acute nicotine	Cigarette	Condition; Task trials	RVIP (Hits, RT, False Alarms)	**Acute nicotine improved RVIP**. Only RT decreased, during first 5mins of task (not Hits or FA).	Other cognitive tasks (digit symbol substitution test, inspection time test)
Parrott & Craig (1992)	*N*=16 smokers	placebo gum, 2mg nicotine gum, 4mg nictotine gum, cigarette smoking (own brand; all low/medium nicotine)	Double-blind	Acute nicotine	Nicotine gum & cigarette	Condition; Time	RVIP (Hits, RT, False Alarms)	**Acute nicotine improved RVP performance** (decreased RT & increased Hits) compared to placebo.	Monotonic dose-response for Hits at post-test 1. Curvilinear dose response effect (inverted U) for Hits and RT at post-test 2. Other cognitive tasks.

Foulds et al. (1996)	*n*=18 Abstainers & *n*=18 Never smokers	Abstainers vs. Never-smokers; 0.3mg nicotine x2, 0.6mg nicotine x2, saline placebo	Double-blind	Acute nicotine	Subcutaneous injection	Condition; Time	RVIP (Hits, RT, sensitivity)	**Acute nicotine improved RVP performance.** For abstinent smokers: increased hits, shorter RT, increased sensitivity. For never-smokers: shorter RT.	Other cognitive tasks
Herbert et al. (2001)	*N*=45 College & staff smokers	Ad lib smoking before testing (55% smoked within 30mins & 2 Ss didn't smoke for 10+hrs) vs. "Abstinent"; distraction (music video)	Unblind	Acute nicotine	Cigarette	Condition; Time	RVIP (Hits, RT, False Alarms)	**Acute nicotine didn't improve RVIP** performance in non-deprived smokers.	Mood measures
File et al. (2001)	*n*=16 nicotine condition & *n*=16 placebo condition; never-smoking med students	Nicotine inhaler vs. Placebo inhaler	Double-blind	Acute nicotine	Nicorette inhalator	Condition; Time; Gender	RVIP (Hits, RT)	**Acute nicotine had no effect on RVIP** on never-smokers, although there was a ns trend of increased Hits.	All Ss never-smoking Medical students. No control or comparison groups (all were never-smoking med students). Other cognitive and mood measures.
Lawrence et al. (2002)	*n*=15 smokers & *n*=15 non-smokers	Nicotine vs. Placebo	Unblind	Acute nicotine	Transdermal patch	Condition; Smoking status; Order of nicotine	RVIP (Hits, RT, False Alarms)	**Acute nicotine improved RVIP performance** (increased accuracy and decreased RT).	fMRI, mood measures
Poltavski & Petros (2005)	*N*=47 College Males; *n*=25 Smokers (*M*=13 cig/day) & *n*=22 Non-smokers	Smokers vs. Non-smokers; Nicotine patch vs. Placebo patch	Double-blind	Acute nicotine & acute abstinence	Transdermal patch	Condition; Time	RVIP (Hits, RT)	**No group differences on RVIP** (never-smokers = smokers in placebo or nicotine condition) - no acute nicotine or acute abstinence.	Other cognitive & physiological measures

Hendricks et al. (2006)	*N*= 50 Smokers	Abstainers vs. Ad-lib Smokers	Unblind	Acute abstinence	N/A	Condition; Time	RVIP (RT, Omission and Commission errors)	**Acute abstinence impaired RVIP performance (**decreased RT within 30mins. of deprivation).	No effects found for RVIP omission errors and FA. Withdrawal measures (e.g., WSWS).
Kelemen & Fulton (2008)	*N*=41 "Moderate" College smokers	Abstinent vs. Non-abstinent sessions; Nicotine gum vs. Placebo gum	Double-blind	Acute nicotine & acute abstinence	Nicotine gum	Condition	RVIP (Hits, RT, False Alarms)	**Acute nicotine improved RVIP performance** (increased hit rate but no increase in false alarms). **For 8-hr abstainers nicotine associated with poor sustained attn** (decreased Hits & increased RT).	Other cognitive tasks
Rusted & Alvares (2008)	*N*=48 Never-smokers college students	Nicotine nasal spray vs. Placebo nasal spray	Double-blind	Acute nicotine	Nasal spray	Condition; Stress (low, high)	RVIP (Hits, RT, False Alarms)	**Nicotine improved RVIP performance.** (Decreased RT compared to placebo in never-smokers. No effects on Hits or FA.	Other cognitive, mood, physiological measures
Leventhal et al. (2010)	*N*=203 smokers not attempting to quit.	Abstinent vs. Non-abstinent (ad-lib smoking) sessions	Unblind	Acute abstinence	N/A	Condition	RIPT (Hits, RT, False Alarms)	**Acute abstinence impaired RIPT performance** (delayed RT & decreased hit rate).	Subjective, other cognitive, mood, & physiological measures
Juliano et al. (2011)	*N*=148 smokers	Nicotine cig vs. Placebo cig	Balanced placebo design	Acute nicotine	Cigarette	Condition; Expectancy (told placebo vs. told cig)	RVIP (RT, Hits, sensitivity)	**Nicotine improved RVIP performance.** Increased Hits, decreased RT, & increased Sensitivity. Expectancy effect of dose for False Alarms (increased FA with placebo instructions compared to nicotine instructions=people expected to do worse and did worse if placebo).	Mood

Nesic et al. (2011)	*N*=48 smokers	Non-abstinence vs. Abstinence		Acute nicotine	Cigarette	Condition; Time; Nicotine Dependence Level (low, high)	RVIP (Hits, RT, False Alarms)	**No effects on RVIP, but likely due to practice effects** (administered 4xs within single day); improvements found across administrations for Hits, FA, and RT. However, less improvement found in the high nicotine dependent group, relative to low dependent (suggesting reduced plasticity [ie, practice effects] in higher dependents).	Other cognitive & mood measures.

Table 2. A comparison of laboratory and EMA methodologies and their respective characteristics.

Laboratory Setting	**Field Setting (EMA)**
Controlled	Uncontrolled
High internal validity	Lower internal validity
Low external/ecological validity	Higher external/ecological validity
Relatively small number of assessments per subject	Relatively large number of assessments per subject
Difficult to examine within-subject associations	Easy to examine within-subject associations

Table 3. Outline of masters and dissertation studies

Smoking Outcome → Variable Type ↓	**Smoking Cessation**	**Cutting Down/Cessation**
RVIP as Predictor Variable	Master's thesis (Kang, 2013) (Project Cognition)	Dissertation Study (EMA Study) Aim 2
RVIP as Moderator Variable	TBD	Dissertation Study (EMA Study) Aim 3
Shipley IQ	TBD	Dissertation Study Exploratory Aim
NIH ToolBox, Cognition Battery Go/No-go Task	N/A	Dissertation Study Exploratory Aim

Note: TBD = to be evaluated in future research

Table 4. Study Procedures Timeline

Study Procedures → **Day of Study →**	**Scr.**	**Visit 1** **1**	**Field** **1-8**	**Visit 2** **8**	**Field** **8-15**	**Visit 3** **15**
Location	Phone	USU	Field	USU	Field	USU
Inclusion/Exclusion Screening	X	X				
Laboratory Procedures						
Obtain informed consent		X				
[a]Assignment into Wk 1 condition order		X				
Wk 2 Cut-down/quit attempt instructions				X		
Equipment return						X
Debriefing/post-experimental interview						X
Laboratory Assessments						
Questionnaires						
Demographics		X				
Smoking history		X				
SASEQ/Overall ratings		X		X		X
FTND		X				
WSWS		X				
QSU-B		X				
Medical/Psychiatric						
General psychiatric		X				
Neurological condition		X				
Handedness & vision problems		X				
Alcohol use		X				
Caffeine use		X				
ADHD diagnosis		X				
Psychotropic & stimulant medication use		X				
Biochemical						
Breath CO		X		X		X
Saliva Cotinine		X		X		X
Neuropsychological						
NIH Toolbox, Cognition Battery		X				
Shipley		X				
PDA						
RVIP		X				
Smoking Stroop		X				
Go/No-Go		X		X		X
Field Assessments						
[b]Subject-initiated assessments (home PDA)			X		X	
[b]4 daily RAs (field PDA)			X		X	
Remote CO monitoring			X		X	
Nightly smoking diary			X		X	
Compensation						
Laboratory sessions		$15		$15		$15
Compliance with manipulation			$2			
Valid subject-initiated PDA assessments			$2		$2	$2
Valid and complete RAs		$1	$1		$1	$1
Daily data contribution		$5	$5	$5	$5	

Note. RVIP=Rapid Visual Information Processing Task; SASEQ=Smoking Abstinence Self-efficacy Questionnaire; FTND=Fagerstrom Test for Nicotine Dependence; WSWS=Wisconsin Smoking Withdrawal Scale; QSU-B= Questionnaire for Smoking Urges-Brief (10 items).

[a] Conditions: AN=Acute Nicotine (smoking before RVIP); AA=Acute Abstinence (RVIP before smoking); Date of Condition switch was assigned at Visit 1.

[b] On PDA: Minnesota Nicotine Withdrawal Scale; recency of last cigarette smoked; self-reported attentional bias; caffeine source and recency; substance use and recency; mood; general physiological state (fatigue, alertness, stress, hunger, pain); environmental context (company and setting); RVIP; interruption inquiry; boredom and effort inquiries.

Table 5. Baseline Characteristics

Variable ↓		**Whole Sample**	**Completers**	**Non-Completers**	**t/χ^2**	***df***	***p***
		***N*=22**	***n*=11**	***n*=11**			
Age		45.0 (13.9)	47.7 (13.5)	42.3 (14.4)	-0.92	20	.37
Gender					0.19	1	.66
	F	59.09%	55.55%	63.64%			
	M	40.91%	45.45%	36.36%			
Race					0.28	2	.87
	White	22.73%	27.27%	18.18%			
	Black	59.09%	54.55%	63.64%			
	Other	18.18%	18.18%	18.18%			
Education					0.92	1	.34
	No College	27.27%	36.36%	18.18%			
	College	72.73%	63.64%	81.82%			
Income**					0.04	1	.84
	<$30K	47.62%	45.45%	50.00%			
	>$30K	52.38%	54.55%	50.00%			
Stage of Change					0.00	1	1.00
	Prep[§]	54.55	54.55%	54.55%			
	Contemp[§]	45.45%	45.45%	45.45%			
Cigarettes/Day		16.32 (10.57)	13.82 (4.26)	18.82 (14.24)	1.12*	11.78	.29
FTND		4.18 (2.28)	3.54 (2.21)	4.82 (2.27)	1.33	20	.20
QSU		21.64 (7.05)	19.45 (8.42)	23.82 (4.81)	1.49	20	.15
RVIP-Hit (no.)		12.40 (5.25)	11.45 (5.32)	13.56 (5.22)	0.89	18[#]	.39
RVIP-RT (ms)		688.34 (332.77)	682.17 (393.45)	695.88 (263.38)	-0.62	18[#]	.55
RVIP-FA (no.)		22.75 (18.45)	25.09 (20.83)	19.89 (15.79)	0.09	18[#]	.93
Shipley		98.00 (11.24)	100.00 (9.04)	96.00 (13.21)	-0.83	20	.42
NIH Total Composite		112.37 (16.73)	110.25 (12.50)	114.49 (20.52)	-0.58	20	.57

NIH Fluid Composite	104.45 (16.96)	98.62 (12.88)	110.28 (19.06)	-1.68	20	.11
NIH Crystallized Composite	116.61 (9.68)	119.59 (7.71)	113.63 (10.86)	1.48	20	.15
NIH Picture Vocabulary	114.76 (9.98)	119.02 (7.76)	110.50 (10.43)	2.17	20	.04
NIH Flanker Inhibitory	110.22 (15.47)	110.32 (14.94)	110.12 (16.71)	0.03	20	.98
NIH Working Memory	103.86 (12.08)	100.47 (8.95)	107.26 (14.18)	-1.34	20	.19
NIH Dimensional Change Card Sort	107.58 (13.13)	102.39 (10.31)	112.77 (14.01)	-1.98	20	.06
NIH Process Speed	104.82 (20.42)	95.57 (11.98)	114.07 (23.33)	-2.34*	14.93	.03
NIH Picture Sequence Memory	98.40 (13.35)	94.65 (12.31)	102.15 (13.84)	-1.34	20	.20
NIH Cog Reading Recognition	116.75 (10.63)	118.15 (9.77)	115.36 (11.73)	0.61	20	.55

Note: Data are *Mean* (*SD*) for continuous measures and % for categorical measures. Completers are defined as participants who attended all three lab visits. t/χ^2 are for comparisons between Completers and Non-Completers. *Satterthwaite t-test used; **n=21; $^{\#}n$=20; §Preparation, Contemplation

Table 6. Compliance Measures

	Week	Time	Denominator	Numerator (Proportion, %)
Completers	1	n/a	22 subjects	15 (68.12%) subjects
Completers	2	n/a	22 subjects	11 (50.00%) subjects
Week 1				
Home PDA Assessments	1	AM	90 days[a]	63 (70.00%) PDA assessments
Usable Video Recordings – first reading	1	AM	90 days[a]	45 (50.0%) recordings
Usable Video Recordings– second reading	1	AM	90 days[a]	46 (51.0%) recordings
CO– first reading	1	AM	90 days[a]	69 (76.7%) readings
CO– second reading	1	AM	90 days[a]	66 (73.3%) readings
Usable Home PDA Assessments	1	AM	90 days[a]	38 (42.22%) days[1]
RAs (Field PDA)	1	All Day	298 RAs[b]	122 (40.90%) RAs
Week 2				
Home PDA Assessments	2	AM	66 days[c]	50 (75.76%) PDA assessments
Usable Video Recordings	2	AM	66 days[c]	40 (60.6%) recordings
Usable Video Recordings	2	PM	66 days[c]	37 (56.1%) recordings
CO readings	2	AM	66 days[c]	61 (92.42%) readings
CO readings	2	PM	66 days[c]	50 (75.76%) readings
Usable Home PDA Assessments	2	AM	66 days [c]	38 (57.58%) days[2]
RAs (Field PDA)	2	All Day	187 RAs[d]	98 (52.41%) RAs

Note: [a]15 subjects x 6 days; [b]14 subjects over 6 days; [c]11 subjects x 6 days; [d]10 subjects x 6 days; AM = procedures completed upon awakening; PM = procedures completed at the end of day. CO readings can derive from one or more sources (video recordings; email report; self-report). [1]23 (25.56%) days had CO $\leq$ 10 ppm; [2]23 (34.85%) days had CO $\leq$ 10 ppm.

Table 7. Laboratory Measures

	Visit 1	**Visit 2**	**Visit 3**
	***N*=22**	***n*=15**	***n*=11**
CO* (ppm)	13.90	14.25	7.66
	(6.50)	(10.62)	(4.93)
Cotinine (ng/ml)	399.52	322.15	206.23
	(254.53)	(247.69)	(158.94)
Errors No-Go (%)	46.20	48.53	39.64
	(25.71)	(15.92)	(29.90)
Errors Go (%)	14.68	5.27	4.41
	(14.93)	(4.09)	(5.80)
Go No-Go (RT; ms)	390.41	338.76	314.44
	(147.78)	(107.49)	(139.44)

Note: Laboratory data from all available subjects (completers and non-completers) are shown. Data are *M* (*SD*). For Go No-Go task, ns are 20 (Visit 1), 15 (Visit 2), 11 (Visit 3); *Predicted CO values based on regression (see text).

Table 8. Week 1 Summary Statistics

Condition →	**AA**	**AA**	**AA**	**AA**	**AN**	**AN**	**AN**	**AN**
Measure ↓	Day 1	Day 2	Day 3	Mean	Day 1	Day 2	Day 3	Mean
CO Reading 1	7.06	11.54	9.16	9.37	12.90	15.49	11.34	13.18
(ppm)	(4.55)	(14.75)	(7.36)	(9.55)	(6.13)	(14.93)	(10.09)	(10.92)
Smoke?	***No***	***No***	***No***	***No***	***Yes***	***Yes***	***Yes***	***Yes***
CO Reading 2	n/a	n/a	n/a	n/a	15.29	17.35	16.10	16.34
(ppm)	n/a	n/a	n/a	n/a	(5.85)	(13.40)	(8.87)	(9.67)
Craving (1-7)	4.40	4.33	4.00	4.22	2.80	3.00	3.50	3.15
	(1.52)	(0.52)	(2.00)	(1.44)	(1.48)	(1.53)	(1.51)	(1.46)
RVIP-Hit (no.)	14.00	9.67	9.71	10.89	12.40	17.57	17.63	16.30
	(6.12)	(9.27)	(8.75)	(8.07)	(10.76)	(10.41)	(9.71)	(9.93)
RVIP-RT (ms)	568.93	578.34	595.05	582.23	627.07	470.17	487.64	516.38
	(132.04)	(206.46)	(198.22)	(175.23)	(203.74)	(104.81)	(134.58)	(152.45)
RVIP-FA (no.)	6.20	5.17	5.71	5.67	4.80	4.43	9.50	6.55
	(5.40)	(5.27)	(4.61)	(4.77)	(6.38)	(6.27)	(15.92)	(10.98)
CO Reading 2	7.43	12.06	9.24	9.70	n/a	n/a	n/a	n/a
(ppm)	(4.39)	(15.26)	(7.60)	(9.70)	n/a	n/a	n/a	n/a

Note: Data are *Mean* (*SD*) for the 12 participants who provided usable home PDA data for Week 1. All data are from morning assessments from the home PDA (data from the field PDA not shown). Measures are listed in chronological order. Reading 1 data refer to the first assessment of the morning (always before smoking). Reading 2 refer to data after smoking in the AN (Smoking) condition and to data during abstinence in the AA (Abstinence) condition. Days 1-3 reflect the three days in the abstinence and smoke conditions. Order of condition assignment was counterbalanced across participants. Data are shown from participants. For *Mean*, n = 18 days (AA) and n = 20 days (AN). For days 1-3, n's vary due to missing data.

Table 9. Week 2 Summary Statistics

Study Day→		9	10	11	12	13	14	Mean
Measure ↓	**Time**							
CO (ppm)	AM	9.74	7.97	8.34	8.52	5.81	5.22	7.48
		(8.45)	(6.09)	(4.46)	(7.85)	(4.02)	(4.00)	(5.63)
Craving (1-7)	AM	3.00	3.86	3.00	3.80	3.17	3.33	3.35
		(1.55)	(1.77)	(1.83)	(2.39)	(1.94)	(2.25)	(1.84)
RVIP-Hit (no.)	AM	7.83	10.57	11.29	11.20	8.33	8.67	9.68
		(7.36)	(8.46)	(8.26)	(10.66)	(10.41)	(7.69)	(8.29)
RVIP-RT (ms)	AM	538.25	566.28	519.70	653.98	530.37	530.03	553.07
		(108.28)	(106.17)	(115.26)	(91.76)	(108.43)	(154.59)	(116.12)
RVIP-FA (no.)	AM	8.83	7.14	5.14	3.00	3.33	3.83	5.32
		(14.62)	(7.86)	(5.43)	(4.53)	(3.72)	(5.64)	(7.62)
Stroop (ms)	AM	-36.00	75.40	35.08	35.13	16.83	20.79	30.08
		(103.24)	(181.58)	(88.46)	(92.50)	(60.08)	(90.69)	(100.97)
Cigs/day (no.)	PM	12.33	11.86	10.14	9.00	8.50	7.86	9.97
		(11.78)	(9.51)	(7.78)	(8.06)	(8.36)	(7.71)	(8.50)
CO (ppm)	PM	13.45	13.54	10.12	9.63	15.84	9.94	11.88
		(9.61)	(5.70)	(6.85)	(6.45)	(7.10)	(6.38)	(6.93)

Note: Data are *Mean* (*SD*) for the 7 participants who provided usable home PDA data for Week 2. PDA data are from morning assessments (data from the field PDA not shown). For days 9-14, maximum $n = 7$, *n*'s vary due to missing data. For *Mean*, *n*'s vary from 30 to 38.

Table 10. Results of LMMs for Week 1 Home PDA data

		n_1	n_2	**Condition**					**Condition x Day**				
	H			*df*	*PE*	*SE*	*F*	*p*	*df*	*PE*	*SE*	*F*	*p*
Craving	1.2	38	12	**1, 23**	**-1.02**	**0.34**	**8.49**	**.008**	2, 21	-0.23	0.78	0.46	.64
RVIP-Hit	1.2	38	12	**1, 23**	**4.00**	**1.46**	**7.51**	**.01**	2, 21	-2.26	3.56	0.51	.61
RVIP-RT	1.2	38	12	1, 23	-66.40	41.69	2.54	.12	2, 21	97.46	103.99	0.64	.54
RVIP-FA	1.2	38	12	1, 23	-0.56	0.87	0.12	.88	2, 21	-2.00	2.10	0.10	.91

Note. n_1 = no. of days; n_2 = number of subjects; H = Hypothesis. Analyses included all subjects who contributed at least one usable home PDA assessment during Week 1 (*n*=12). All models include the main effect of Day, a categorical variable with 3 levels (1, 2, 3). The columns labeled Condition show the results for the main effect of Condition (AN vs. AA). The comparison category is AA. The columns labeled Condition x Day show results for the Condition x Day interaction. *PE* = (unstandardized) parameter estimate; *SE* = standard error; *F* = *F* value from LMM.

Table 11. Prediction of Week 2 Smoking - Specific Aims 2 & 3

DV→				n_1	n_2	**Cigarettes Smoked Week 2**					n_1	n_2	**Evening CO level Week 2**				
IV↓	RVIP	Level	H			*df*	*PE*	*SE*	*F*	*p*			*df*	*PE*	*SE*	*F*	*p*
RVIP-Hit	Wk 1	Mean	2.1	30	5	1, 24	0.078	0.49	0.16	.87	23	5	1, 17	-1.16	1.31	0.78	.39
RVIP-RT	Wk 1	Mean	2.1	30	5	1, 24	0.003	0.007	0.13	.71	23	5	1, 17	0.004	0.02	0.04	.84
RVIP-FA	Wk 1	Mean	2.1	30	5	**1, 24**	**0.30**	**0.13**	**5.29**	**.03**	23	5	1, 17	0.27	0.61	0.20	.66
RVIP-Hit	Wk 2	Day	2.2	23	5	1, 16	-0.15	0.23	0.42	.53	20	5	**1, 13**	**-0.55**	**0.22**	**6.41**	**.03**
RVIP-RT	Wk 2	Day	2.2	23	5	1, 16	-0.008	0.004	3.07	.09	20	5	1, 13	0.006	0.007	0.74	.40
RVIP-FA	Wk 2	Day	2.2	23	5	**1, 16**	**0.41**	**0.19**	**4.78**	**.04**	20	5	**1, 13**	**0.48**	**0.19**	**6.19**	**.03**
RVIP-Hit x Wk2 Craving	Wk 1	Mean	3.1	16	3	1, 10	-0.09	0.63	0.02	.89	14	3	1, 8	0.61	0.82	0.56	.48
RVIP-RT x Wk2 Craving	Wk 1	Mean	3.1	16	3	1, 10	0.03	0.02	1.38	.27	14	3	**1, 8**	**0.08**	**0.03**	**9.44**	**.02**
RVIP-FA x Wk2 Craving	Wk 1	Mean	3.1	16	3	1, 10	0.14	0.66	1.66	.23	14	3	**1, 8**	**0.39**	**0.12**	**10.07**	**.01**
RVIP-Hit x Wk2 Stroop	Wk 1	Mean	3.2	15	3	1, 9	0.003	0.003	1.01	.34	13	3	1, 7	0.003	0.004	0.72	.42
RVIP-RT x Wk2 Stroop	Wk 1	Mean	3.2	15	3	1, 9	0.0003	0.0002	0.79	.45	13	3	1, 7	-0.0008	0.0004	5.53	.05
RVIP-FA x Wk2 Stroop	Wk 1	Mean	3.2	15	3	1, 9	0.001	0.001	0.70	.42	13	3	1, 7	-0.004	0.002	5.59	.05

Note. n_1 = no. of days; n_2 = number of subjects; H = Hypothesis. RVIP: Wk 1 = data from AA condition in Week 1 (home PDA) used as IV; Wk 2 = data from morning assessments (home PDA) used as IV. Level: Mean = Mean RVIP value used; Day = Daily RVIP value used. Analyses for H 2.1, 3.1 & 3.2 use Wk 1 morning assessments from AA condition with CO ≤ 10 ppm. Day is the only covariate. Analyses for H 3.2 use Wk 2 morning assessments with "timely" CO ≤ 10 ppm. Day is the only covariate. *PE* = (unstandardized) parameter estimate; *SE* = standard error; *F* = *F* value from LMM.

Table 12. Prediction of Week 2 Smoking - Exploratory Analyses

				n_1	n_2	Cigarettes Smoked Week 2					n_1	n_2	Evening CO level Week 2				
IV	Visit	Level	H			*df*	*PE*	*SE*	*F*	*p*			*df*	*PE*	*SE*	*F*	*p*
Shipley IQ	1	Subject	Expl	66	11	1, 54	0.16	0.25	0.39	.53	46	10	1, 35	0.08	0.26	0.09	.76
GNG: Errors on No Go	1	Subject	Expl	66	11	1, 54	-0.15	0.08	3.59	.06	46	10	1, 35	-0.05	0.08	0.34	.56
GNG: Errors on Go	1	Subject	Expl	66	11	1, 54	0.11	0.17	0.43	.51	46	10	1, 35	0.08	0.22	0.15	.70
GNG: Mean RT	1	Subject	Expl	66	11	1, 54	0.00	0.02	0.01	.93	46	10	1, 35	0.01	0.02	0.53	.47
Cotinine in Saliva	1	Subject	Expl	66	11	**1, 54**	**0.02**	**0.01**	**7.69**	**.008**	46	10	1, 35	0.02	0.01	2.47	.12
FTND	1	Subject	Expl	66	11	1, 54	0.75	1.02	0.53	.47	46	10	1, 35	0.86	1.01	0.73	.40

Note. n_1 = no. of days; n_2 = number of subjects. H = hypothesis; Expl = exploratory. Exploratory analyses use data from all 11 subjects who completed Week 2. Day is the only covariate. *PE* = (unstandardized) parameter estimate; *SE* = standard error; *F* = *F* value from LMM.

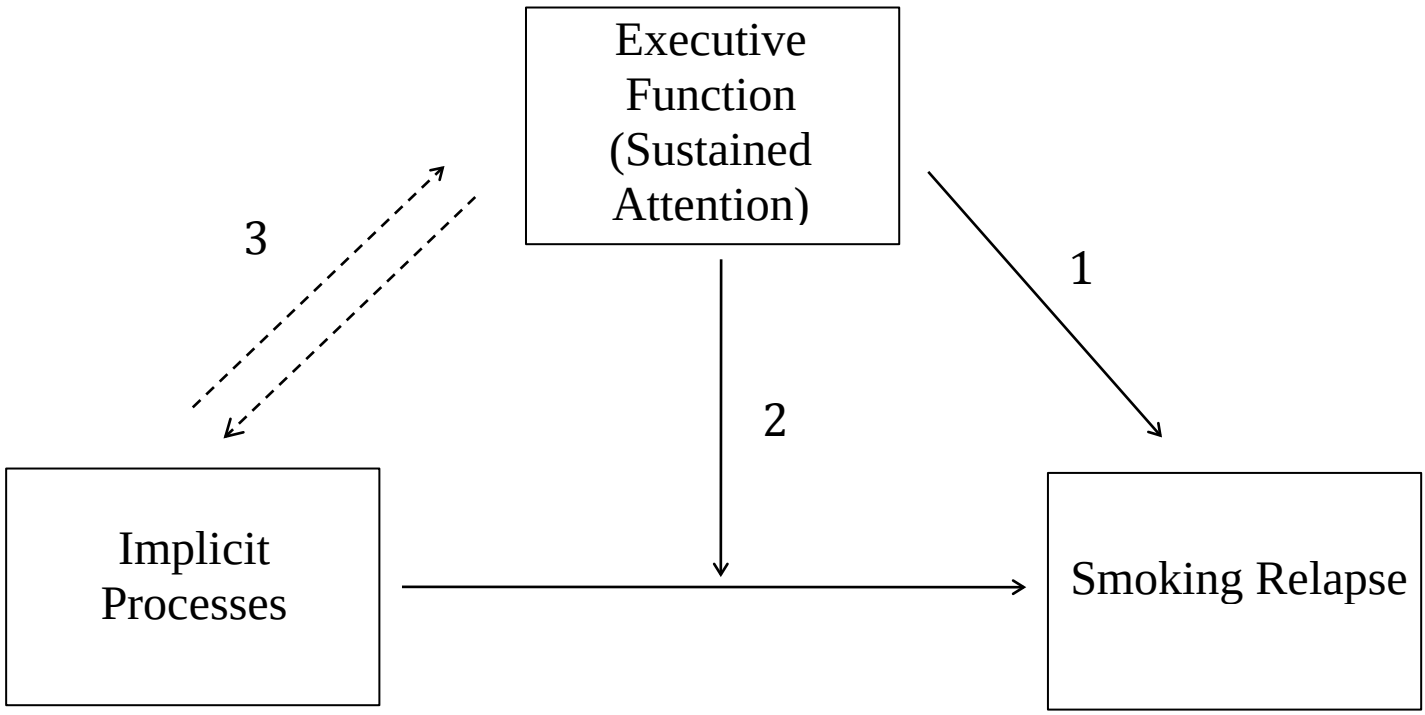


Figure 1. Conceptual Model. The key pathways examined in the current study are pathway 1 (which examines RVIP as a predictor variable, Specific Aim 2) and pathway 2 (which examines RVIP as a moderator variable, Specific Aim 3). Pathway 3 is shown in dashed lines as this was not examined in the current study.

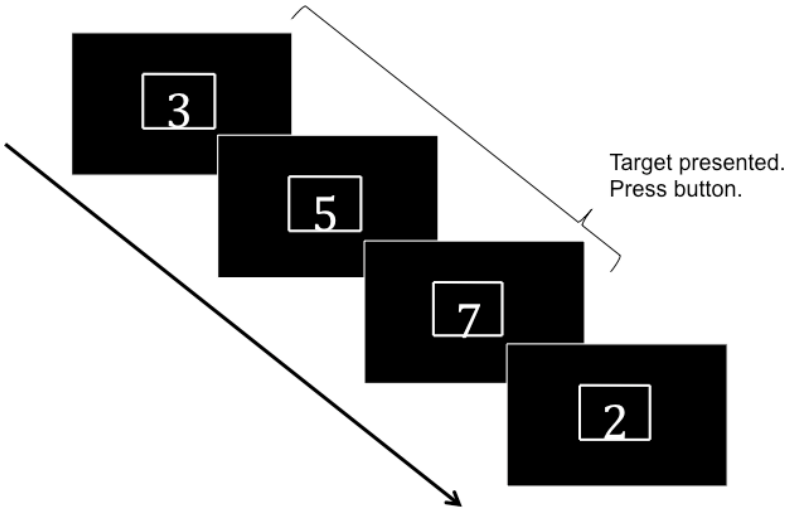


Figure 2. Sample serial presentation of the Rapid Visual Information Processing task.

Figure 3. The Rapid Visual Information Processing task on CANTAB hardware utilized in Kang (2013).

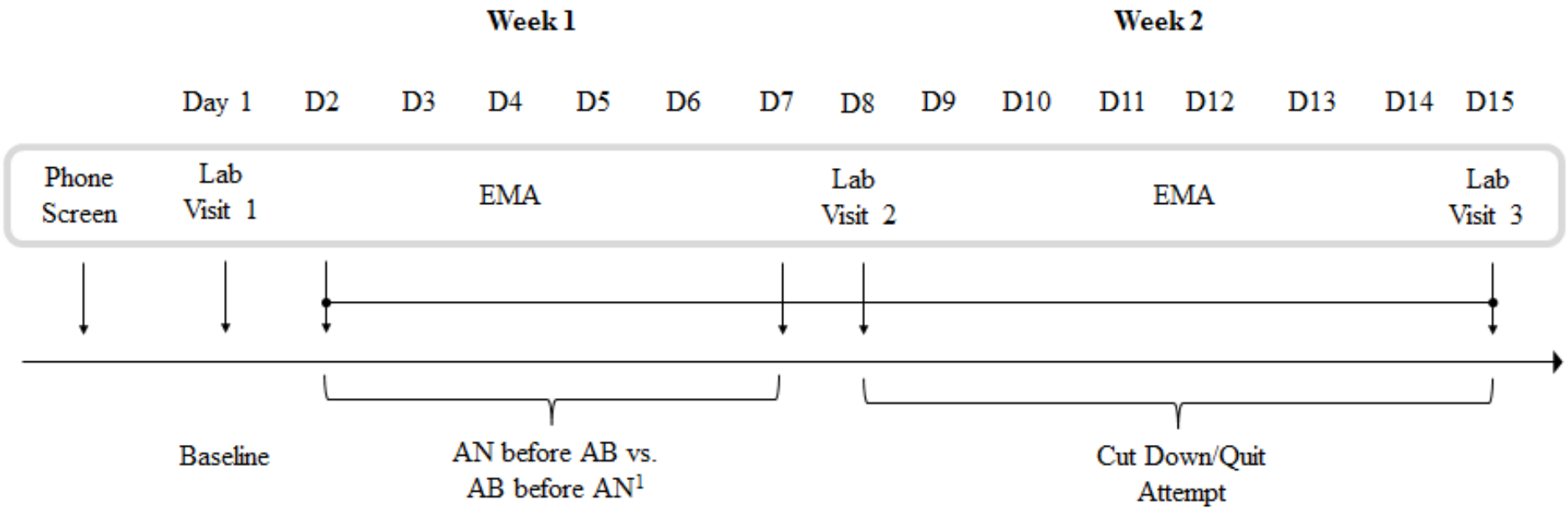


Figure 4. Major study procedures timeline. Randomized experimental condition order AN before AB = Acute Nicotine for 3 days before Acute Abstinence for the next 3 days. AB before AN = Acute Abstinence for 3 days before Acute Nicotine for the next 3 days.

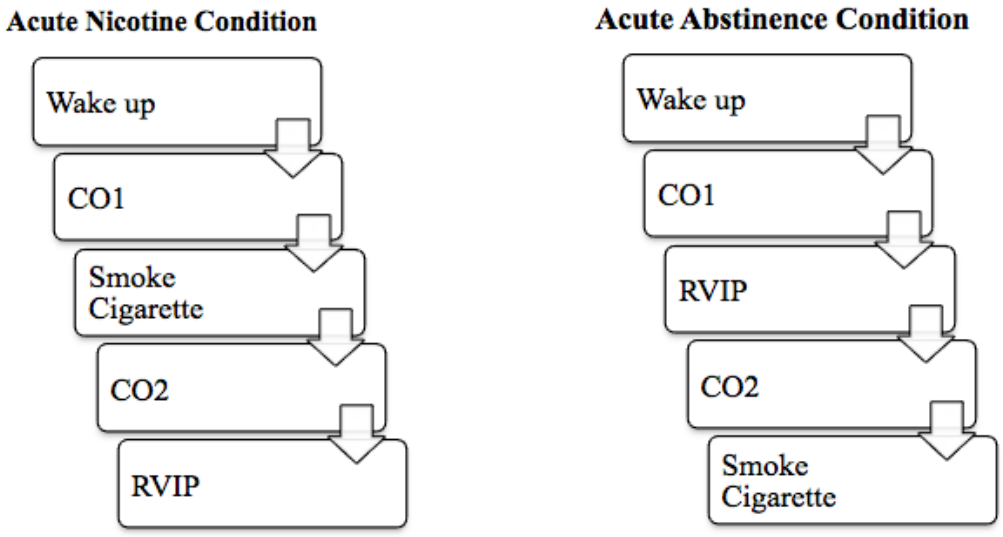
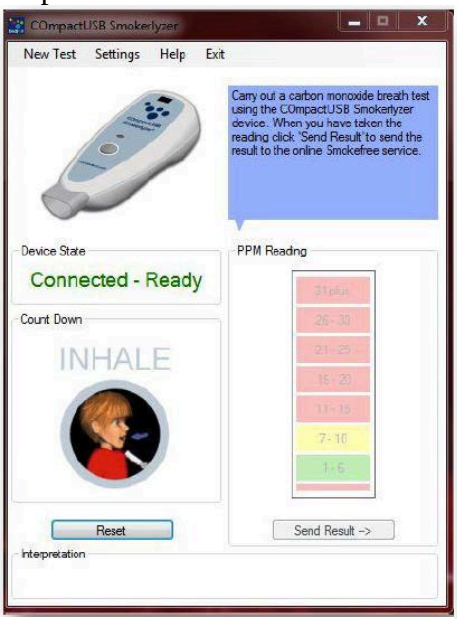
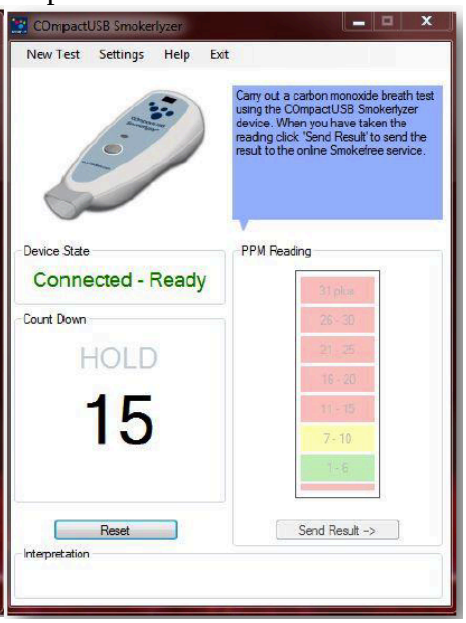


Figure 5. Week 1 experimental condition procedures.

Step 1



Step 2



Step 3

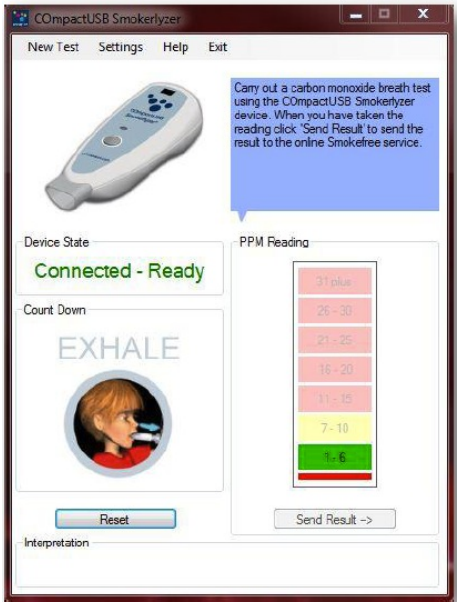


Figure 6. COmpact™USB device software main instructional steps to obtaining CO readings.

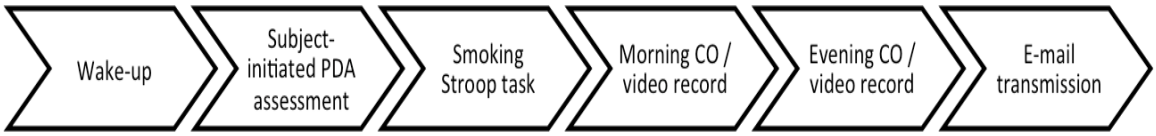


Figure 7. Week 2 study procedures. All morning tasks (cognitive assessments and morning CO reading) took place during an overnight abstinent state.

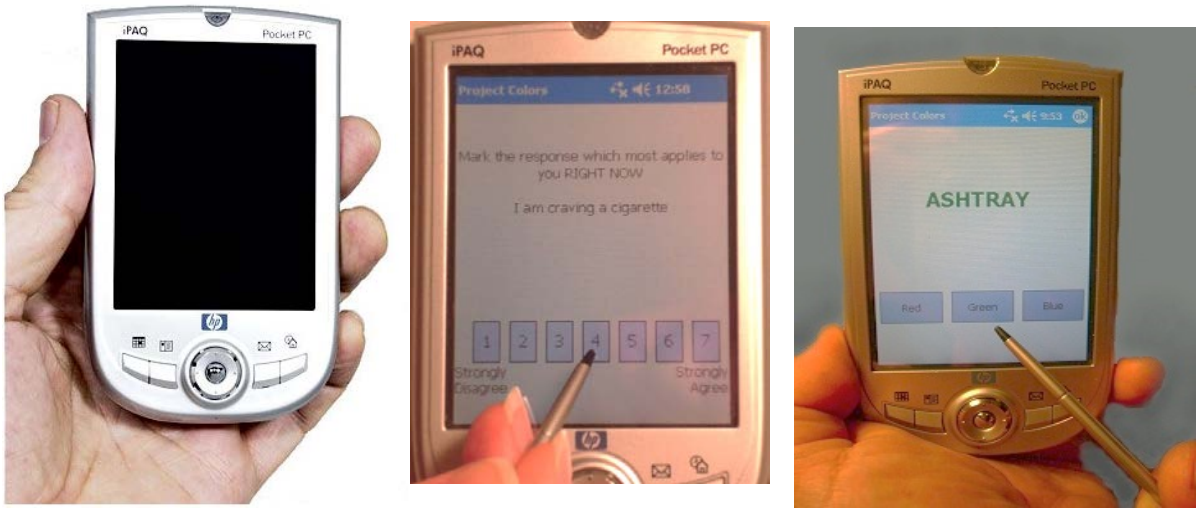


Figure 8. Hewlett Packard iPAQ handheld computer (size shown relative to adult human hand). Subject-initiated and random assessments were assessed on the PDAs. Shown here are two of the primary measures: self-reported craving and smoking Stroop.

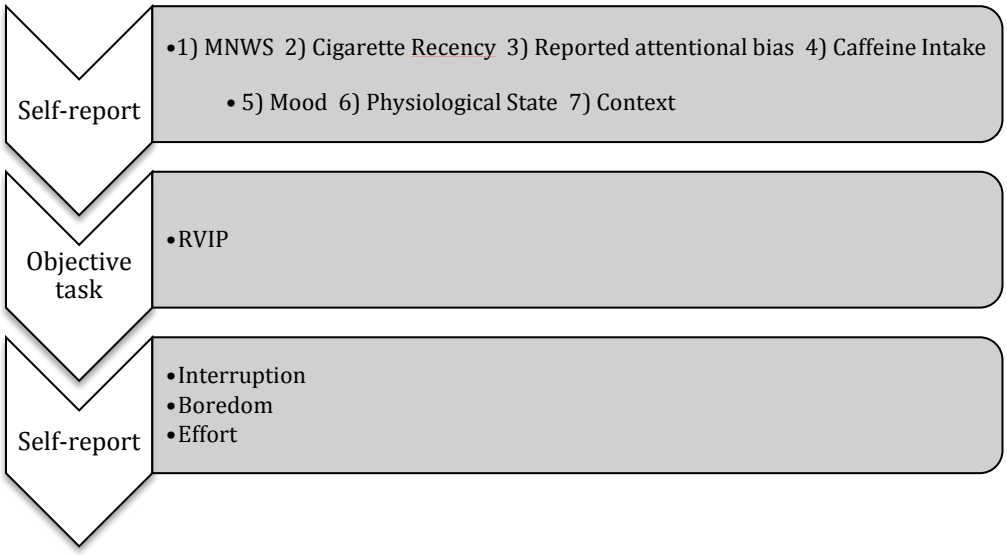


Figure 9. Order of PDA assessments for subject-initiated events and random assessments for Weeks 1-2.

Figure 10. The Rapid Visual Information Processing task on a PDA utilized in the field setting.

Figure 11. COmpact™USB device on the left and demonstration of its use on the right.

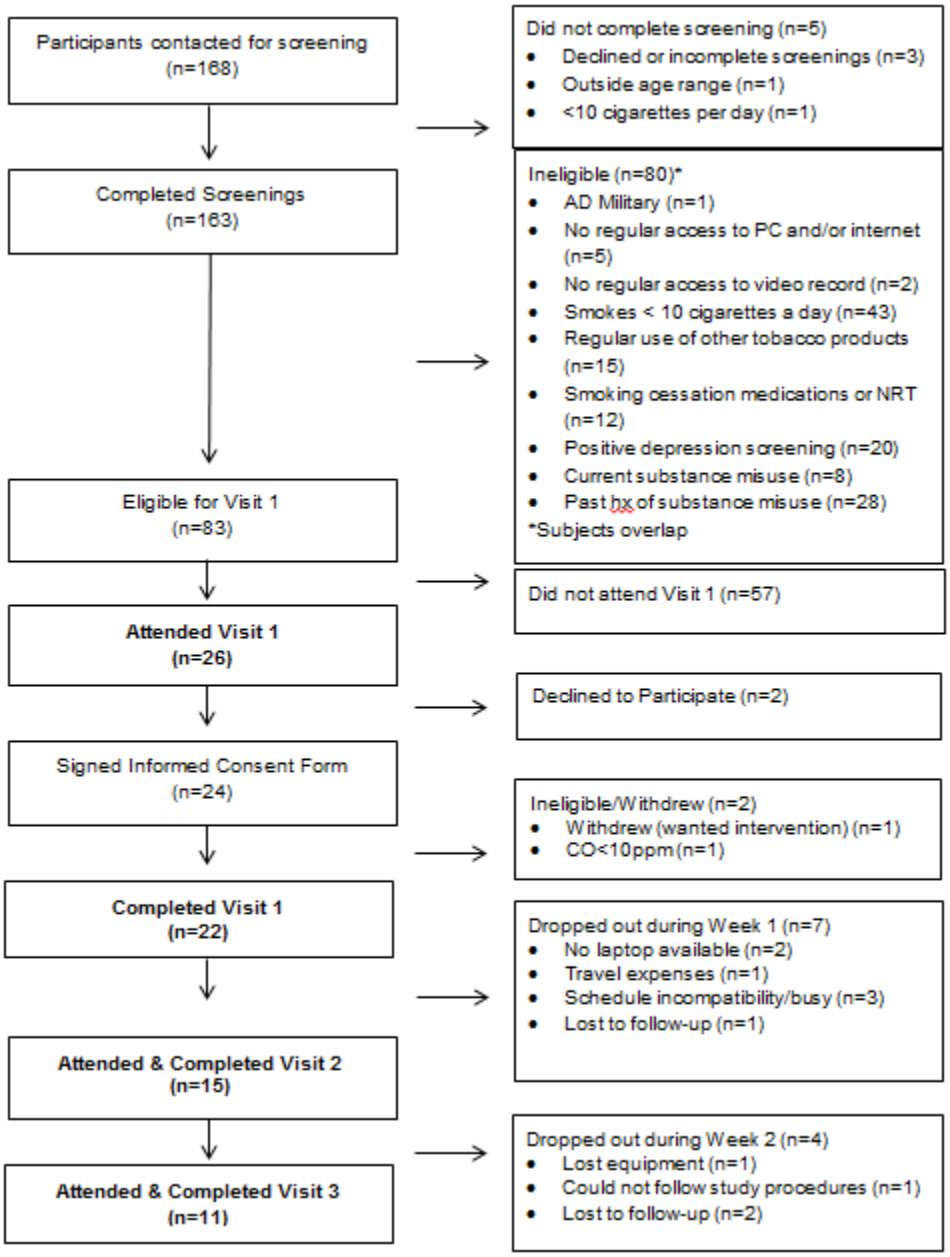


Figure 12. CONSORT Statement

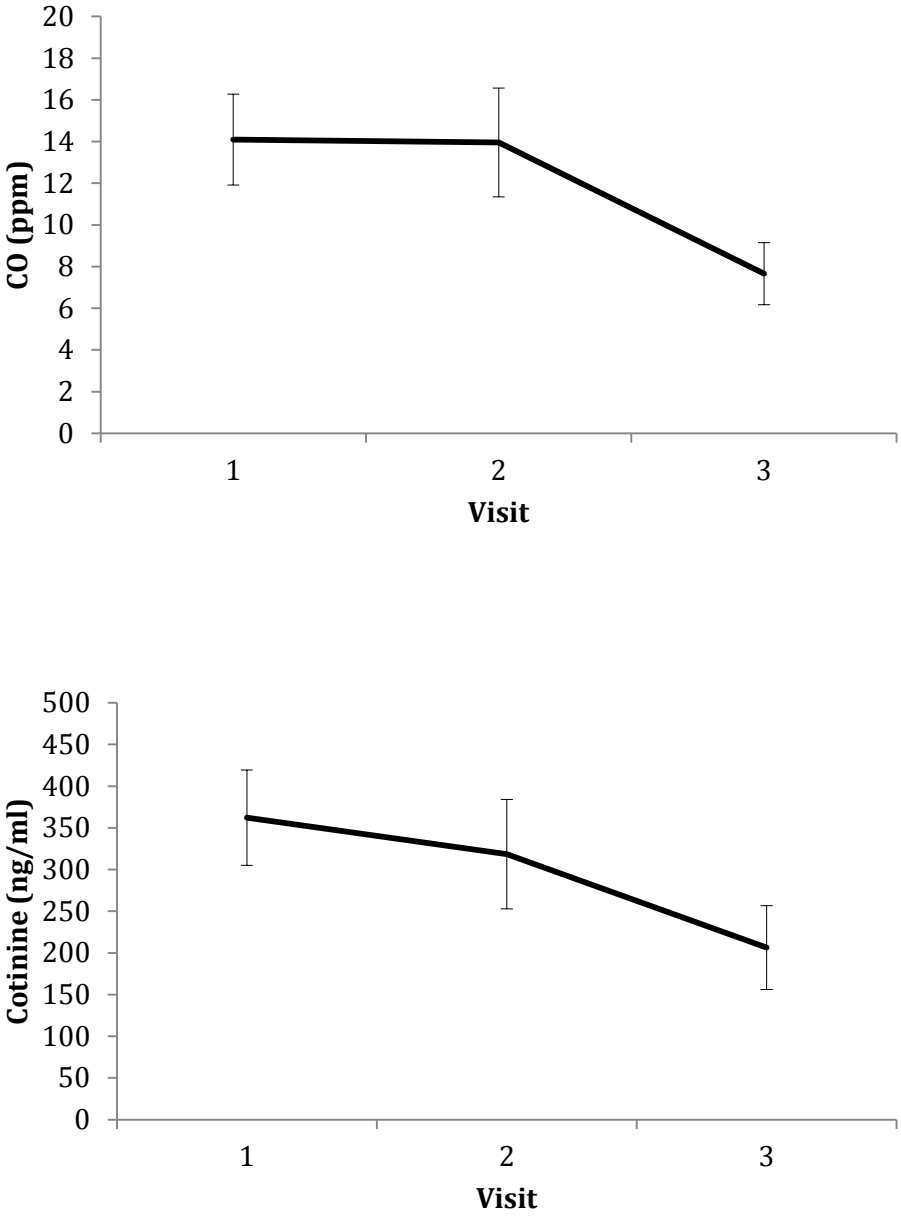


Figure 13. Mean CO and Cotinine levels of time. Error bars are ±1SE.

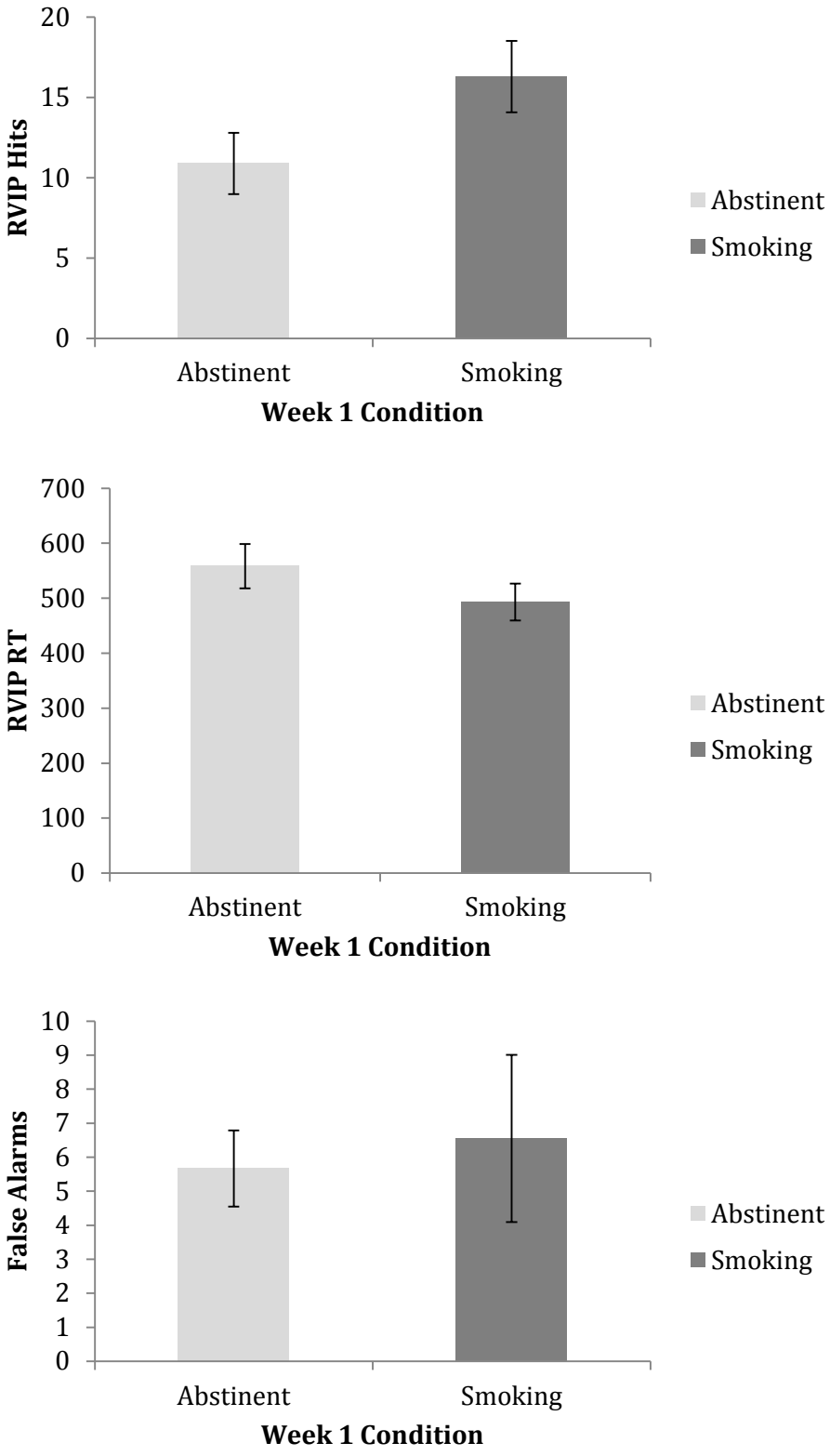


Figure 14. RVIP performance by Week 1 Condition (Abstinent = Acute Abstinence; Smoking = Acute Nicotine). Error bars are ±1SE. (Hypothesis 1.2)

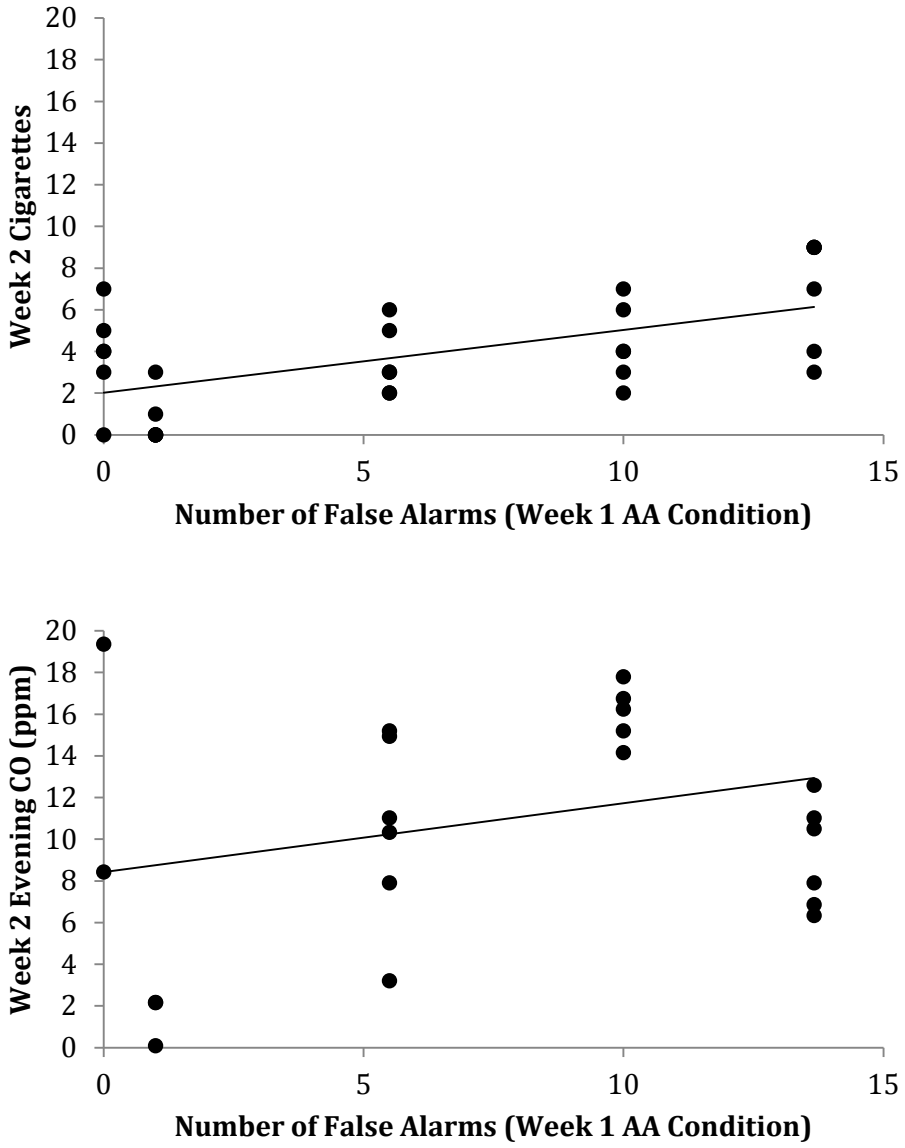
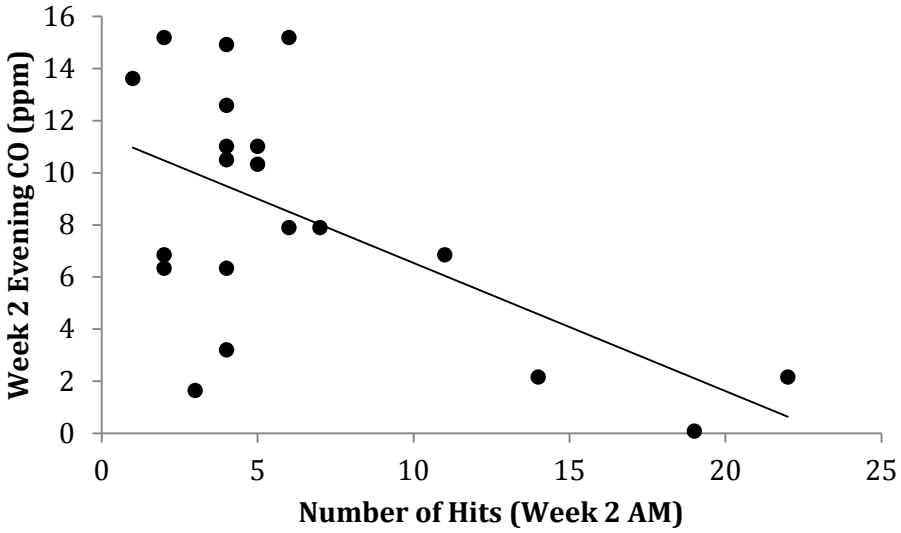


Figure 15. Week 2 Smoking as a function of Number of False Alarms in Morning Week 1 Home Assessments (Hypothesis 2.1). AA = Acute Abstinence Condition



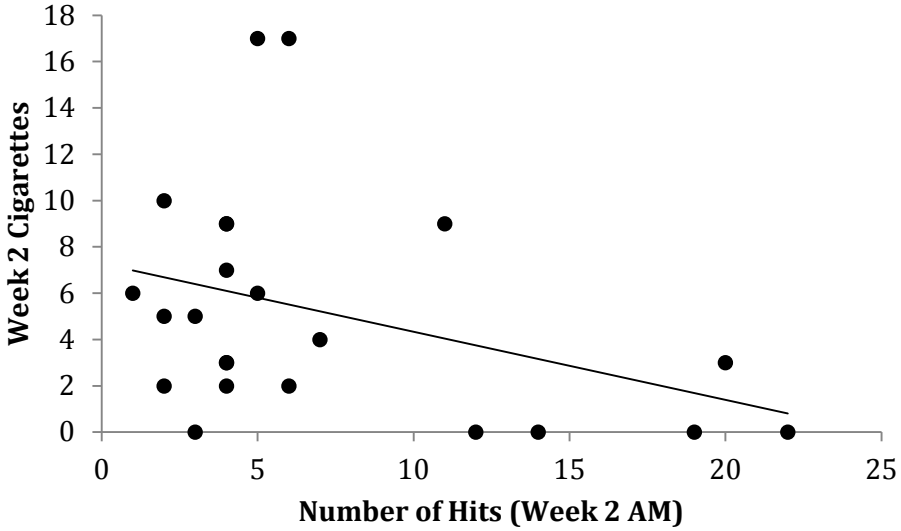
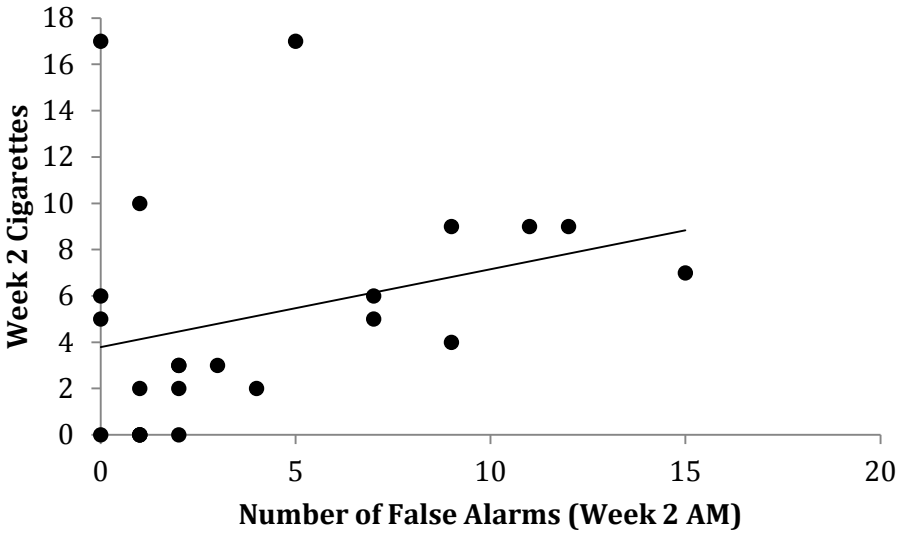


Figure 16. Week 2 Smoking as a function of Number of Hits in Morning Week 2 Home Assessments (Hypothesis 2.2)



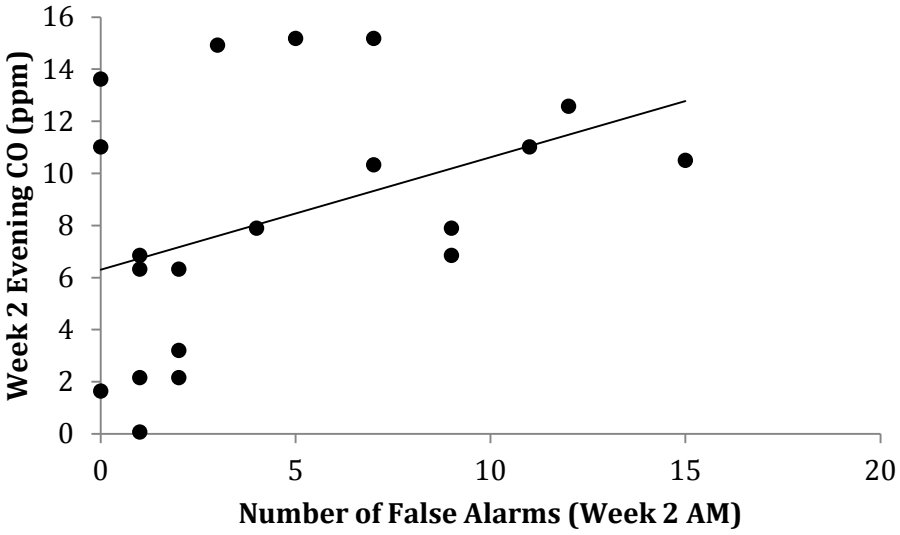


Figure 17. Week 2 Smoking as a function of Number of False Alarms in Morning Week 2 Home Assessments (Hypothesis 2.2)

APPENDIX A: Informed Consent

UNIFORMED SERVICES UNIVERSITY OF THE HEALTH SCIENCES
4301 JONES BRIDGE ROAD
BETHESDA, MARYLAND 20814-4712
http://www.usuhs.mil

UNIFORMED SERVICES UNIVERSITY
BETHESDA, MARYLAND

This consent form is valid only if it contains the IRB stamped date

Consent for Voluntary Participation in a Non-Clinical Research Study

1. INTRODUCTION OF THE STUDY

You are invited to participate in a research study entitled "Cognitive Processes in Cigarette Smoking Cessation: An EMA Investigation" at the Uniformed Services University of the Health Sciences (USUHS), Bethesda, Maryland. You have been asked to take part in this study because you are a smoker willing to cut down or quit smoking. Your participation is voluntary. Declining to participate will not result in any punishment or loss of benefits to which you are otherwise permitted. Please read the information below and ask questions about anything you do not understand, before deciding whether to take part in the study.

2. PURPOSE OF THE STUDY

The purpose of this study is to examine how cognitive processes (thinking) affect your smoking. Results from this study may help researchers create more effective cessation (quitting) programs in the future. Typically, research studies such as this have measured thinking in the laboratory. Here, we're interested to see if this can be done in the smokers' normal environment with the use of personal digital assistants (PDAs). Likewise we want to monitor smoking in the normal environment, using a new device that measures carbon monoxide in breath. If you agree to be part of the study, you will be loaned a smoking monitoring device and 2 PDAs (one of which will be provided during the second lab visit).

3. PROCEDURES TO BE FOLLOWED

You will attend up to 3 laboratory sessions in Building 28 at USUHS. The first laboratory session will last about 90 minutes and the second and third laboratory sessions will last about 30 minutes. This first session (today's session) is an orientation session. If you are eligible and you agree to be in this study, a research staff member will show you how to use the PDA. You will also complete a practice assessment on the PDA. You will be asked to complete questionnaires assessing your demographics (such as your age and income), smoking-related questions (such as craving), and health-related items (including ADHD diagnoses, brain injuries, and medication use). You will also complete brief reaction time tests on the PDA. At the end of the first (today's) session you will be given a PDA and a carbon monoxide monitoring device. A research staff member will go

over instructions on how to use these devices later today.

At all of the laboratory sessions, including today, you will be asked to provide a breath sample and a saliva sample. This will help the researchers find out how much you have smoked. To prepare for the saliva sample, you will be asked to refrain from eating and drinking for 10 minutes before sampling. The research assistant will open the vial and give you the cotton roll. You will be asked to place the cotton piece in your mouth and to gently roll it in your mouth for a whole minute to saturate it with saliva. You will then place most of the cotton piece on the edge of your mouth and re-insert it to the vial without touching the vial. The research assistant will tightly replace the cap on the vial.

You will be asked to carry a PDA around with you for 2 weeks. During these 2 weeks you will complete a PDA assessment each morning. You will be asked to refrain from smoking in the morning before you start a morning PDA assessment (with the exception of 3 days during the first week, as will be described later today). During the 2 weeks, the PDA will also beep you at random times during the day (about 4 times each day). After the PDA beeps, you will be asked to respond to a series of questions that ask how you are feeling and perform a reaction time task on the PDA. Each PDA assessment should last about 10 minutes total. Every evening during the two weeks of the study, we will ask you to video-record yourself taking a carbon monoxide reading with the carbon monoxide monitoring device. We will ask you to share the results and video with us. During the two weeks, you will be asked to record how much you smoked each day on a smoking diary.

For the first week, after waking up you will be asked to smoke your first cigarette of the day either before or after the morning PDA assessment. These procedures will be explained to you later today. For these morning assessments you will also video record yourself taking carbon monoxide readings and share the results with us. During the first week, we ask you to smoke as you normally would.

After one week, you will be asked to attend a second session at USUHS Building 28. During this session you will complete a reaction time task and we will ask you questions about your confidence in cutting down and quitting.

For the second week, you will be asked to try to cut down your smoking or quit smoking altogether if you can. We will also loan you a second PDA to take with you. Please complete the second reaction time task with this PDA every morning.

After another week you will be asked to attend a final (third) laboratory session. You will also complete reaction time tasks and questionnaires. At the end of the session, we will conduct a brief interview to ask about your experiences during this study. You will be asked to return the PDAs and carbon monoxide monitoring device at this visit.

When your participation in the study is over, if you're interested, we will offer resources for quitting smoking and a referral to smoking cessation programs.

_____Participant Initials

_____Date

USUHS IRB APPROVED
Tm 13 MAR 2014
Expires: 12 MAR 2015

4. NUMBER OF PEOPLE THAT WILL TAKE PART IN THIS STUDY

Up to 50 individuals may be recruited to participate in this study.

5. AMOUNT OF TIME FOR YOU TO COMPLETE THE STUDY

Participation in this study is expected to require about 17 hours of your time over a period of about 2 weeks.

6. ELIGIBILITY AND PAYMENT FOR BEING IN THIS STUDY

Participation:

Civilians may participate in this study. Federal civilians must receive supervisor approval to take part in this study and they may only participate during off-duty status.

To be eligible for the study, the level of carbon monoxide in your breath needs to be 10 parts per million (ppm) or higher at the first visit. If your breath carbon monoxide is lower than 10 ppm this means you are not a heavy enough smoker for this study. You will still receive compensation for attending this orientation visit and you will be offered resources for quitting smoking and a referral to smoking cessation programs if you're interested.

Compensation:

Non-federal civilians may receive compensation for their participation in this study. Per federal instruction, federal employees may not receive compensation for their participation.

Non-federal civilians will receive compensation for participating in this study. Non-federal civilians will receive $15 for completing the orientation session (even if ineligible), and $15 for completing the second laboratory and third laboratory sessions each. Non-federal civilians will receive $2 for each subject-initiated morning PDA assessment during week two and $1 for each PDA random assessment that they complete throughout the study. Non-federal civilians will also receive $3 for each day (except the final day) that they contribute data to the study, up to a maximum of 14 days. They will also receive $3 for completing the week one study procedures on each day (i.e., order of smoking, remote CO monitoring, and subject-initiated assessments) and $20 for returning the PDA at the end of the study. If a non-federal civilian completes all scheduled PDA assessments and completes the week one study procedures, they will receive $201: $45 (3 laboratory sessions * $15) + $42 (14 days completed in study * $3) + $16 (8 week two subject-initiated PDA assessments * $2) + $18 (6 week one study procedures * $3) + $60 (4 RA * 15 days * $1) + $20 for returning the PDA at the end of the study.

A check will be mailed to non-federal civilians following completion of the study. Checks may take 4 to 6 weeks to be mailed.

_____Participant Initials

_____Date

USUHS IRB APPROVED
Dt. 13 MAR 2014
Expires: 12 MAR 2015

If you agree to take part in this study you are free to withdraw from the study at any time, and you will be compensated for the time you have spent in the study.

7. POSSIBLE RISKS OR DISCOMFORTS FROM BEING IN THIS STUDY

The risks or discomforts from being in this study are not expected to exceed risks or discomfort associated with cutting down or quitting smoking if you were to do so on your own. Common nicotine withdrawal symptoms include difficulty concentrating, headaches, irritability, anxiousness, and sadness, which are typically temporary. However, if you do experience withdrawal symptoms that become unbearable and/or beyond what is typical, we will provide referrals to medical services as needed.

There are no known risks associated with completing the PDA or the carbon monoxide assessments. Your smoking will likely not be increased by participation in the study. Rather, your smoking may decrease due to participation in the study.

You may refuse to answer any question that makes you feel uncomfortable. If you have concerns after completing the questionnaires, you are encouraged to contact your doctor or the study chair, Nicole Kang, at (301) 295-0802.

If something in this research makes you uncomfortable or upset, you may choose to stop taking part in this research at any time without loss of benefits; you may contact the investigator for referral. If the investigators note any distress or anxiety associated with the research, you will receive referrals, if appropriate.

PLEASE DO NOT USE THE PDA WHILE DRIVING A CAR OR OPERATING A MOTOR VEHICLE. This is dangerous and may be illegal. If you disregard this warning and use the PDA while driving, we will not be responsible for any tickets or accidents resulting from this behavior.

8. POSSIBLE BENEFITS FROM BEING IN THIS STUDY

Some participants may reduce their smoking or quit altogether by the end of the study. However, no benefit can be guaranteed.

The information we learn may help us develop better smoking cessation programs. Therefore, smokers in general may benefit from what is learned in the study. This may be beneficial to society.

9. CONFIDENTIALITY/PRIVACY AND HOW YOUR IDENTITY AND YOUR RESEARCH RECORDS WILL BE MAINTAINED

All information you provide as part of this study will be confidential and will be protected to the fullest extent provided by law. Your responses to our laboratory and PDA assessments will be maintained in a locked filing cabinet or on a password-

protected computer in lab offices in the Department of Medical and Clinical Psychology. All records related to this study will be accessible only to those persons directly involved in conducting this study and members of the USUHS Institutional Review Board (IRB), which provides oversight on the protection of human research volunteers. In addition, the IRB at USUHS and other federal agencies that help protect people who are involved in research studies, may need to see the information you give us. Other than those groups, records from this study will be kept private to the fullest extent of the law. Scientific reports that come out of this study will not use your name or identify you in any way.

The breath sample you provide will allow us to measure carbon monoxide (CO) levels in your breath. This will allow us to measure how much you have smoked. We will use a USB-enabled CO monitor (Bedfont Scientific Ltd., UK, Vitalograph, Lexena, KS) according to the manufacturer's instructions. Video recordings of CO readings will be shared with researchers using a secure method. At USUHS, the data will be stored on password-protected computers in Room 113 of Building 28. The password is only known to the research staff.

The saliva samples will be stored in a freezer (-80°F) in Building 28 for up to three months. Batches of saliva samples will be sent to Salimetrics, LLC (State College, PA) to determine the level of cotinine. Cotinine is a breakdown product of nicotine and tells us how much you smoked during the past few days. No other tests will be performed on the saliva samples. Only the study researchers will have access to the saliva samples. The samples are labeled with a participant study number (and visit number); only the research staff will know the linkages between study numbers and participants. Thus, confidentiality is maintained during storage and distribution. Shipping procedures will be in accordance with the U.S. Centers for Disease Control (CDC) guidelines for transport of biological specimens. Once the cotinine test is performed, Salimetrics, LLC will destroy the samples. Because you are free to drop out of the study at any time, you can request that your saliva samples are destroyed. Saliva samples will only be stored at USUHS.

10. CONDITIONS WHICH YOUR PARTICIPATION IN THIS STUDY MAY BE STOPPED WITHOUT YOUR CONSENT

The investigator may stop you from taking part in this study if being in the study is unsafe or dangerous to you. The investigator may also stop you from participating if you experience difficulty in following the procedures.

11. IF YOU DECIDE TO STOP TAKING PART IN THIS STUDY AND THE INSTRUCTIONS FOR STOPPING EARLY

You have the right to withdraw from this study at any time. If you decide to stop taking part in this study, you should tell the principal investigator as soon as possible. If you drop out of the study, you will still receive compensation for the parts of the study you completed before dropping out.

_____Participant Initials

_____Date

USUHS IRB APPROVED
13 MAR 2014
Expires: 12 MAR 2015

12. RECOURSE IN THE EVENT OF INJURY

If at any time you believe you have suffered an injury or illness as a result of participating in this research project, you should contact the Director of Human Research Protections Programs at the Uniformed Services University of the Health Sciences, Bethesda, Maryland 20814-4799 at (301) 295-9534. This office can review the matter with you, can provide information about your rights as a subject, and may be able to identify resources available to you. If you believe the government or one of the government's employees (such as a military doctor) has injured you, a claim for damages (money) against the federal government (including the military) may be filed under the Federal Torts Claims Act. Information about judicial avenues of compensation is available from the University's General Counsel at (301) 295-3028.

CONTACT FOR QUESTIONS OR PROBLEMS

If you have questions about this research, you should contact Nicole Kang or Dr. Andrew Waters, the individuals in charge of the study. Nicole's number at USUHS is (301) 295-0802 and Dr. Waters can be reached at (301) 295-9675. During the evenings or on weekends, you can leave a message at those numbers. If you have questions about your rights as a research subject, you should call the Director of Human Research Protections Programs at USUHS at (301) 295-9534. This individual is your representative and has no connection to the researcher conducting this study.

SIGNATURE OF RESEARCH PARTICIPANT OR LEGAL REPRESENTATIVE

You have read (or someone has read to you) the information in this consent form. You have been given a chance to ask questions and all of your questions have been answered to your satisfaction.

BY SIGNING THIS CONSENT FORM, YOU FREELY AGREE TO TAKE PART IN THE RESEARCH IT DESCRIBES.

_____ _____

Participant's Signature Date

_____

Participant's Printed Name

SIGNATURE OF INVESTIGATOR/RESEARCH TEAM MEMBER

You have explained the research to the participant, or his/her legal representative, and answered all of his/her questions. You believe that the volunteer subject understands the information described in this document and freely consents to participate.

_____

Investigator's/Research Team Member's Signature Date (must be the same as the participant's)

_____

Investigator's/ Research Team Member's Printed Name

SIGNATURE OF WITNESS

Your signature as witness is intended to attest that the information in the consent document and any other information was explained to and apparently understood by the participant, or the participant's legal representative, that questions and concerns were addressed and that informed consent was freely given.

_____

Witness' Signature Date (must be the same as the participant's)

_____

Witness' Printed Name

APPENDIX B: Self-Report Measures

DEMOGRAPHICS QUESTIONNAIRE

Q1. What is your date of birth? __ __ / __ __ / __ __ __ __ mm / dd / yyyy

2098 Decline to Answer (Year)

Q2. What is your gender?

1 Male

2 Female

Q3. What is your present marital status? (Choose one)

1 Single

2 Married
3 Divorced
4 Widowed
5 Living with significant other
6 Separated
8 Decline to Answer

Q4. How many years of education have you completed? (Choose one)

01 1 (Elementary School)
02 2 (Elementary School)
03 3 (Elementary School)
04 4 (Elementary School)
05 5 (Elementary School)
06 6 (Middle School)
07 7 (Middle School)
08 8 (Middle School)
09 9 (High School)
10 10 (High School)
11 11 (High School)
12 12 (High School)
13 13 (Some College)
14 14 (Vocational or Community College Degree)
16 16 (Four Year College Degree)
17 17 (Some Postgraduate Work)
18 18 (Postgraduate Degree; Master Degree)
20 20 (Postgraduate Degree; M.D., Ph.D., DDS, Dr.P.H., etc.)
98 Decline to Answer

Q5. Are you of Hispanic/Latino origin?

1 Yes

0 No
8 Decline to Answer

Q6. What category best describes your race? (Choose one)

1	Caucasian or White
2	African American or Black
3	Asian
4	Hawaiian Native or Other Pacific Islander
5	Native American or Alaskan Native
6	Mixed Race
7	Other
8	Decline to Answer

If Q6 is equal to 8 or Q6 is less than 7, then skip to Q8.

Q7. Please specify your race. _

Q10. What is you total family income per year, before taxes? (Choose one)

01	Less than $10,000 per year or less than about $833 per month
02	$10,000 to $19,999 per year or less than about $1250 per month
03	$20,000 to $29,999 per year or less than about $2083 per month
04	$30,000 to $39,999 per year or less than about $2916 per month
05	$40,000 to $49,999 per year or less than about $3750 per month
06	$50,000 to $59,999 per year or less than about $4583 per month
07	$60,000 to $69,999 per year or less than about $5416 per month
08	$70,000 to $79,999 per year or less than about $6250 per month
09	$80,000 to $89,999 per year or less than about $7083 per month
10	$90,000 to $99,999 per year or less than about $7916 per month
11	$100,000 or more per year or more than $8333 per month
98	Decline to Answer

Q13. **Employment Status.** Please choose the best response: (Choose one)

01	Regular full-time (30 or more hours per week)
02	Regular part-time (less than 30 hours per week)
03	Unemployed, currently *looking* for work
04	Unemployed, currently *NOT looking* for work
05	Homemaker
06	Student
07	Retired
08	Unable to work or disabled
09	Other
98	Decline to Answer

If Q13 is less than 9, then skip to Q15.

Q14. Please specify your employment status.

_

_ _

Q15. In the past 30 days, what was the primary source of your income? (Choose one)

1 A job
2 Unemployment Benefits
3 VA/Disability/Social Security Income
4 Welfare/Food Stamps/Aid to Family with Dependent Children
5 Alimony or Child Support
6 Spouse/partner is main source of income
8 Decline to Answer

HEALTH-RELATED QUESTIONNAIRE/INTERVIEW

Please answer the following health-related questions to the best of your ability. Indicate "N/A" for any questions that do not apply to you.

1) Do you **currently** have any problems seeing things, such as the following (check all that apply):

- ☐ Blurred vision
- ☐ Double vision
- ☐ Cataracts
- ☐ Eye disease (e.g., glaucoma)
- ☐ Eye injury
- ☐ Other: _____

2) Do you wear corrective lenses (e.g., glasses, contact lenses)?

_____

3) Are you color-blind? If so, what colors can you not detect?

_____

4) **Have you ever** been given a diagnosis for any neurological condition(s), such as the following (check all that apply):

- ☐ Stroke / "brain attack"
- ☐ Seizure disorder (e.g., epilepsy)
- ☐ Huntington's Disease
- ☐ Dementia (specify either):
  - ☐ Parkinson's disease
  - ☐ Alzheimer's disease
- ☐ HIV/AIDS
- ☐ Creutzfeldt-Jakob disease
- ☐ Brain tumor
- ☐ Brain aneurysm
- ☐ Brain infection (e.g., meningitis, encephalitis)
- ☐ Multiple Sclerosis
- ☐ Toxic poisoning
- ☐ Nutritional deficiencies (e.g., vitamin B12)
- ☐ Other: _____

5) **Have you ever** had brain surgery?

_____

6) What abovementioned neurological conditions are you **currently** being treated for?

_____

_____

7) **Have you ever** had any head injuries? If so, how many?

7a) Head injury 1:
When did it occur?

Did you lose consciousness? If so, how long were you passed out?

Were you hospitalized?

7b) Head injury 2:
When did it occur?

Did you lose consciousness? If so, how long were you passed out?

Were you hospitalized?

7c) Head injury 3:
When did it occur?

Did you lose consciousness? If so, how long were you passed out?

Were you hospitalized?

7d) Head injury 4:
When did it occur?

Did you lose consciousness? If so, how long were you passed out?

Were you hospitalized?

7e) Did you have more than 4 head injuries? Please circle: YES / NO and use the back of this sheet to respond to the same questions.

8) Do you **currently** have any of the following symptoms (check all that apply):

- ☐ Headaches
- ☐ Dizziness
- ☐ Nausea
- ☐ Sad
- ☐ Tense, anxious
- ☐ Irritability / easily annoyed
- ☐ Forgetfulness / can't remember things
- ☐ Poor concentration / easily distracted / can't pay attention
- ☐ Sleep problems
- ☐ Fatigue, getting tired easily
- ☐ Numbness or tingling on parts of my body
- ☐ Change in taste and/or smell
- ☐ Noise sensitivity
- ☐ Light sensitivity
- ☐ Other: _____

9) What is your handedness (circle whichever applies to you)?
Left / Right / Ambidextrous (use both hands equally well)

10) What type(s) of caffeinated product(s) do you consume regularly?
Type: (e.g., coffee, energy drink) _____
Daily Amount: (e.g., 2 cups of coffee) _____
Frequency: (e.g., 7 days/week) _____

11) **Over the past 2 weeks**, how often have you been bothered by any of the following problems (circle which applies to you the most)?

	Not At all	Several Days	More Than Half the Days	Nearly Every Day
i) So nervous or anxious that nothing could calm you down.....	0	1	2	3
ii) So restless that you could not sit still.....	0	1	2	3
iii) Trouble relaxing.....	0	1	2	3

12) **Have you ever** been given any other psychiatric diagnosis, such as the following (check all that apply):

- ☐ Depression
- ☐ Anxiety disorder (e.g., OCD)
- ☐ Learning disorder (e.g., dyslexia)
- ☐ Autism
- ☐ Bipolar
- ☐ Schizophrenia
- ☐ Sleep disorder
- ☐ Other: _____

13) **Have you ever** been given a diagnosis of Attention Deficit Hyperactivity Disorder (ADHD) or Attention Deficit Disorder (ADD)? If so, when?

_____ _____

14) Are the attention problems **currently** being treated? Are you still having problems with attention?

15) Some medications can affect your thinking. Please list the prescription medications you are **currently** taking.

SMOKING HISTORY QUESTIONNAIRE

About how old were you when you first started smoking at least 1 cigarette a day? _____ **years old**

About how old were you when you started smoking regularly **everyday**? _____ **cigarettes a day**

How many cigarettes do you smoke on a **normal day**? _____ **cigarettes a day**

	Definitely not	**Probably not**	**Possibly**	**Probably**	**Definitely**
Do you think you are addicted to smoking?	☐	☐	☐	☐	☐

Are you seriously thinking of quitting smoking?

☐ Yes, within the next 30 days

☐ Yes, within the next 6 months

☐ No, not thinking of quitting

	Yes	**No**
Have you used any other tobacco products (i.e., cigars, pipes, smokeless tobacco, bidis, cloves)? Describe:	☐	☐

	Yes	**No**
Have you ever made a serious and deliberate attempt to **STOP SMOKING** cigarettes completely?	☐	☐

If so, how many times? _____ times

In the **last year**, how many times have you quit smoking for at least 24 hours? _____ times

How hard was it for you to quit smoking on your most recent attempt?

Easy	**Slightly Difficult**	**Difficult**	**Very Difficult**

How severely did you experience any of the following symptoms below in your most recent attempt to quit smoking? Choose the answer that most reflects the severity of each symptom.

	Not at all	Mild	Moderate	Severe	Very severe
Cravings for cigarettes	1	2	3	4	5
Irritability	1	2	3	4	5
Nervousness	1	2	3	4	5
Difficulty concentrating	1	2	3	4	5
Physical symptoms	1	2	3	4	5
Difficulty sleeping	1	2	3	4	5

FAGERSTROM TEST FOR NICOTINE DEPENDENCE

Fagerstrom Test for Nicotine Dependence (FTND)

	0	1	2	3
1. How soon after you wake up do you smoke your first cigarette?	After 60 Minutes	31 – 60 minutes	6-30 minutes	Within 5 minutes
2. Do you find it difficult to refrain from smoking in places where it is forbidden, e.g., in church, at the library, cinema, etc?	No	Yes		
3. Which cigarette would you hate most to give up?	All others	The first one in the morning		
4. How many cigarettes/day do you smoke?	10 or less	11-20	21-30	31 or more
5. Do you smoke more frequently during the first hours of waking than during the rest of the day?	No	Yes		
6. Do you smoke if you are so ill that you are in bed most of the day?	No	Yes		

WISCONSIN SMOKING WITHDRAWAL SCALE

Please answer the following questions based on how you generally have felt or what you have noticed during the past week, including today.

0	1	2	3	4
Strongly Disagree	*Disagree*	*Feel Neutral*	*Agree*	*Strongly Agree*

1. Food is not particularly appealing to me.
   0 1 2 3 4
2. I am getting restful sleep.
   0 1 2 3 4
3. I have been tense or anxious.
   0 1 2 3 4
4. My level of concentration is excellent.
   0 1 2 3 4
5. I awaken from sleep frequently during the night.
   0 1 2 3 4
6. I have felt impatient.
   0 1 2 3 4
7. I have felt upbeat and optimistic.
   0 1 2 3 4
8. I have found myself worrying about my problems.
   0 1 2 3 4
9. I have had frequent urges to smoke.
   0 1 2 3 4
10. I have felt calm lately.
    0 1 2 3 4
11. I have been bothered by the desire to smoke a cigarette.
    0 1 2 3 4
12. I have felt sad or depressed.
    0 1 2 3 4
13. I have been irritable, easily angered.
    0 1 2 3 4
14. I want to nibble on snacks or sweets.
    0 1 2 3 4
15. I have been bothered by negative moods such as anger, frustration, and irritability.
    0 1 2 3 4
16. I have been eating a lot.
    0 1 2 3 4
17. I am satisfied with my sleep.
    0 1 2 3 4
18. I have felt frustrated.
    0 1 2 3 4
19. I have felt hopeless or discouraged.
    0 1 2 3 4
20. I have thought about smoking a lot.
    0 1 2 3 4
21. I have felt hungry.
    0 1 2 3 4
22. I feel that I am getting enough sleep.
    0 1 2 3 4
23. It is hard to pay attention to things.
    0 1 2 3 4
24. I have felt happy and content.
    0 1 2 3 4
25. My sleep has been troubled.
    0 1 2 3 4
26. I have trouble getting cigarettes off my mind.
    0 1 2 3 4
27. It has been difficult to think clearly.
    0 1 2 3 4
28. I think about food a lot.
    0 1 2 3 4

QUESTIONNAIRE OF SMOKING URGES, BRIEF

Questionnaire of Smoking Urges

Instructions: Indicate how much you agree or disagree with each of the following statements by circling the number between strongly disagree and strongly agree. The closer you choose a number to one end or the other indicates the strength of your disagreement or agreement. Please complete every item. We are interested in how you are thinking or feeling **right now** as you are filling out the questionnaire.

	Strongly Disagree					**Strongly Agree**
1. I have a desire for a cigarette.	0	1	2	3	4	5
2. Nothing would be better than smoking a cigarette.	0	1	2	3	4	5
3. If it were possible, I probably would smoke a cigarette.	0	1	2	3	4	5
4. I would control things better if I could smoke.	0	1	2	3	4	5
5. All I want is a cigarette.	0	1	2	3	4	5
6. I have an urge for a cigarette.	0	1	2	3	4	5
7. A cigarette would taste good.	0	1	2	3	4	5
8. I would do almost anything for a cigarette.	0	1	2	3	4	5
9. Smoking would make me less depressed.	0	1	2	3	4	5
10. I am going to smoke as soon as possible.	0	1	2	3	4	5

SMOKING DIARY

Study ID:_____

Tobacco Use Record Form

Instructions for Participant:

- **Complete this form each day.**
- **Just before going to sleep, indicate how many cigarettes you have smoked that day.**
- **Be honest… Accurate information is important!**

I agree to complete this form every night. I will provide information that is as accurate as possible.

SIGNATURE AND DATE:

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Week 1							
Week 2							

SMOKING ABSTINENCE SELF-EFFICACY QUESTIONNAIRE

1. You feel agitated or tense. Are you confident that you will not smoke?
□ Certainly
□ Probably
□ Neutral / don't know
□ Probably not
□ Certainly not

2. You are (very) angry. Are you confident that you will not smoke?
□ Certainly
□ Probably
□ Neutral/don't know
□ Probably not
□ Certainly not

3. You are in a café, at a party, or paying a visit. Are you confident that you will not smoke?
□ Certainly
□ Probably
□ Neutral/don't know
□ Probably not
□ Certainly not

4. You feel (very) sad. Are you confident that you will not smoke?
□ Certainly
□ Probably
□ Neutral/don't know
□ Probably not
□ Certainly not

5. Someone offers you a cigarette of your own brand. Are you confident that you will not smoke?
□ Certainly
□ Probably
□ Neutral/don't know
□ Probably not
□ Certainly not

6. You see someone enjoy smoking. Are you confident that you will not smoke?
□ Certainly
□ Probably
□ Neutral/don't know
□ Probably not
□ Certainly not

OVERALL SELF-EFFICACY TO CUT-DOWN/QUIT

1. Overall, I am confident that I will be able to reduce my smoking.

□ Certainly
□ Probably
□ Neutral/don't know
□ Probably not
□ Certainly not

2. Overall, I am confident that I will be able to quit smoking.

□ Certainly
□ Probably
□ Neutral/don't know
□ Probably not
□ Certainly not

APPENDIX C. Post-Experimental Interview Questions

Thank you for participating in this study. Your input is very valuable and may potentially be used to inform future research studies with the ultimate goal of finding better ways to help people, like yourself, quit smoking. For instance, it might be worthwhile to remotely monitor CO levels because it alleviates your burden as a participant in a research study or in a clinical setting. It may also be a source of positive reinforcement to see the immediate feedback and the progress one's making towards quitting. Also, tracking people's cognitive function might be able to tell us when an intervention is most critical.

I want to take this time to ask what your experience was like undergoing some of the study procedures. I hope this is okay with you.

Please feel free to share what your experience, sense, and/or perceptions are. And feel free to elaborate as necessary. If you'd prefer to answer these questions on your own, I could leave a copy here with you. And I'll be available in case you have any questions.

The following questions pertain to the ease of use of the devices.

1) How easy or difficult was it to do the PDA assessments?

2) What about the USB CO monitor?

3) How about the video recording?

4) Lastly, what about the emailing process?

The next set of questions pertains to the feasibility or practicality of using the devices.

1) How practical or impractical was it to complete the PDA assessments?

2) What about the USB CO monitor?

3) How about the video recording?

4) Lastly, what about the emailing process?

Is there anything else you'd like to add?

Was there anything you particularly liked or disliked?

Overall, were the procedures you followed while at home acceptable?

Well, that's it! Thank you so much for your time and participation in this study.

Record behavioral observations (e.g., facial expressions, any inconsistencies with verbal and non-verbal communication, tone of voice, etc. be sure to clarify any perceived inconsistencies!):

_____

_____

**NOTE to research staff: if it's unclear whether a response would be considered *Favorable, Acceptable, Neutral, Unacceptable, or Adverse*, probe with additional questions. For instance:
Did you like it?
Did you dislike it?
Could it go either way?
Is it acceptable to you?
Would you do _(fill in blank)_ again?
Would you use _(fill in blank)_ device as a smoking cessation tool if an intervention was developed that incorporates it?

For terse/brief responses, please inquire further. For instance:
Why/Why not?
Please tell me more.

APPENDIX D: Rapid Visual Information Processing CANTAB Desktop Task Standardized Instructions

RVIP standardized task instructions. Subjects were instructed to use the index finger of their dominant hand to press the external press pad. At the outset of the training session, subjects were given these instructions.

"You are going to see some numbers appearing one at a time in a box in the center of the computer screen. What you have to do is to look for a target sequence of three numbers and press the button whenever you spot the target.

The target sequence will be a '3' immediately followed by a '5', immediately followed by a '7'. It is only when you see the last number of the sequence that you should press the button.

Full prompts will be provided.

To begin, you will know that a sequence has begun because the target sequence will appear in red and be underlined in yellow. There will also be a 'beeping' sound if you press the button correctly. As the practice sequence progresses you will find that these cues and the 'beeping' sound will gradually be phased out."

If the subject responds too early, the test administrator prompts the subject to "Wait until you see the last digit before pressing the button."

The subject will next be informed that some prompts will be provided: "Now the sequences will only be underlined in yellow."

Next, the subject will be informed that no prompts will be provided: "Now you will have to spot the sequences yourself. There will be no underlining or beeping."

Upon completion of the training trials, the test trials will commence with the following instructions:

"This time we will do the same thing, but there will now be two other sequences you have to remember, 2-4-6 and 4-6-8 as well as 3-5-7.

Whenever you see any of these three target sequences you should press the button when the third digit appears. The test will last for four minutes, so please try to concentrate until the end. The target sequences will remain on the screen to help you remember them. However, try to concentrate on the box in which the umbers are changing. Please respond as quickly as you can whilst trying to avoid making mistakes. Take a few seconds to familiarize yourself with the three different sequences, 3-5-7, 2-4-6, and 4-6-8. Remember there will be no color, no underlining, and no beeping sound."

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