Measuring Attentional Bias Among Abstinent Smokers with a Manual Aiming Task

by

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A thesis submitted in conformity with the requirements for the degree of Master of Science
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Abstract

Attentional bias (AB) is exhibited by substance users for addiction-related stimuli, influencing consumption, craving, and relapse. Due to limitations of AB measurements, this study developed and evaluated a novel method using manual aiming (MA). Participants completed modified visual dot-probe tasks while monitoring their eyes and limb movements. Reaction time (RT), movement time (MT), and limb trajectory (LT) were measured and compared between non-smokers (n=15) and abstaining smokers (n=13) and within smokers. Using 3 (probe) x 2 (accompanying image) x 2 (group) ANCOVAs, controlling for age, there were no significant differences for RT or LT. Trends for group and condition differences in MT were found although in the opposite direction. As expected, cravings negatively correlated with the time elapsed to complete MA. There was some tentative evidence to suggest that AB may have properties that can be examined by MT. Replication is needed with a larger sample and more dependent smokers.
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There were many occasions in which I believed that I would never arrive at this stage....the stage of writing my thesis acknowledgements. Yet here I am, on a commute back to the city from my job. This job would have been impossible to get without the skills and knowledge acquired during my Masters Degree. The task of trying to put into words all the feelings from the previous chapter of my life is no easy feat.

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Chapter 1
Introduction

1.1 Tobacco smoking in Canada

Tobacco smoking is a major public health concern. Societal cost of tobacco in Canada is about $17 billion per year, accounting for 42.7% of the total cost of substance abuse, translating to an annual per capita value of $541 (Rehm et al., 2006) in both direct and indirect costs, including health care, prevention and research, and productivity lost. In addition to these economic costs, tobacco smoking also poses a major threat to public health due to its negative health implications. It is considered as one of the global leading causes of preventable death, associated with numerous illnesses, including cardiovascular disease, respiratory disease, and various forms of cancers (WHO, 2009). Tobacco smoke contains over 7000 chemicals and at least 250 are identified as harmful and more than 50 are carcinogenic (NCI, 2011; WHO, 2011). On average, tobacco smoking kills up to half of its users prematurely (WHO, 2013). Currently, approximately 6 million deaths worldwide annually can be attributed to tobacco in both direct consumption and indirect exposure in the form of second-hand smoke or environmental tobacco smoke (WHO, 2011). This is roughly equivalent to one tobacco related death every 6 seconds (WHO, 2012). This figure is projected to increase to 7.5 million, accounting for 10% of annual global deaths, by the year 2020 (WHO, 2011). Despite these alarming statistics, tobacco smoking remains the most common addiction in Canada (PHAC, 2008) with a prevalence rate of 17% (Health Canada, 2012).

Because more than 1 in 6 people self-identify as active smokers, it is important to recognize the benefits of smoking cessation. The overall benefit is an increase in life expectancy by minimizing risks of smoking-related diseases and cancers (CDC, 1990); moreover, many of the negative health impacts of smoking are considered reversible (Fagerström, 2002). For instance, smokers are twice as likely to die from coronary heart disease than their non-smoking counterparts; however, this risk is reduced by half after one year of smoking abstinence and further reduced to that of a non-smoker after 15 years of abstinence (CDC, 1990). Short-term benefits of smoking cessation can be experienced after as little as 20 minutes of abstinence; physiological responses such as heart rate and blood pressure will return to normal and within hours, carbon monoxide in the blood will also decline (NCI, 2011). Within weeks of cessation,
improved circulation and respiratory functions, including less phlegm production and less coughing, can be felt (NCI, 2011).

A great majority of smokers want to quit smoking; a Canadian survey revealed that 91% of smokers had some intention of quitting and over half have seriously considered making an attempt over the next six months (Canadian Lung Association, 2008). However, smoking cessation can be a difficult endeavour. Nearly 80% of smokers with quit intention have already made unsuccessful quit attempts in the past (Canadian Lung Association, 2008). Additionally, even when smokers have successfully quit, they still encounter the risk of relapse; at the one-year follow-up of former smokers, only 10% had remained successfully abstinent (Reid et al., 2012).

1.2 Challenges of smoking cessation and attentional bias

One of the main challenges to smoking cessation is the addictive nature of nicotine, which contributes to persistent cravings, which can be predictive of relapse. For example, research on the impact of exercise on craving reduction has been well established (Taylor et al., 2007; Ussher et al., 2008). However, little is known about the mechanisms underlying the observed reduction in cravings. Moreover, evidence is also largely based on self-reported measures of craving and few studies have concentrated on objective measures or outcomes. Recently, a study was done examining attentional bias as a possible mechanism behind exercise related craving reduction (van Rensburg et al., 2009). Attentional bias is a cognitive bias that substance users have for addiction-related stimuli, such as cigarettes in the context of a smoker; specifically, these stimuli may grab the attention of experienced substance users (Field & Cox, 2008). This bias influences underlying processes of substance-seeking behaviour, craving, and relapse (Field & Cox, 2008). Furthermore, addiction models posit the likelihood of a positive correlation between objective bias and subjective cravings (van Rensburg et al., 2009).

Despite the role of exercise in craving reduction and the presence of attentional bias in smokers, there is minimal literature on the effects of exercise on attentional bias in smokers and little is known about their relationship. More research is required to grasp a better understanding of the effect of exercise on attentional bias and to establish a relationship. Recent research on the effect of exercise on attentional bias has primarily used eye-tracking technology; however, there are inherent, methodological limitations with the use of eye-tracking to measure attentional bias (see 2.6 Limitations to current literature). Thus, as an initial step, an alternative method of measuring
attentional bias should be explored, namely using manual aiming because of the relationship between limb trajectory and locus of attention (Song & Nakayama, 2009; see section 2.7 A case for motor control and attentional bias). As such, the purpose of this study is to develop and evaluate the feasibility of a novel method of manual aiming for assessing attentional bias.
Chapter 2
Literature Review

2.1 Overview

Attentional bias is an important aspect underlying addiction as it has implications for substance-seeking behaviours, cravings, and relapse (Field & Cox, 2008), essentially playing a role in addiction maintenance. Attentional bias has been demonstrated to exist in smokers, and yet, despite its relationship to addiction, it is a concept not heavily explored and with little consensus on how it should best be measured. This literature review focuses on the primary methods of measuring attentional bias in nicotine addiction. These methods range from the well-established, indirect measures of a Stroop task to the more recent direct methodology of eye-tracking. There are also few studies exploring the effect of exercise on attentional bias. While results are mixed and no conclusive statements can yet be made on how attentional bias changes in response to exercise, these studies all employed an eye-tracker as the measurement tool. Despite being an objective and direct measurement of attentional bias, eye-tracking technology has its methodological limitations (see 2.6 Limitations to current literature). Research should be done exploring alternate methods of measuring attentional bias. There may be properties of attentional bias that remain unexplored, particularly in the upper limb-motor control field. Measuring attentional bias within motor control, specifically via manual aiming for upper-limb movements, is an innovative approach, and if validated as feasible, it would not only provide an alternative mean of assessing attentional bias, but it would also allow the examination of possible upper-limb, motor components of this bias.

2.2 History of attentional bias

In the early 1980s, Bower (1981) postulated the Associative Network Theory of Memory and Emotion to account for studies that demonstrated a mood-state-dependent effect. This is a memory bias where recollection is enhanced when a person’s emotional state is congruent with the one that was experienced at the time of learning or when the situation occurred (Bower, 1981). Anecdotally, Bower explained the observation of enhanced memory recall with the reinstatement of a particular emotional state at the time of learning with that of an alcohol user for recalling events that occurred while in an inebriated state (Bower, 1981). This recollection
bias prompted researchers to investigate biases in mood and emotional disorders with the framework that anxious individuals would exhibit a recall bias for fear-related words. Macleod et al. (1986) postulated that this bias resulted from a selective attention shift towards emotionally threatening stimuli. In addition to a recall bias based on state-dependent learning, people with alcohol abuse often experience enhanced urges when they revisit sites where alcohol was once consumed (Johnsen et al., 1994). At the cognitive level, this is believed to be the result of selective processing for particular stimuli that are related to the substance (Johnsen et al., 1994).

Tiffany’s cognitive model of drug use (1990) identifies the bias in selective processing as an outcome of the repeated use of a particular substance which enhances the action schemata that underlie behaviours of drug consumption, making drug use an automatic process that can occur quickly without effort and conscious awareness. The action schemata are integrated sequences of associated connections containing sufficient information for the initiation and coordination of drug consumption that are stored as a unitized structure in memory (Tiffany, 1990). In alcohol abusers’ situation, when exposed to cues associated with drinking, the action schemata get activated and this in turn activates other cognitive processes responsible for urges and as such, urges can be experienced in light of salient alcohol cues (Johnsen et al., 1994). In the context of a substance-related cue, there is a bias in selective processing occurring at the cognitive level of an individual with substance abuse. Moreover, under an abstinent state, there is an increased attention towards these substance-related stimuli (Tiffany, 1990), and thus, an attentional bias.

2.2.1 Theoretical background to attentional bias and addiction

A theory for the development of attentional bias in addiction that is often cited in research is the Incentive-Sensitization theory proposed by Robinson and Berridge (1993). Developing the work of Tiffany (1990), they stated that drug-taking behaviour evolves into one with compulsion and this progression is critical to understanding the concept of addiction. They further provided explanation to the attraction and captivation of substance-related cues by substance users in a type of craving that is cue-reactivity induced (Robinson & Berridge, 1993). Over time, with repeated drug use, cues themselves acquire saliency and become attractive enough to substance users to induce attentional bias and cravings.

Craving is a fundamental concept in drug addiction; it is the driving force which compels someone with substance abuse to seek and consume drugs. “Craving is obsessive, irrational,
pathologically intense drug ‘wanting’ for no obvious reason, which leads to compulsive drug-seeking and drug-taking behaviour” (Robinson & Berridge, 1993, p. 272). In accordance to the Incentive-Sensitization theory, cue-reactive drug craving and its subsequent, compulsive drug-taking, addictive behaviours are the result of neuroadaptations that occur through repeated drug use (Robinson & Berridge, 1993). As such, repeated, intermittent drug use is a compulsory component as it incrementally causes changes in the neural substrate that mediates drug cravings and it also attributes incentive salience to drug-related stimuli making them more prominent (Robinson & Berridge, 1993). This attribution is an unconscious process interpreted by the users as craving and wanting as drug-related stimuli become increasingly more salient (Robinson & Berridge, 1993).

A common neural system that is affected by substances of abuse is the mesotelencephalic dopamine (DA) system. With drug use, the system becomes enhanced and dopamine neurotransmission is increased in the nucleus accumbens and dorsal striatum regions (Robinson & Berridge, 1993). In addition to the mesotelencephalic dopamine system being involved in dopamine release in drug use, the system also mediates incentive motivational properties (Robinson & Berridge, 1993), i.e., it has implications in drug craving and drug seeking behaviours. Then, through the repeated administration of drugs, the mesotelencephalic dopamine system, gradually and incrementally, becomes hypersensitized. This sensitization can be observed as an increase in drug effects, typically of stereotyped behaviour, and this phenomenon has been termed, ‘behavioural sensitization’. Although, the effect is most pronounced for psychomotor stimulants like cocaine and amphetamine, it, too, can be observed with other drugs, including nicotine (Robinson & Berridge, 1993). When the neural system becomes hypersensitized, the incentive motivational effects of drug use also become sensitized. Additionally, as drug consumption increases, behavioural sensitization also occurs and the drug experience is enhanced. This is then accompanied by an increase in the incentive value of drug taking which may lead to an increased likelihood of drug-seeking and drug consumption in the near future (Robinson & Berridge, 1993).

As stated previously, craving is mediated by the hypersensitized mesotelencephalic dopamine system and the associative processes of this system are involved in directing craving to substance-related stimuli. Craving and the obsessive wanting are what the user experiences in response to the unconscious process of incentive salience that have been attributed to drug-
related stimuli. Akin to the concept of classical conditioning, substance-related stimuli can adopt properties of the substance itself and become a proxy with the ability to elicit sufficient cravings to induce drug-seeking and drug-taking behaviours (Robinson & Berridge, 1993). In classical conditioning, the unconditioned stimulus elicits an unconditioned response and when this unconditioned stimulus is repeatedly paired with another stimulus, the second stimulus becomes the conditioned stimulus. With time the conditioned stimulus alone can elicit a conditioned response that is similar to the unconditioned response (Robinson & Berridge, 1993; Field & Cox, 2008). In other words, substance-related cues begin to develop motivational properties themselves (Field & Cox, 2008) and in the presence of these cues, sufficient craving can be elicited causing the substance users to seek-out and take the drug.

An aspect of addiction is the occurrence of relapse, which is characterized as a state wherein an abstaining substance user or a former user succumbs and begins to consume the substance again. The pressure to relapse is typically caused by negative affect arising from withdrawal symptoms and cravings (Allen et al., 2008). Cravings, especially, play a crucial role in relapse because former users still have tendencies to relapse even after long periods of abstinence when other withdrawal symptoms have subsided (Robinson & Berridge, 1993). Incentive-Sensitization theory can account for the occurrence of relapse due to the persistence and perhaps the permanence of the adaptations in the brain. The dopamine system remains sensitized to drug-related cues even after periods of abstinence and this sensitization induces strong cravings in the presence of cues, which may ultimately lead to relapse (Robinson & Berridge, 1993).

The mesotelencephalic dopamine system that undergoes the neuroadaptation of becoming sensitized with repeated drug use is hypothesized to mediate the process of incentive motivation (Robinson & Berridge, 1993). It is responsible for attributing incentive salience to the physical and mental perception of stimuli. Thus, through classical conditioning, substance-related cues attain incentive motivation, acquire saliency, and become the incentive that drives drug-seeking behaviour. In turn, the system becomes sensitized to not only the drugs themselves, but also drug-associated stimuli. The substance-related cues alone can then elicit an increased activation in the mesotelencephalic dopamine system, release dopamine, and mimic the drug response. Moreover, this activation of the neural system is experienced as wanting and craving by the user (Robinson & Berridge, 1993). The substance-related cues not only become salient, incentive
stimuli, but they can cause an increase in subjective cravings and physiological arousal (Field & Cox, 2008) and they can then guide the users to drug-seeking and drug-taking behaviours.

Franken (2003) extended the theory by attributing a mutual excitatory relationship between attentional bias and cravings. When attention is placed on the cue, cravings are elicited and increased, and this increase reinforces the attention grabbing properties of the cue and these two components – attention and craving – enter a mutual cyclical excitatory relationship until substance administration (Field & Cox, 2008). In summary, with classical conditioning and neuroadaptations from repeated drug use, substance-related cues acquire saliency and become more attractive to the substance users, and thus, users exhibit an attentional bias for these cues. Upon the perception of these cues, the mesotelencephalic dopamine system becomes activated, and this is experienced as wanting by the substance users and in turn, they are guided by their cravings towards drug consumption. For this reason, the risk of relapse is present and heightened for abstinent substance users, particularly in the presence of substance-related cues.

### 2.3 Attentional bias and smoking

In the context of tobacco smoking, nicotine is the unconditioned stimulus that elicits physiological responses. With repeated use, cigarettes, the vehicle through which nicotine is delivered, become the conditioned stimulus. Cigarettes then have the ability to capture the attention of experienced substance users exhibiting attentional bias for smoking-related cues and elicit cue-reactive cravings in smokers. Cravings elicited by attentional bias can be strong enough to cause users to engage in smoking. Yaxley & Zwann (2005) focused on smoking behaviours under an abstinent state and using Tiffany’s addiction theory (1990), when drug-seeking plans are impeded, attentional bias for the particular substance is exhibited. The presentation of attentional bias can cause a reduction in attentional resources that would have otherwise been available for other processes. Thus, attentional bias can be observed when smokers are exposed to smoking-related cues but cannot enact on them by smoking (Yaxley & Zwann, 2005). Likewise, attentional bias has been found to increase with smoking abstinence (Gross et al., 1993). In an experimental paradigm, attentional bias for smoking also occurs when smokers, regardless of abstinence state, are presented with two stimuli where one of the pair is smoking-related, and they effectively display a bias in their attention to the smoking related cue. The smokers would find themselves more attracted to one cue over another and since the
substance-related one is associated with positive, rewarding feelings of smoking, there would be a bias for the related cue.

In terms of clinical implications, attentional bias to smoking can be a unique predictor of smoking relapse in individuals trying to quit (Waters et al., 2003a; Powell et al., 2010). Attentional bias was able to predict lapses in smoking, especially early on in the quitting stages, among participants in a smoking cessation treatment program. Similarly, Powell and colleagues found that, along with pre-cessation salivary cotinine levels, attentional bias scores during acute abstinence were able to predict relapse rate at one week, one month (a trend), and three months. Moreover, attentional bias and lapses in smoking also have neurobiological implications; using an fMRI, correlations were found between attentional bias measurements and reactivity in neural substrates predicting relapse, including insula and dorsal anterior cingulate cortex (Janes et al., 2010). Thus, attentional bias is a critical concept in smoking and smoking cessation as it is implicated with cravings and it can also be a predictor of relapse.

Given the relationship between attentional bias and cravings, strategies to modify attentional bias in order to minimize cue-elicited cravings have been explored. Attentional bias can be trained and modified in a way that (a) smokers would no longer exhibit a bias for smoking-related cues and/or (b) they would learn to avoid these cues. Modification can be done via visual dot-probe (see 2.4.1.1 Visual dot-probe task) by consistently probing non-smoking related cues and over time, smokers would learn to attend to neutral cues over smoking cues (Attwood et al., 2008).

2.4 Measuring attentional bias in smoking research

Due to the cognitive construct of attention and attentional bias, any measurement or attempt thereof can only be reflective or a representation of attentional bias. To date, there are two categories of measurements – direct and indirect. In a review of attentional bias and addictive substances by Field and Cox (2008), a collection of tasks and methodologies used for measuring attentional bias were outlined. The indirect measurements include visual dot-probe task, the Stroop test, and dual-task procedures. More recently, a direct measurement of attentional bias can be assessed with eye-tracking technology, which allows for the measurement of visuo-spatial selective attention (Field & Cox, 2008).
With the review of Field and Cox as a starting point, a search was conducted using PsycINFO to determine common methodologies of measuring attentional bias in the context of smoking. Eleven relevant articles were identified that employed some sort of task or technology to measure attentional bias and cravings without any further manipulation to attentional processes other than using tobacco smoking-related cues to elicit or elevate attentional bias (see Appendix A for keywords and a breakdown of the searches).

2.4.1 Indirect measurement: visual dot-probe task, modified Stroop task, and visual search paradigm

Visual dot-probe task was first introduced as a measure of attentional bias with emotional stimuli (Macleod, Mathews, & Tata, 1986) and then progressively applied to addiction studies. More than half of the identified articles (Mogg et al., 2003; Waters et al., 2003b; Field et al., 2004; Mogg, Field, & Bradley, 2005; Yan et al., 2009; Leventhal et al., 2010) had used visual dot-probe task in their paradigm as one of the methods to assess attentional bias. In addition to visual-dot probe, some studies also examined eye movements (Mogg et al, 2003; Field et al., 2004; Mogg et al., 2005) and another paired the task with a modified Stroop test as well (Leventhal et al., 2010). In the original visual dot-probe task, first introduced by Macleod and colleagues (1986), emotionally threatening words were presented on a monitor in pairs with neutral words that were matched in length just above and below the centre of the screen. After 500 ms of word-pair presentation, there was 25 ms of blank screen, followed by a dot probe replacing the location on the screen of either the threatening or the neutral word. Participants were instructed to press a handheld button as quickly as possibly at the onset and detection of the dot probe (Macleod et al., 1986). The probe detection latency data were used to interpret the impact of the threatening stimuli, i.e. a reduced latency when the probe replaced a salient cue is attributed to attending to the region the probe had replaced and thus, reflects an attentional bias (Macleod et al., 1986).

All the identified studies, except for Yan and colleagues (2009), employed a variant of the original visual dot-probe task where pictorial representations were used instead of words. Smoking related images (e.g., a person holding a cigarette) were matched with neutral images, which were close in content but without smoking relevance (e.g., a person holding a pen), and presented on the screen on either side (left or right) of the screen for a specified duration, lasting
either 500 or 2000 ms. A dot probe or a pair of dots (· or ..) then immediately replaced either one of the picture’s location at the offset of the images and participants were instructed to respond as quickly as possible to whether the probe replaced the right or left image or which of the pair of dots they saw by pressing on one of two keys (Mogg et al., 2003; Waters et al., 2003b; Field et al., 2004; Mogg et al., 2005; Leventhal et al., 2010). The visual dot-probe task was aimed at measuring visuo-spatial attention and attentional bias was assessed by reaction time across conditions (Mogg et al., 2003; Field et al., 2004; Mogg et al., 2005) or by bias scores. Bias scores, which linearly correlated with attentional bias, were measured as the difference in reaction time on trials when probes replaced smoking images and when probes replaced neutral images (Waters et al., 2003b; Yan et al., 2009, Leventhal et al., 2010).

Another popular indirect method for assessing attentional bias was the modified Stroop task. In the modified version of the Stroop task for smoking (Waters et al., 2009; Leventhal et al., 2010), neutral or smoking-related words were presented on a monitor in different colours in sequence and participants were instructed to respond to the colour and not the semantics of the words presented with a key-press. Three measures were obtained to assess for the effect of attentional bias: standard Stroop, acute Stroop, and error Stroop. The standard Stroop was the difference in reaction time of the first neutral block and the second smoking block. The acute Stroop only assessed the reaction time of a sub-block, resulting in the first 11 trials of the smoking block, as this sub-block exhibited maximal attentional bias and subtracted that with the mean reaction time across all trials of the neutral block. Finally, error Stroop compared the number of errors made between the blocks (Waters et al., 2003b; Leventhal et al., 2010). It should be noted that Waters et al. (2009) assessed the Stroop effect as the difference in reaction time between smoking words and neutral words with no distinction regarding standard or acute Stroop effect. To assess for a standard or acute Stroop effect, latency in responding to a smoking-related cue was representative of smokers exhibiting attentional bias for those cues, i.e., a longer reaction time when smoking words are displayed versus neutral words. Alternatively, error Stroop was assessed by comparing the number of errors made in a smoking block versus neutral block. For these studies, smoking Stroop effects were observed in abstinent smokers for all three studies. Moreover, Waters et al. (2003b) found an effect for all three Stroop measures, while Leventhal et al. (2010) found an effect only in acute Stroop.
More recently, a novel task has been introduced to assess attentional bias and smoking. Oliver and Drobes (2012) applied the visual search paradigm to smoking, which had traditionally been used to measure attentional bias in mental health contexts including, anxiety and eating disorders. In this visual search paradigm, participants were instructed to locate a particular type of image among a field of irrelevant images that act as distractors (Oliver & Drobes, 2012) and an “odd-one-out” visual search task was employed where participants had to respond, with a key-press, as to whether a presentation of 20 images all belonged to a single category of smoking, office supplies, or toiletries, or if there was one deviant, target image embedded amongst 19 distractors of another category (Oliver & Drobes, 2012). Attentional bias was assessed by performance with reaction time as the primary outcome, and accuracy as the secondary outcome; additionally a smoking image could either be a target or a distractor (Oliver & Drobes, 2012). In theory, reaction time for a smoking target trial would be faster than the neutral condition and smoking distractor trial because of biases for smoking-related cues. By the same rationale, smoking distractor trials would be associated with longer reaction time, i.e., a decline in performance. While Oliver and Drobes (2012) did observe attentional bias for the visual search paradigm where participants were faster and more accurate when smoking images were targets as opposed to distractors, this effect was observed for all testing groups including non-abstinent smokers, abstaining smokers, and non-smokers.

The three different tasks for indirect measurement of attentional bias all involved the presentation of smoking-related cues with a neutral or matched image. In the visual dot-probe task, attentional bias was assessed by a shorter reaction time to trials where probes replaced smoking-related cues. On the contrary, for the modified Stroop task, evidence of an attentional bias occurred when reaction time for identifying the colour of the smoking words was longer due to interference. Lastly, for a visual search paradigm, primarily, a shorter reaction time in identifying smoking as a target image and a longer reaction time when smoking was the distracting category were indicative of a bias.

2.4.2 Direct measurement using eye movement and eye-tracking technology

When using eye movement data to assess attentional bias, two main measurements are used – initial eye gaze and duration of dwell time. There are various eye-tracking technologies, but they all have assessed either one (Kang et al., 2012) or both of these measurements (Mogg et al.,
2003; Field et al., 2004; Mogg et al, 2005; Kwak et al., 2007; van Rensburg et al., 2009). In these paradigms, participants were situated in front of a monitor while a pair of pictures were presented on the screen lasting 2000 ms (Mogg et al., 2003; Field et al., 2004; Mogg et al., 2005, Kwak et al., 2007), 6000 ms (Kang et al., 2012), or 10000 ms (van Rensburg et al., 2010 (an erratum)) after a brief fixation of 1000 or 2000 ms. The duration for which an image was presented had an impact on attentional bias measurement: while initial attention orientation can be assessed by a shorter image presentation time, a longer duration was appropriate for measuring attention maintenance or sustained attention (Kang et al., 2012). The pair of pictures presented consisted of a smoking-related image paired with a neutral or matched one, where the matched image resembled the smoking image without any smoking content (Mogg et al., 2003; Field et al., 2004; Mogg et al, 2005; Kwak et al., 2007; van Rensburg et al., 2009; Kang et al., 2012).

In eye-tracking studies, initial eye gaze or initial fixation was identified when three criteria were met: (1) participants’ eyes were on the central region, specifically the fixation point, of the monitor prior to picture onset, (2) an eye movement occurred at least 100 ms after picture onset and before the images were removed; movements prior to this cut-off were unlikely a response to the pictures, and (3) participants’ eyes were fixated on either one of the pictures during their presentation, i.e., participants moved their eyes and did not maintain their gaze on the central fixation point during picture presentation (Mogg et al., 2003; Field et al., 2004; Mogg et al., 2005; Kwak et al, 2006; van Rensburg et al., 2009). A direction bias score was calculated by expressing as a percentage of the number of trials where initial eye movements were directed to the smoking-related cue compared to those directed to the neutral or matched cues. A direction bias score greater than 50%, as expressed by directing initial fixation to the smoking cue on more trials compared to neutral or matched cues, was reflective of an attentional bias (Mogg et al., 2003; Field et al., 2004, Mogg et al., 2005; Kwak et al., 2006; van Rensburg et al., 2009).

The other measurement of attentional bias in eye-tracking studies was duration of dwell time and this assessed attention maintenance. Dwell time could be calculated as the average total amount of time when participants’ eyes were fixated on a smoking-related picture in comparison to a non-smoking one in an instance of image pair presentation. This measurement was expressed as a measure of time in milliseconds (Mogg et al., 2003; Field et al., 2004; Mogg et al., 2005; Kwak et al., 2007) or as a percentage of total time (van Rensburg et al., 2009; Kang et al., 2012). Kang
and colleagues (2012) also calculated a bias score from the percentage of dwell time with the difference in means of dwell time for smoking-related pictures and neutral pictures.

The rationale behind initial fixation and duration of dwell time measurements is that if smokers are more attentive to smoking cues versus matched or neutral cues due to smoking cues’ saliency, then smokers are more likely to be attracted to them. Moreover, once they direct their initial gaze to these smoking cues, they will have a tendency of spending more time dwelling and fixating on these images due to their attractive nature.

Of all the methods mentioned above, eye-tracking is the most advanced technology in the field. It provides a direct, behavioural measurement of attentional bias in the form of selective visuo-spatial attention with the assumption that attention coincides with the direction of visual gaze. Eye-tracking technology is able to provide two measures of attentional bias as opposed to a single reaction time difference between conditions. Eye-tracking can measure the initial orientation of attention with direction of initial gaze and attention maintenance with duration of dwell time. Additionally, this methodology can be used complementary to other tasks, such as the visual dot-probe, which were the two methods adopted in three of the studies (Mogg et al., 2003; Field et al., 2004; Mogg et al., 2005). However, when visual dot-probe was paired with eye-tracking, the image pair stimulus was presented longer (2000 ms) than it normally would have been (500 ms) without the eye-tracker. The longer presentation was to ensure attention maintenance can be measured in addition to attention orientation. Overall, eye-tracking technology allows for attentional bias to be assessed in novel ways.

2.5 Attentional bias, smoking, and exercise

As mentioned previously, one of the challenges to smoking cessation lies in the addictive nature of nicotine leading to persistent cravings. Strategies to alleviate these cravings are needed to assist smoking cessation and maintenance. Research on the impact of exercise on craving reduction has been well established (Taylor et al., 2007; Ussher et al., 2008). A recent review concluded that there was strong evidence that acute bouts of exercise reduced cravings (Hassova et al., 2013). However, little is known about the mechanism underlying the observed reduction in cravings. Moreover, evidence has also largely been based on self-reported measures of craving and few studies have concentrated on objective measures or outcomes. As discussed, because attentional bias influences underlying processes of cravings and substance-seeking behaviour, it
has important implications in maintaining addictive behaviours and leading to relapse when users are in an abstinent state (Field & Cox, 2008).

A review was done to synthesize current evidence concerning the effect of an acute bout of exercise on attentional bias amongst smokers and four relevant articles were identified (see Appendix A for keywords and a breakdown of the searches) that met the inclusion criteria (Thompson & Taylor, 2009; van Rensburg et al., 2009; Oh & Taylor, 2011; Hassova & Taylor, 2012).

All four articles employed eye-tracking technology, albeit using different eye-tracking equipment, to assess attentional bias with percentage of initial fixation time and percentage of dwell time. One study paired the eye-tracking paradigm with a visual-dot probe task as well (Hassova & Taylor, 2012). Percentage of initial fixation and percentage of dwell time were assessed at two time points – pre- and post-exercise.

There was heterogeneity in the exercise dosage reported in these studies. Half of the studies instructed participants to cycle on an ergometer for 15 minutes at different intensities with a rating of perceived exertion (RPE) ranging from 11 to 16.7 (van Rensburg et al., 2009; Oh & Taylor, 2011). Another asked participants to jog and to walk briskly on a treadmill at a self-directed pace with a mean RPE rating of 16 for jogging and 11.8 for walking (Thompson & Taylor, 2009). The last study also employed two exercise bouts where participants were instructed to walk briskly on a treadmill with an average RPE of 11.8 or to engage in seated isometric exercises (Hassova & Taylor, 2012).

Self-report instruments were used to assess cravings and withdrawal symptoms. After a bout of acute exercise, cravings to smoke were significantly reduced in all four studies with moderate to large effect sizes (Thompson & Taylor, 2009; van Rensburg et al., 2009; Oh & Taylor, 2011; Hassova & Taylor, 2012). There also appeared to be a more sustained effect of craving reduction with more vigorous intensity, but evidence was not strong enough to preferentially advocate for one intensity or type of exercise over another. Withdrawal symptoms, which also have implications for relapse, were also assessed in three of the four studies. It was found that during and following a bout of exercise, nicotine withdrawal symptoms were alleviated with low to moderate effect sizes (Thompson & Taylor, 2009; Oh & Taylor, 2011; Hassova & Taylor, 2012).
Thus, following a bout of exercise, participants reported fewer withdrawal symptoms and reduced cravings.

In terms of attentional bias outcomes, three of the four studies (Thompson & Taylor, 2009; van Rensburg et al., 2009; Oh & Taylor, 2011) reported a reduction in percentage of dwell time post-exercise while half of the studies found evidence for reduction in percentage of initial fixation (van Rensburg et al., 2009; Oh & Taylor, 2011). Thus, after engaging in physical activity, some smokers directed their initial gaze less at smoking images relative to non-smoking ones when compared to their pre-exercise state. Moreover, when their initial gaze was directed at smoking images, they also spent less time maintaining gaze on them than they did prior to exercise. Overall, following an acute bout of physical activity, there was a significant reduction in subjective measures of cravings and withdrawal symptoms and some evidence to suggest a modest reduction in attentional bias for smoking cues as objectively measured by percentage of initial fixation and percentage of dwell time. This emerging literature suggested that exercise may influence the saliency and attentional bias towards smoking-related cues among abstaining smokers.

2.6 Limitations to current literature

After conducting literature reviews of studies measuring attentional bias in smoking and the effect of physical activity on attentional bias, it is evident that there are inconsistent methodologies and assessment tools for attentional bias. This lack of consensus on a measurement tool makes it difficult to aggregate results and to compare across studies.

Even though the four identified attentional bias and exercise studies all employed an eye-tracking technology to assess for the impact of exercise on attentional bias with direction of initial fixation and duration of dwell time, there was still variation in the type of eye-trackers used. Three different kinds of eye-trackers were used and these included Eyelink II, which was a head-mounted device (van Rensburg et al., 2009), Pan/Tilt Optics System A504 (Thompson & Taylor, 2009), and the ASL Mobile Eye-tracker (Oh & Taylor, 2011; Hassova & Taylor, 2012). Because all four studies were conducted in the same laboratory, the rationale behind which type of eye-tracker to use should not have been a matter of accessibility. The question remains what would make one eye-tracker more preferential to another or perhaps, because there was no
consensus on the appropriate equipment, different eye-trackers were used as an explorative analysis.

As was observed earlier, attentional bias measurements using eye-tracking are sensitive to the presentation time of the stimulus. There is a trade-off effect between a shorter duration for the assessment of initial fixation and a longer duration for the assessment of attention maintenance. Moreover, eye movements, particularly saccades, occur very rapidly and there may be crucial information that may be lost during this rapid movement. Furthermore, eye-tracking technology necessitates expensive equipment and it is also not always feasible and accessible. The costs associated with eye-tracking technology are not limited to the high cost of the equipment itself. Data collection and analysis with an eye-tracker can be very time consuming as it requires recalibration between tasks during testing (Johansen & Hansen, 2006), and also whenever the equipment loses signal. Additionally, there is a vast amount of data to be reduced and interpreted. Being able to use eye-tracking technology requires extensive training and data collection can be quite challenging (Schnipke & Todd, 2000). Furthermore, not everyone’s eyes are capable of being tracked (Schnipke & Todd, 2000). Individuals may have difficulty having the equipment register their eye fixation and pupil signals. There are also criteria that cannot be screened out with simple questionnaires such as an individual’s pupil not reflecting enough light or the iris is not dark enough to be distinguished by the eye-tracker from pupil reflection (Schnipke & Todd, 2000). Physically, there are also factors that prevent signals to be tracked including, eyes being too small or too big, too occluded by eyelids and eyelashes, or their eyes may dry out during testing (Schnipke & Todd, 2000). At times, glasses may also be an occluding factor affecting results because of glares and reflection. Despite the technological advancement with eye-tracking, it may not be the optimal method for assessing attentional bias.

In order to grasp a better understanding of the effect of exercise on attentional bias and to establish a relationship between the two, more research needs to be done on the subject. However, there are some methodological limitations with the use of the recent and more direct eye-tracking technology in measuring attentional bias. Oliver and Drobes (2012), in their discussion of the visual search paradigm, also acknowledged the limitations of current methodologies for assessing attentional bias and recognized the importance of identifying and evaluating new paradigms in order to advance the field as current methods may have
questionable validity and reliability. Thus, as an initial step, alternative methods of measuring attentional bias should be developed and evaluated.

### 2.7 Motor control and attentional bias

Assessments of attentional bias have advanced throughout the years from modifying classic tasks like visual-dot probe and the Stroop task to the more recent eye-tracking technology. As described, eye tracking is not without its limitations and other cognitive tasks like visual dot-probe and Stroop task involve an arbitrary key-press response (Allport, 1987). To date, no work has been done investigating the limb-specific motor aspects of attentional bias in addiction research. Imaging studies with smokers have shown activation in neural correlates of pre-motor regions when being shown smoking-related cues and this may be reflective of motor preparation for drug-taking behaviour (Smolka et al., 2006).

The purpose of this study was to develop and evaluate a novel approach for assessing attentional bias, specifically one that employs the use of manual aiming. There are four reasons supporting the consideration of a manual aiming paradigm for assessing attentional bias. First, while an eye movement occurs rapidly and instantaneously, limb movements, in contrast, require a longer duration from movement initiation to its completion. During a movement, there may be shifts in attentional processes that cannot be observed with a saccadic eye movement due to its speed. Upper limb movements take longer to complete and to reach a target. As such, changes in attentional processes can be reflected in limb trajectories with deviations from a movement’s original path. Any amendments to movement made while attempting to reach a target after movement onset can be captured by manual aiming as revealed in their limb trajectories. Second, in comparison to eye-tracking technology, the equipment necessary for assessing upper-limb motor control are potentially more accessible to researchers and practitioners in terms of operating cost and there is considerably less difficulty with tracking an individual’s limb movement as opposed to their eye movements since eye signals are more particular and sensitive. Third, with manual aiming, measures additional to reaction time can be explored and assessed. Because limb movements are longer in duration than eye movements, movement times can also be investigated providing measurement of a potential unexplored property of attentional bias. In addition to reaction time and movement time, limb trajectories can also offer insight into
attentional bias because the direction of curved trajectories reflects attention and the evolution of which depicts current locus of attention (Song & Nakayama, 2009).

Speculatively, this proposed manual aiming approach using goal-directed movements to assess attentional bias may offer further insight into the nature of such bias that extends beyond current measurement approaches.

Objectives

1. To develop and evaluate the feasibility of a novel method for measuring attentional bias through the use of upper-limb specific motor control via manual aiming
   a. Assess attentional bias with reaction time by employing a method which combined visual dot-probe paradigm with that of manual aiming
   b. Due to the nature of manual aiming, assessments of movement time and limb trajectories could also be made

2.8 Hypotheses

1. Because the protocol used a modified visual dot-probe task with manual aiming, reaction time for conditions wherein probes replaced smoking images would be shorter than when probes replaced non-smoking cues and the shorter reaction time would be indicative of attentional bias.

2. Similar to reaction time data, the smoking group was expected to have a shorter movement time due to attentional bias when probes replaced smoking-related cues.

3. In terms of limb trajectory, it was hypothesized that the smoking group would make predictable curved trajectories towards smoking-related images when completing an upper limb movement due to biases for these images.

2.9 Significance and impact

In summary, attentional bias is an important focus for addiction research given its association with relapse. Emerging evidence suggests exercise may assist in attenuating attentional bias among abstaining smokers. However, current measures of attentional bias may be less than optimal. This study aimed to test a novel approach for assessing attentional bias that has a number of unique features which may make it an attractive option for researchers interested in
attentional bias in general, and among those interested in assessing the impact of acute bouts of exercise on attentional bias. As such, the study aimed to make a methodological contribution by determining the potential for using manual aiming in assessing attentional bias.
Chapter 3
Methodology

3.1 Overview

This study combined two existing tasks, including the visual dot-probe task adopted from the field of psychology for measuring attention, and a manual aiming task from the field of motor control used for assessing limb movements and limb trajectories. As such, the visual dot-probe task employed in the study had been modified to accommodate the features of manual aiming which is outlined in section 3.3 Experimental set-up.

Given the methodological nature of the study, the experimental group of smokers was tested against a control group of non-smokers. The two groups underwent the same protocol involving two separate sessions. Interested participants who met the inclusion criteria were invited to come to the Perceptual-Motor Behaviour Lab at the University of Toronto for a brief screening session. After screening, if participants were deemed eligible, they were asked to return to the lab for a testing session.

The purpose of the initial screening was twofold: (1) to confirm the eligibility of participants and (2) to obtain demographic and smoking status information. For the testing session, participants were instructed to abstain from smoking for at least three hours in order to induce cravings. Craving measures in addiction research can be sensitive to floor and ceiling effects (Sayette et al., 2000). The latter is particularly true for heavy smokers under an abstinent condition. An abstinence of three hours was chosen for this study as it was consistent with past acute study protocols of exercise and nicotine cravings (Faulkner et al., 2010; Arbour-Nicitopoulos et al., 2011) and it had been shown to be sufficient in increasing cigarette cravings for testing to prevent floor and ceiling effects. Craving assessments were included in this study as it plays an important role in Incentive-Sensitization theory and this allows for the examination of the relationship between cravings and measurements relating to attentional bias. During testing, participants were asked to complete two blocks of 80 trials of the modified visual dot-probe task with manual aiming, following a training session of ten trials for each block, while their eye and limb movements were monitored. Additionally, craving measurements were assessed at pre-, mid-, and post-testing.
3.2 Participants

The study protocol, including participant recruitment and its inclusion criteria, was approved by the University of Toronto Health Sciences Research Ethics Board.

3.2.1 Inclusion criteria

Inclusion criteria were imposed on the participants to ensure a relatively homogeneous sample. Participants were required to be between 18 to 37 years old. The upper age limit was consistent with research in the motor control field that had used limb trajectories as a measurement of interest. According to the Incentive-Sensitization theory, attentional bias is a result of neuroadaptations incurred with repeated cigarette use, this study, therefore, was restricted to moderate to heavy smokers, who smoked on average at least ten cigarettes a day. This number coincided with Health Canada’s terminology where moderate smokers are classified as consuming more than 10 cigarettes a day and heavy smokers are those who consume more than 20 cigarettes a day (Health Canada, 2008). Smokers were also asked to abstain from smoking at least three hours before the testing session. Participants in the control group were self-identified non-smokers. All participants also had to be right-handed because of the experimental set-up.

3.2.2 Exclusion criteria

Participants were excluded from the study if they had any health contraindications that would prevent them from completing the study appropriately. This included any vision problems that could not be corrected by corrective lenses and also any motor movement conditions, such as spasms and early onset Parkinson’s disease. Not having normal or corrected-to-normal vision would interfere with how participants’ perceived the images and the probes of the visual dot-probe paradigm. Having a motor movement condition would interfere with the upper-limb movement and limb trajectories participants were required to make when responding to the probes. Lastly, participants were excluded if they were addicted to any substance of abuse other than nicotine and this was assessed by self-report. This criterion was included to prevent any interference of attentional bias to addictive substances other than nicotine because this study was solely interested in attentional bias to nicotine and smoking-related images.
3.2.3 Sample size

To the best of our knowledge, no research has been done in the field of motor control with manual aiming and nicotine addiction. For this reasons, an a priori sample size could not be determined by calculations with effect sizes. However, one study employing manual aiming used a sample size of eight (Kennedy, 2011). In past studies on the effect of exercise on smoking cravings (Daniel et al., 2004; Taylor & Katomeri, 2006), a sample size of fifteen was deemed adequate for identifying differences in craving measures between the exercise conditions with a power of 0.8. Because this study hoped to validate manual aiming for measuring attentional bias for future studies involving exercise and smoking, a target sample size of fifteen was adopted for this study for each of the two groups, giving a total sample size of thirty participants. This chosen sample size was also reflective of typical sample sizes reported in the four identified smoking, exercise and attentional bias studies. However, with fifteen smokers, this target sample size was on the low-end based on the range of 14 (Kwak et al., 2007) to 203 (Leventhal et al., 2010) found in other attentional bias and smoking studies. Findings from this pilot study can be used to inform future power calculations and sample size estimation.

3.2.4 Recruitment and remuneration

Participants were recruited through various approaches. Recruitment posters and cards were placed and distributed throughout the University of Toronto St. George Campus community. After exhausting the use of distributing recruitment posters and cards, advertisements were placed both online via community websites such as Craigslist and Metro Classifieds, and in print within the classifieds section of a community newspaper, the Toronto Metro. Participants were given $5 for their time and participation in the initial screening session. Remuneration for participating in the testing session was initially set at $15. This was then increased to $20, then $25 towards the end of the study to increase interest and participation. Thus, total compensation for completing the two sessions of the study was between $20 and $30.
3.3 Experimental set-up

3.3.1 Study design

This study was a 3 (probe: smoking, matched, filler) x 2 (accompanying image: more-like-smoking, less-like-smoking) x 2 (group: control, smokers) mixed design. The design was also further divided by directionality – aiming directed to the right of the fixation point and aiming directed to the left of the fixation point.

3.3.2 Apparatus and experimental set-up

The experimental set-up for the testing session of the study is depicted in Figure 1. Participants were instructed to sit in front of a touch-screen monitor with a head-and-chin rest with a measured distance of 50 cm between their eyes and the screen, which was the distance used in a previous manual aiming study (Finkbeiner et al., 2008). Also following established distances reported in past studies, participants’ right index finger rested on a button/home position that was fixed at 20 cm in front of the participant. The button was aligned with the midline of the monitor, head-and-chin rest, and consequently, the participant as well (Song & Nakayama, 2006; Finkbeiner et al., 2008). The participant was fitted with disposable electrodes (3M Red Dot, Canada) for the electro-oculogram (EOG) and an infrared light emitting diode (IRED) for the Optotrak Certus (Northern Digital Inc., Canada). This equipment was used to monitor eye and limb movements, respectively. The EOG was set to AC current and collected corneo-retinal potential signal of the eye, which was a standing electrical charge between the positive terminal at the cornea and the negative terminal at the retina. The signal was filtered at 0.1 to 20 Hz with an amplification of 2000 and it provided information about the gaze location in space and the velocity of visual saccades. The information was recorded by Matlab (The MathWorks, USA) through an analog-to digital board (PCI-6024E, National Instruments Corp.) and eye movements were displayed on another computer monitor that was only available to the researcher as a time-displacement graph. The IRED was placed at the distal end of the participant’s right index and finger and the signal was sampled by the Optotrak Certus at 200 Hz to determine the location of the finger’s position throughout the trial. After each trial, time-displacement graphs were displayed on the researcher’s computer monitor for finger position, eye movement, and limb velocity.
3.3.3 Image presentation and set-up

Images were selected from the International Smoking Image Series (ISIS) database. These images have been used in previous studies involving visual-dot probe and eye-tracking (Field, Mogg, & Bradley, 2004; van Rensburg et al., 2009).

Three categories of images – smoking, matched, and filler – were used for this study. Smoking images consisted of objects or scenes with smoking-related cues like cigarettes or a person holding a cigarette. Matched ones were images that were chosen to closely resemble the smoking images but they did not contain any smoking-related cues, for example, a picture of a pen stacked on top of a notepad as opposed to a picture of a cigarette stacked on top of a cigarette carton (Figure 2). The brightness and contrast of the matched images were adjusted to correspond with that of the smoking images. The filler images were neutral in their contents and they were of random objects and scenes that were not smoking-related nor matched to any of the smoking-related cues.

Figure 1. Experimental set-up with a modified visual dot-probe task with electro-oculogram for eye tracking and Optotrak Certus for limb tracking. The Optotrak Certus is a wall-mounted device that was aligned parallel to the experimental set-up to ensure optimal tracking without signal interference. The image to the left depicts the position before probe onset where the participants are fixating on the fixation cross with the home button depressed and when a pair of smoking/matched/filler images are presented. This is an example of a condition wherein the right image was probed as the participant reaches toward the right side of the screen in response to probe onset (image to the right). The above diagram has been adapted from Hesse et al., 2012.
With the three categories of images, four different pairs were possible: (1) smoking image paired with a matched image, (2) smoking image paired with a filler image, (3) matched image paired with a filler image, and (4) a filler image paired with another filler image. The fourth pairing with both filler images served as a control condition for baseline measures and this image pairing condition was used for calculating limb trajectory deviations (see 3.6.8. Limb trajectory). All the image pair presentations can be found in Appendix B. With the four image pairs, there were seven conditions in total based on which image the probe replaced. For example, for the smoking and matched image pairing, there was a condition when the probe replaced the smoking image and another condition for when the probe replaced the matched image. Another factor to be considered was the directionality of the aiming that was dependent on the probe location, i.e., when probes replaced the image that was to the left of the fixation cross, participants made manual aiming movements to the left and movements to the right were made when images to the right of the fixation cross were probed.

To determine the image pair presentation set-up, studies on smoking and eye-tracking that have used image pair presentation were reviewed. Field and colleagues (2004) provided detailed accounts of the experimental set-up and image presentations. In their study, the images were 95 mm high and 130 mm wide, their inner edges were 30 mm apart when presented in pairs, and the distance between the probes was 105 mm. The participants were seated 111 cm from the computer screen (Field et al., 2004). In the present study, participants were seated approximately 50 cm from the screen as other manual aiming studies have reported (Song & Nakayama, 2006;
This was done to ensure that participants were able to reach the touch screen comfortably because 111 cm would have been too far for them to achieve the task. The 105 mm distance between the probes signified a distance of 52.5 mm between the probes and the fixation point. Because the button/home position was aligned with the centre of the screen and the fixation point, the 52.5 mm distance was also reflective of the x-axis distance between the probe and the starting button. The x-axis corresponded with medial and lateral movements. A manual aiming movement from the button to the probe would consist of movements in all three axes: x-axis for directing the finger laterally towards the probe location, y-axis to move the finger vertically towards the height of the probe, and z-axis for moving anteriorly towards the monitor from the button (see Figure 3 for set-up and its corresponding axes). The 52.5 mm distance on the x-axis would have been too narrow to capture the full trajectory effect and to discern any appreciable differences between left and right aiming movements. As such, the distance between the probe and the centre of the screen was set to 100 mm, reflecting that of past manual aiming studies (Song & Nakayama, 2006; Finkbeiner et al., 2008). For the present study, to account for the difference in the distance between the screen and the participant, the image size was also adjusted but scaled proportional to the study as reported by Field and colleagues (2004). Consequently, the images used in the present study were 43 mm high by 59 mm wide.

Figure 3. Experimental set-up of the axes between the button and the monitor. Each manual aiming movement requires movement from the button laterally along the x-axis, vertically along the y-axis, and anteriorly along the z-axis.
3.4 Screening session

Interested participants who met the inclusion criteria were invited to the Perceptual-Motor Behaviour Lab at the University of Toronto to participate in a brief screening session. During this session, they were asked to read the information sheet for the study and to sign the consent form. After obtaining consent, all participants were asked to fill out questionnaires on their demographics, handedness, and smoking status and habits based on WHO’s Guidelines for Controlling and Monitoring Tobacco Epidemic. Additionally, self-identified smokers further completed questionnaires on their level of nicotine dependence including the Fagerström Test for Nicotine Dependence (FTND), and the Hooked on Nicotine Checklist (HONC).

After completing the questionnaires, participants’ breaths were analyzed for breath carbon monoxide (BCO) level with the piCO+ Smokerlyzer expressed in parts per million (ppm) (Bedfont Scientific, USA). The BCO level was an objective measure assessing the smoking status of participants as it reflects the percentage of carbon monoxide found in the blood. BCO readings are widely used in both research and clinical settings as an indicator of smoking status and smoking abstinence. For the control, non-smoking group, the BCO reading served as an objective indicator that the participants in this group were non-smokers. Non-smokers who live in the city often obtain a reading between 0-5 ppm, depending on their second-hand smoke exposure levels. For the experimental group, the BCO reading served as an objective indicator that the participants in this group were smokers. The makers of the piCO+ Smokerlyzer have set a cut-off point of 7 ppm, where below this reading, an individual is considered a non-smoker and a reading of 7 to 15 ppm is classified as a low-dependence smoker (Bedfont Scientific, USA). However, the manufacturer also reported that a reading of 7-10 ppm indicates ‘danger zone’ and to be classified as a smoker, it requires a reading more than 10 ppm. To be conservative, and consistent with previous smoking studies (Scerbo et al., 2010; Faulkner Arbour-Nicitopoulos & Hsin, 2010), a BCO reading of 10 ppm was chosen as the cut-off to be identified as a smoker. A smoking participant’s continued eligibility for the study was dependent on this BCO reading. Non-smokers were invited to return to the lab for the testing session if their BCO reading was between 0 to 5 ppm and smokers were invited for the testing session if their reading was greater than 10 ppm.
3.5 Testing session

For the testing session, BCO level was again assessed to confirm abstinence and a reading that was less than that of the baseline from the screening measure was indicative of smoking abstinence for the smoking group. This procedure was done for both smokers and non-smokers. For the latter group, they again, had to have a BCO reading of less than 10 ppm.

After BCO level was analyzed, all participants completed questionnaires assessing their craving with the Desire to Smoke and Strength of Desire. These same questionnaires were again assessed at the middle and end of the testing session to determine their relationship to attentional bias at different time points of the study.

Participants were then equipped with the EOG electrodes (3M Red Dot, Canada); two electrodes were placed on either side of the eyes and one was on the forehead, after these areas had been cleaned with an alcohol swabs. Participants were also equipped with an IRED on the distal end of their right index finger, which was used for determining the finger’s location in space. Once equipped with the three electrodes and the IRED, participants were seated in front of the touch screen monitor while resting their head on the head-and-chin rest. They were also instructed to press down on the button, with their right index finger. This starting point was termed the ‘starting position’ or ‘home position’. The participants then completed two blocks of 80 experimental trials, which were preceded by ten training trials each block, for a total of 180 trials.

At the beginning of each block, there were baseline measurement procedures for both the Optotrak Certus and the EOG signal where participants were instructed to point and look to various points on the touch screen monitor respectively. This process ensured that the equipment was functioning and assessing limb and eye positions properly. For the hand movement measures, participants were first instructed to keep the button depressed and then bring their finger toward the centre of the monitor and to touch the fixation point, readings of the limb position were taken at both points for the three axes and assessed against a pre-determined standard range for the position readings. The EOG location measures were obtained by having participants make a series of saccades by alternating eye positions between the fixation point, left probe position, and right probe position. Eye movements were plotted on a graph and they were assessed for the saccadic movements to ensure proper EOG measurements. After the baseline
measures, participants engaged in a series of manual aiming tasks while their eye and limb movements were tracked in response to the on-screen images. Each trial began with a 1000 ms presentation of a fixation cross, which was followed by 1000 ms of stimulus presentation of the image pairs with the fixation cross still present on the screen. Instantaneous with the stimulus offset, a single probe appeared on the screen replacing either of the images previously present for 1500 ms. This presentation was then followed by an inter-trial interval of 1000 ms (Figure 4). The timed presentations of the images were programmed via Matlab. The image pair conditions were presented in randomized order as determined by a random number function on Excel (Microsoft, USA). During the entire presentation of the fixation point and the image pair, participants’ right index fingers of their dominant hand were at the home position, pressing down on the button and they were requested to have their eye gaze remain fixated on the fixation cross at the centre of the screen. In contrast to the typical visual dot-probe task where probe onset is responded to by a key press, e.g., left or right arrow key, in this novel paradigm, participants responded by making a manual aiming movement. Upon detection of probe onset, participants were instructed to remove their fingers from the button and to physically point to the probe and make contact with the touch screen as quickly and as accurately as possible. They were instructed to maintain their touch on the target until its offset. At the probe offset and the simultaneous onset of the fixation cross for the next trial, participants had to return their right index fingers to the home position and keep the button depressed in preparation for the next trial.

At the end of each trial, feedback of limb and eye positions was presented as time-lapsed graphs for the researcher and the validity of each trial was assessed based on this information. Trials were deemed invalid if: (i) participants did not maintain their eye gaze on the fixation cross during image presentation, i.e., if they made eye movements towards either of the images, (ii) participants did not aim for the target probe location, or (iii) participants did not aim for the target probe in time, i.e., a full manual aiming movement was not made by trial end. Once a trial was deemed invalid (which comprised of 4.0% across trials and participants), it was noted by the researcher and the trial was repeated. Participants were instructed to remain their eye gaze on the fixation cross to ensure that they were focused on the task and that the content of the images were not being consciously processed. Maintained fixation could also maximize probe detection as it had equal chances of occurring on either side (Welsh, 2011).
Figure 4. A series of image presentation depicting an example of a trial. Every trial starts with a fixation cross for 1000 ms. This is followed by image pair presentation for another 1000 ms. Simultaneously with image pair offset, the probe onsets for 1500 ms. During the 1500 ms, participants are required to make a manual aiming movement towards the probe. If a movement was not made in time, the trial is considered invalid and is repeated. The 1500 ms of probe presentation is replaced once again with the fixation cross. This, specifically, is an example of a matched-smoking presentation with probe appearing on the right, replacing the smoking image (MS|S).

Between the two blocks of trials there was a five-to-ten minutes break where the participants were instructed to again complete questionnaires assessing their cravings. This assessment was also done at the end of the second block. Accordingly, cravings were assessed at the beginning, middle, and end of the session; this approximately corresponded to time 0, half an hour to forty minutes into the session, and again at an hour or an hour and twenty minutes into the testing. The timing of the sessions was dependent on how quickly participants responded to the probes, how many trials had to be repeated, and how many breaks they had requested between trials.
3.6 Measures

There were various measures assessed throughout the study and these can be classified into two sections: self-report measures and objective measures. Self-report measures consist of those obtained from questionnaires that were assessed at both the screening and testing session and these were the (a) smoking status questionnaire, (b) Fagerström Test for Nicotine Dependence, (c) Hooked on Nicotine Checklist, handedness questionnaires, and (d) cravings. Objective measures include the breath carbon monoxide level, reaction time, movement time, and eye movement.

3.6.1 Smoking status questionnaire

The smoking status questionnaire was based on a questionnaire from WHO’s Guidelines on Controlling and Monitoring the Tobacco Epidemic (1998). This included questions for current smokers, former smokers, and non-smokers. Questions for current smokers and former smokers were similar in nature and assessed smoking status in terms of how often they smoke/smoked and past and current cessation attempts. Questions for all three groups included the amount of exposure to second-hand smoke at home and at work. This questionnaire allowed for the identification of participants as either a smoker or a non-smoker based on WHO (1998) criteria. Questions on second-hand smoke could serve as an indication of the prevalence of smoking in participants’ lives independent of their own smoking status.

3.6.2 Fagerström Test for Nicotine Dependence (FTND)

The FTND is a six-item questionnaire used extensively in smoking research as an indicator of nicotine dependence amongst smokers (Scherbo et al., 2010; Arbour-Nicitopoulos et al., 2010). It was revised from the original eight-item Tolerance Questionnaire (Fagerström, 1978) to the current six-item form in 1991 (Heatherton et al., 1991). The scoring of the questionnaire depended on the answers to the six questions and the answers to each could be summed to provide an overall score. The FTND score could range from 0 to 10 with a score of 10 signifying high nicotine dependence on the dependency scale.

3.6.3 Hooked for Nicotine Checklist (HONC)

HONC is also a questionnaire commonly used in smoking research and it measured diminished autonomy over tobacco. It was a 10-item questionnaire with “yes” or “no” answers (DiFranza et
al., 2002). Each “yes” responded on the HONC was given a score of 1. Thus, like the FTND, scores also ranged from 0 to 10, with a higher score indicating less autonomy over tobacco, i.e., a greater nicotine dependence and addiction. Although not as widely used as FTND, HONC has proven to be effective at capturing nicotine dependence amongst youth. This questionnaire was included in this study to be complementary to the FTND for the younger smokers in the sample.

3.6.4 Handedness questionnaire

A handedness questionnaire was used to assess the handedness of the participants. As an inclusion criterion, participants had to be right-handed due to the physical experimental set-up for the study. This questionnaire was adapted from the original assessment to only include fourteen common household items (Oldfied, 1971). Participants answered “right” or “left” in correspondence to which hand do they use for the identified object or action. To be included in the study, majority of the items had to be identified as being performed with the right hand.

3.6.5 Cravings

Cravings were assessed with two items that are frequently used in smoking research that each measures a different aspect of craving: desire to smoke and strength of desire to smoke (e.g., Scerbo et al., 2010; Arbour-Nicitopoulos et al., 2010).

Desire to smoke was assessed with the statement “I have a desire to smoke right now” and the participant responded by choosing a number that corresponded to their state at the time on a seven-point Likert scale with 1 = strongly disagree, 4 = neither agree nor disagree, and 7 = strongly agree.

Strength of desire to smoke was assessed with the statement “My desire to smoke right now is” and the participant responded by choosing a number that corresponded to their state at the time on a seven-point Likert scale with 1 = low, 4 = neither high nor low, and 7 = high.

Objective measures, other than the breath carbon monoxide (BCO) level, were obtained during the testing session for assessing attentional bias and these included reaction time, movement time, and limb trajectory. For details surrounding BCO level refer to section 3.4 Screening session.
3.6.6 Reaction time

Due to the novel paradigm of the study, there were two ways used to obtain reaction time data, one from the starting button and another from the Optotrak Certus. Reaction time from the button was registered as the time elapsed between probe onset and button release. Reaction time from the Optotrak Certus was assessed by the displacement of the finger as tracked by IRED. Optotrak Certus was programmed to record reaction time as when the velocity of the finger reached 30 mm/s in three consecutive samples with a sampling rate of 200 Hz. As such, reaction time was the time elapsed between probe onset and when this velocity threshold was reached. Although there were two sources for reaction time, only one (the one originating from Optotrak Certus) was analyzed, as discussed in Results.

3.6.7 Movement time

Similar to reaction time, there were also two sources of movement time data, one from the touch screen and another from the Optotrak Certus. Movement time from the touch screen was the time elapsed between button release and when the finger made physical contact with the screen, i.e., when the screen was touched. Alternatively, movement time from the Optotrak Certus was the duration between the first point when limb velocity reached 30 mm/s in three consecutive samples and the point when limb velocity falls below 30 mm/s for three consecutive samples. Again, despite the two sources, only one set of data, that of the Optotrack Certus, was analyzed and as discussed in Results section.

3.6.8 Limb trajectory

For limb trajectory data, a "peak trajectory differences" variable was introduced to be used for analysis. This variable was calculated by first comparing limb positions at different time points for each condition to that of the control, filler-filler condition. Then the magnitude of the differences was assessed to determine the peak trajectory difference – when limb position differed the most from the control condition. Due to the set-up, limb trajectory could be either a positive or a negative value based on whether the movements were made toward or away from the fixation point (Table 1). However, to simplify sign interpretations for the analysis, signs of peak trajectory differences for movements to the left were converted to reflect that of movements to the right (by multiplying -1). For simplicity, peak trajectory differences and limb trajectory are henceforth used synonymously.
3.6.9  Eye movement

Eye movement data, expressed as a time-lapsed displacement graph on a separate monitor only available to the researcher, was displayed after each trial. The graph was assessed to ensure that (1) participants were fixating on the fixation cross at the beginning of the trial and (2) no saccadic movements were made during the presentation of image pairs. This was done to verify the focus of the participants on the task and also that participants were not already physically attending to a particular area of the screen via eye movements prior to probe onset as attentional bias should be a subconscious process.

3.7  Statistical analyses

All statistical analyses were done using IBM SPSS Statistics for Windows, Version 21.0. (IBM Corp., USA). All variables were assessed for normality and statistical analyses were done in three stages: (i) between-group, (ii) within-group, (iii) craving and attentional bias.

3.7.1  Between-group analysis

Although 14 different conditions were mentioned previously between the two directions, this study was organized as a 3 (probe: smoking, matched, filler) x 2 (accompanying image (accimage): more-like-smoking, less-like-smoking) x 2 (group: control, smokers) mixed design. The first factor with the three levels expressed the images that the probe replaced, the probed image. The second factor with the two levels expressed the accompanying images and whether it was more-like-smoking or less-like-smoking, with the following gradient going from less-like-smoking to more-like-smoking: filler → matched → smoking. The third factor was a comparison between the control non-smoking participants and the smoking group. Direction was also factored in by conducting separate analyses for when manual aiming was directed to the right or to the left. This analysis was done for reaction time, movement time, and limb trajectory. A
mixed-model repeated-measures ANCOVA, with the probes and accompanying images as the within-subject variables and group as the between subject variable, tested for any group differences. The model also controlled for any demographic variable(s) that significantly differed between the two groups. If significant differences were found at $\alpha = 0.05$ level, post-hoc analyses were conducted using t-tests with Bonferroni correction.

3.7.2 Within-group analysis

For within-group analysis, ANOVAs were used to determine conditional differences within the smoking group. As such, it was a 3 (probe: smoking, matched, filler) x 2 (accimage: more-like-smoking, less-like-smoking) repeated-measures ANOVA. Because conditional differences were only assessed within the smoking group, there was no between-group variable. Again, this analysis was done for reaction time, movement time, and limb trajectory and twice each for the two directions. If significant differences were found at $\alpha = 0.05$ level, post-hoc analyses were conducted using t-tests with Bonferroni correction.

3.7.3 Craving and attentional bias

Given the implication of cravings in the Incentive-Sensitization theory, Kendall's Tau was done analyzing any correlations between reaction time, movement time, and total time and craving assessments. Total time was an extension of reaction time and movement time; it was the summation of reaction time and movement time and it encompassed the time elapsed between probe detection until movement end and the movement was made as a response to that probe detection.

3.8 Expected findings

Overall, there should be group differences for reaction time, movement time, and limb trajectory between the control group and the smoking group, and particularly a probe by group interaction.

3.8.1 Between-group differences

For the smoking group, their reaction time and movement time were expected to be smaller than that of the non-smoking group. The former group was expected to respond and move towards the probe faster because of attentional bias. For the non-smokers, their data should be independent of the conditions, i.e., there should be no differences in these measurements between the different
image pair presentations and which image the probe replaced. However, for the smokers, reaction time and movement time were expected to be faster when probes replaced a smoking or more-like-smoking image when presented with a less-like-smoking image. This should be observed for both right and left movements.

The smoking group was expected to have greater peak trajectory differences than the non-smoking group. They were expected to have greater deviations in their limb trajectory when smoking or more-like-smoking images were probed because their attention would have been directed towards their location.

3.8.2 Within-group differences

For within-group analyses, conditional differences were expected. It was hypothesized that when smoking images were probed or when matched images were probed, while presented alongside filler images, reaction time and movement time would be smaller, corresponding to faster response and movement due to attentional bias than when a non-smoking image was probed. As for limb trajectory, it was expected that deviations, would be larger for the same conditional comparisons.

3.8.3 Craving and time measurements

When measurements of time (reaction time, movement time, and total time) are correlated with cravings, there should be a negative relationship between the variables. With greater cravings, there should be greater attentional bias which would be reflected by shorter reaction time and movement time, and subsequently total time. This may seem to be counter-intuitive to the positive relationship between attentional bias and cravings, but this is because of the negative relationship between time-based performance (reaction time, movement time, and total time) and attentional bias, i.e., shorter times would be indicative of greater attentional bias.
Chapter 4
Results

4.1 Demographics

A total of one hundred and ninety-seven people responded to print and online advertisements. Fifty-six were still interested in the study and met the inclusion criteria after initial contact via phone or e-mail. A total of thirty-eight participants attended and completed the screening session. Five of which, all smokers, were ineligible after the screening session on account of not having a high enough breath carbon monoxide (BCO) level. To be included in the study, a baseline BCO reading of 10 ppm was required as an objective indication of participants’ smoking status. There was an additional attrition of four participants from the study due to scheduling conflicts (n = 2), unable to abstain from smoking for the testing session (n = 1), and unable to follow instructions and complete the study (n = 1). Thus, a total of twenty-nine participants completed both screening and testing sessions. The twenty-nine participants were categorized into two groups: non-smokers (n = 15) and smokers (n = 14). However, one smoker was ultimately excluded from any analysis (see Data Exclusion under section 4.4 Data Cleaning) resulting in a group size of 13 for the smoking group.

The non-smoking group consisted of 8 males. This group had an average age of 22.20 (SD = 2.83) with mean BMI score of 21.97 (SD = 2.22). They had a baseline BCO reading of 2.47 ppm (SD = 0.92) and a testing/abstinent BCO reading of 2.00 ppm (SD = 0.76). Non-smokers were exempt from completing other measures of smoking, including the Fagerström Test of Nicotine Dependence (FTND) and Hooked on Nicotine Checklist (HONC) as they were not dependent on nicotine (Table 2).

The smokers consisted of 6 males. This group had an average age of 27.38 (SD = 5.35) with mean BMI score of 23.05 (SD = 3.23). On average, this group smoked 13.04 cigarettes per day (SD = 3.25) and had a mean FTND score of 3.92 (SD = 1.98) and a mean HONC score of 8.00 (SD = 1.96). Additionally, their baseline BCO reading was 18.15 ppm (SD = 10.36) and post-abstinent BCO was 9.46 ppm (SD = 4.10) (Table 2).
4.2 Group comparison

A $\chi^2$ test and independent samples t-test found no significant between-group differences for gender ($\chi^2(1, N = 28) = 0.14, p = 0.71$) and BMI ($t(26) = 1.05, p = 0.30$) respectively. There was a significant difference in age between the non-smokers and the smokers ($t(26) = 3.27, p < 0.01$); the smokers were significantly older than the non-smokers. As expected, between-group differences were observed for available smoking measures. These measures included cigarettes per day ($t(12.00) = 14.47, p < 0.001$) and BCO readings for both baseline ($t(12.16) = 5.44, p < 0.001$) and post-abstinent testing ($t(12.71) = 6.48, p < 0.001$) conditions (Table 2).

An attempt was made to equalize the two groups by removing participants with extreme age values, i.e., youngest and oldest individuals. However, to effectively render the two groups statistically equal in age, this required participants to be between the ages of 22 to 27, giving a total sample of 9 participants with $n_{\text{smokers}} = 3$ ($t(7) = 0.85, p = 0.43$). Because this procedure removed more than two-thirds of the data, it was not a practical approach. As such, age was taken into consideration as a covariate in further between-group analyses.

4.3 Different sources of reaction time and movement time

The two ways of obtaining reaction time and movement time from the button/screen and Optotrak Certus resulted in four variables respectively: (i) reaction time$_{\text{Optotrak}}$, (ii) movement time$_{\text{Optotrak}}$, (iii) reaction time$_{\text{button}}$, and (iv) movement time$_{\text{button}}$.

Table 2
Group demographics and comparison

<table>
<thead>
<tr>
<th>Demographics</th>
<th>Non-smokers (n = 15)</th>
<th>Smokers (n = 13)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n$ Male</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>MAge</td>
<td>22.20 (2.83)**</td>
<td>27.38 (5.35)**</td>
</tr>
<tr>
<td>BMI</td>
<td>21.97 (2.22)</td>
<td>23.05 (3.23)</td>
</tr>
<tr>
<td>CPD</td>
<td>0**</td>
<td>13.04 (3.25)**</td>
</tr>
<tr>
<td>Baseline BCO (ppm)</td>
<td>2.47 (0.92)**</td>
<td>18.15 (10.36)**</td>
</tr>
<tr>
<td>Testing BCO (ppm)</td>
<td>2.00 (0.76)**</td>
<td>9.46 (4.10)**</td>
</tr>
<tr>
<td>FTND</td>
<td>N/A</td>
<td>3.92 (1.98)</td>
</tr>
<tr>
<td>HONC</td>
<td>N/A</td>
<td>8.00 (1.96)</td>
</tr>
</tbody>
</table>

** $p < 0.001$ for between-group differences
4.3.1 Reaction time comparison between the sources

Using Pearson Correlation, the two reaction times correlated strongly with each other \((r = 0.96, F(1, 26) = 278.96, p < 0.001)\). Their strong correlation was expected because the two measurements were assessing the same response. When reaction time was assessed across all conditions and the two groups, the mean reaction times of the two sources were \(M_{\text{RT button}} = 324\) ms \((SD = 57)\) and \(M_{\text{RT Optotrak}} = 298\) ms \((SD = 58)\). However, despite their strong, linear relationship, the two reaction times were still statistically different from each other \((t(27) = 8.07, p < 0.001)\). Despite the different reaction times, regardless of which one was used, there was no evidence for significant findings for one of the main variables – group differences between smokers and non-smokers (Appendix C). That is, conclusions about the study results remained the same irrespective of chosen reaction time measure. For this reason, only one set of data was selected to be further analyzed. Data originating from the Optotrak Certus was preferentially selected to maintain consistency between the other variables including movement time and limb trajectory.

4.3.2 Movement time comparison between the sources

Using Pearson Correlation, the two movement times correlated strongly with each other \((r = 0.95, F(1, 26) = 230.23, p < 0.001)\). Like reaction time, their strong correlation was expected as both measurements were assessing the time elapsed between target detection and goal attainment, i.e., aiming for the target via a touch screen monitor. When movement time was assessed across all conditions and the two groups, the mean movement times were as follows, \(M_{\text{MT button}} = 505\) ms \((SD = 106)\) and \(M_{\text{MT Optotrak}} = 516\) ms \((SD = 78)\). In the case of movement time, there was no statistical difference between movement time from the Optotrak and that of the button \((t(27) = 1.40, p = 0.17)\).

Since limb trajectory is only assessed by Optotrak Certus, to ensure consistency across measures, reaction time and movement time as measured by Optotrak Certus were used for further analysis instead of those measured by button and touch screen. Henceforth, unless otherwise specified, reaction time and movement time refer to that as measured using Optotrak Certus.
4.4 Data filtering

4.4.1 Data exclusion

The data from one participant was excluded from any analysis due to a significant portion of outliers (see Data Reduction for identification of outlier).

4.4.2 Data reduction

Reaction time and movement time were first assessed for implausible data such as negative values or zero values. Furthermore, reaction times and movement times below 100 ms were also excluded as being likely indicative of movement onset (both reacting to and reaching for the probe) prior to probe onset, i.e., false starts. Implausible and false data were thus selected and subjected to a pairwise deletion. Corresponding trajectory data from implausible and false movement times were also removed based on the rationale that if movement time was erroneous, subsequently, its trajectory data would also be erroneous and unreliable. After pairwise deletion, the overall average and standard deviation were calculated for each condition and for all the participants. Outliers were then defined as being more than 2.5 standard deviations from the mean. Outliers were identified and removed from further analysis. A restricted mean approach, i.e., using a set standard deviation cut-off, is a common approach taken for reaction time (and by extension, movement time in this case) and cut-offs of 2.0, 2.5, and 3.0 standard deviations are most used (Miller, 1991). However, while Miller (1991) expressed concern in a restriction bias that accompanied the use of the restricted mean approach, it was warranted in this case because of the small sample size and the similar sample size between the groups. Moreover, the 2.5 standard deviation restricted mean was also consistent with a past study using a selective reaching task (Welsh, 2011).

Altogether, 2.82% of data was excluded from further analysis after identifying and removing implausible data (1.21%), false movements (0.27%), and outliers (1.34%) as determined by being more than 2.5 standard deviations away from the mean.

4.5 Manipulation check

There were two manipulation checks in place for this study: breath carbon monoxide (BCO) level for smokers and movement time and directionality.
4.5.1 BCO level

The study protocol required all participants to abstain from smoking for at least three hours prior to testing. In order to assess abstinence objectively, two BCO readings were obtained from participants at baseline and at testing. If the smokers had abstained from smoking for at least three hours prior to the testing session, then their post-abstinent BCO reading would be lower than that at baseline when abstinence was not required. As expected, a paired samples t-test showed that at the testing session, post-abstinent BCO reading ($M_{\text{BCO}_{\text{testing}}} = 9.46$ ppm) was significantly lower than that at baseline ($M_{\text{BCO}_{\text{baseline}}} = 18.15$ ppm) ($t(12) = 4.06, p = 0.001$).

4.5.2 Movement time and directionality

For the protocol, because probes replaced one of the pictures appearing on the touch screen, either to the right or left of the home position and fixation point, a corresponding manual aiming movement was made in the same direction. Participants all had right-hand dominance and they were instructed to aim for the probes with their right-hand, contralateral movements, i.e., movements to the left of the screen, would take longer to complete than ipsilateral ones, i.e., movements to the right of the screen. A paired samples t-test showed this difference in movement time with movements to the right ($M_{\text{MT}_{\text{right}}} = 488$ ms) being significantly shorter than movements to the left ($M_{\text{MT}_{\text{left}}} = 546$) ($t(27) = 11.45, p < 0.001$).

4.6 Inter-reliability of conditions

There were three main variables in this experimental protocol: reaction time, movement time, and limb trajectory. Reaction time and movement time could be further subdivided into when probes replaced images to the right and when they replaced images to the left. Of these five variables, there were six conditions associated with each variable based on image pairing and which image was being replaced by the probe: (i) smoking image paired with matched image when smoking image was replaced (SM), (ii) smoking image paired with filler image when smoking image was replaced (SF), (iii) smoking image paired with matched image when matched image was replaced (MS), (iv) matched image paired with filler image when matched image was replaced (MF), (v) smoking image paired with filler image when filler image was replaced (FS), and (vi) matched image paired with filler image when filler image was replaced (FM).
Due to the novelty of this protocol and the assessments taken, inter-reliability measures were calculated for the conditions of each variable and can be found in Table 3. Reliability analyses confirmed that there was high inter-reliability across the conditions for all the variables.

<table>
<thead>
<tr>
<th>Variables</th>
<th>N</th>
<th>Cronbach’s α</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaction time to the right (RT&lt;sub&gt;right&lt;/sub&gt;)</td>
<td>6</td>
<td>0.98</td>
</tr>
<tr>
<td>Reaction time to the left (RT&lt;sub&gt;left&lt;/sub&gt;)</td>
<td>6</td>
<td>0.98</td>
</tr>
<tr>
<td>Movement time to the right (MT&lt;sub&gt;right&lt;/sub&gt;)</td>
<td>6</td>
<td>0.99</td>
</tr>
<tr>
<td>Movement time to the left (MT&lt;sub&gt;left&lt;/sub&gt;)</td>
<td>6</td>
<td>0.99</td>
</tr>
<tr>
<td>Limb trajectory</td>
<td>6</td>
<td>0.82</td>
</tr>
</tbody>
</table>

4.7 Data analyses overview

Data were analyzed in three stages. First, the three main variables – reaction time, movement time, and limb trajectory – were assessed for group differences between non-smokers and smokers. Subsequently, any meaningful main and interaction effects were further explored. The second stage of analysis exclusively examined data from smokers. The final stage was also exclusive to smokers and it assessed the relationship between cigarette cravings and time measurements.

4.8 Stage one: Between-subjects analysis

4.8.1 Data distribution and assumptions

Reaction time, movement time, and limb trajectory data were collapsed across conditions, i.e., the different image pair presentations, and the distribution for each direction was assessed. Reaction time data for probes appearing to the right (RT<sub>right</sub>) was normally distributed ($D(28) = 0.11, p = 0.20$) with a skewness of $0.22 (SE = 0.44)$ and kurtosis of $-0.62 (SE = 0.86)$ and that of the left (RT<sub>left</sub>) was normally distributed ($D(28) = 0.08, p = 0.20$) with a skewness of $0.19 (SE = 0.44)$ and kurtosis of $-0.55 (SE = 0.86)$. Movement time data for probes appearing to the right (MT<sub>right</sub>) was normally distributed ($D(28) = 0.08, p = 0.20$) with a skewness of $0.14 (SE = 0.44)$ and kurtosis of $-0.77 (SE = 0.86)$ and for probes appearing to the left (MT<sub>left</sub>), data was normally distributed ($D(28) = 0.10, p = 0.20$) with a skewness of $-0.02 (SE = 0.44)$ and kurtosis of $-0.94$. 
(SE = 0.86). Limb trajectory data were normally distributed ($D(28) = 0.14, p = 0.20$) with a skewness of 0.32 ($SE = 0.44$) and kurtosis of 0.86 ($SE = 0.86$).

Mauchly’s Test of Sphericity was used to assess sphericity for the main effect of probe and the interaction effect of probe image and accompanying image interaction for each of the five variables ($RT_{right}$, $RT_{left}$, $MT_{right}$, $RT_{right}$, and limb trajectory). When the assumption of sphericity was violated and cannot be assumed, degrees of freedom were corrected for using Greenhouse-Geisser procedures. Mauchly’s sphericity tests and when appropriate, Greenhouse-Geisser corrections, were also completed for the within-group analysis. Homogeneity of between-group variances for all levels of the repeated-measures variables were assessed by Levene’s Test for Equality of Variances and could be assumed for all cases.

### 4.8.2 Analysis model

A series of 3 (probed image [probe]: smoking, matched, filler) x 2 (accompanying image [accimage]: more-like-smoking, less-like-smoking) x 2 (group: smokers, non-smokers) mixed design ANCOVA were conducted on the five variables while controlling for age.

### 4.8.3 Reaction time

#### 4.8.3.1 Hypothesis

Attentional bias, the cognitive bias exhibited by substance users acquired from repeated drug use over time, should be observed in the smoking group over the non-smoking group. Smokers were hypothesized to be more attracted to images of a smoking nature as opposed to matched or filler images when presented together. Because of attentional bias, smokers’ attention would already be oriented in the visual space of the monitor where smoking or like-smoking images were presented and thus, they would be quicker to detect the probe onset when it replaced these images. In other words, smokers were expected to behave faster than non-smokers with a shorter reaction time, when: (a) smoking images were probed, presented with a matched image, (b) smoking images were probed, presented with a filler image, and (c) matched images were probed, presented with a filler image.
4.8.3.2 Probes appearing on the right

Although the analysis was run with a covariate, age was not a significant covariate in this model of reaction time with probes appearing on the right ($F(1, 25) = 0.03, p = 0.87$). Additionally, there was no evidence of a between-group effect for reaction time depending on participants’ smoking status ($F(1, 25) = 0.82, p = 0.38$) (Table 4).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Df</th>
<th>F-statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaction time to the right</td>
<td>(1, 25)</td>
<td>0.82</td>
</tr>
<tr>
<td>Reaction time to the left</td>
<td>(1, 25)</td>
<td>0.95</td>
</tr>
<tr>
<td>Movement time to the right</td>
<td>(1, 25)</td>
<td>3.85†</td>
</tr>
<tr>
<td>Movement time to the left</td>
<td>(1, 25)</td>
<td>3.96†</td>
</tr>
<tr>
<td>Limb trajectory</td>
<td>(1, 25)</td>
<td>0.57</td>
</tr>
</tbody>
</table>

† signify a trend in the analysis (both at $p = 0.06$)

4.8.3.3 Probes appearing on the left

Similar to probes appearing on the right, age again was not a significant covariate in this model of reaction time with probes appearing on the left ($F(1, 25) = 0.17, p = 0.69$). Additionally, there was no between-group effect for reaction time depending on participants’ smoking status ($F(1, 25) = 0.95, P = 0.34$) (Table 4).

4.8.4 Movement time

4.8.4.1 Hypothesis

Because of attentional bias and smokers already attending to a particular visual space of the monitor, they would also be quicker to enact on the probe onset when it replaced a smoking or like-smoking image. In other words, smokers are expected to move to the target probe faster than non-smokers with shorter movement time, when: (a) smoking images were probed, presented with a matched image, (b) smoking images were probed, presented with a filler image, and (c) matched images were probed, presented with a filler image.
4.8.4.2 Probes appearing on the right

For probes appearing to the right side of the screen, age, again, was not a significant covariate for movement time \((F(1, 25) = 2.28, p = 0.14)\). There was a trend for group differences in movement time for probes appearing to the right \((F(1, 25) = 3.85, p = 0.06, \text{partial } \eta^2 = 0.13)\) with the smoking group being close to having a greater movement time \((\text{MMT}_{\text{smoker}} = 520 \text{ ms})\) than the non-smokers \((\text{MMT}_{\text{non-smokers}} = 460 \text{ ms})\) (see Table 4 for group differences and Table 5 for a breakdown of the means).

4.8.4.3 Probes appearing on the left

For probes appearing to the left side of the screen, age, again, was not a significant covariate for movement time \((F(1, 25) = 2.71, p = 0.11)\). There was a significant main effect for probe \((F(2, 50) = 3.24, p < 0.05, \text{partial } \eta^2 = 0.12)\). Post-hoc analysis was done by collapsing left movement time data across each probe, i.e., whether the probed image was smoking, matched, or filler. Repeated measures ANOVA was done with the three different probes and this yielded no significant differences in movement time \((F(2, 52) = 2.47, p = 0.10)\).

Additionally, there were trends for an interaction between probe, accimage, and smoke image \((F(2, 50) = 2.69, p = 0.08)\) and for group differences in movement time for probes appearing to the left \((F(1, 25) = 3.96, p = 0.06, \text{partial } \eta^2 = 0.14)\) with the smoking group showing a trend for greater movement times \((\text{MMT}_{\text{smoker}} = 585 \text{ ms})\) than the non-smokers \((\text{MMT}_{\text{non-smokers}} = 513 \text{ ms})\) (Tables 4 and 5).
Table 5

Group mean and standard deviation for each condition of each variable in ms for time variables (reaction time and movement time) and mm for distance variables (limb trajectory). Limb trajectory presented as the mean peak trajectory differences for each condition.

<table>
<thead>
<tr>
<th>Variables &amp; Condition</th>
<th>Non-smokers (n = 15)</th>
<th>Smokers (n = 13)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reaction time to the right (RT_{right})</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SM</td>
<td>279 (73)</td>
<td>298 (44)</td>
</tr>
<tr>
<td>SF</td>
<td>277 (62)</td>
<td>306 (37)</td>
</tr>
<tr>
<td>MS</td>
<td>279 (60)</td>
<td>301 (44)</td>
</tr>
<tr>
<td>MF</td>
<td>274 (70)</td>
<td>297 (45)</td>
</tr>
<tr>
<td>FS</td>
<td>276 (63)</td>
<td>296 (44)</td>
</tr>
<tr>
<td>FM</td>
<td>272 (54)</td>
<td>303 (47)</td>
</tr>
<tr>
<td><strong>Reaction time to the left (RT_{left})</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SM</td>
<td>292 (63)</td>
<td>319 (48)</td>
</tr>
<tr>
<td>SF</td>
<td>281 (57)</td>
<td>315 (54)</td>
</tr>
<tr>
<td>MS</td>
<td>293 (59)</td>
<td>320 (59)</td>
</tr>
<tr>
<td>MF</td>
<td>288 (64)</td>
<td>321 (49)</td>
</tr>
<tr>
<td>FS</td>
<td>287 (51)</td>
<td>319 (50)</td>
</tr>
<tr>
<td>FM</td>
<td>291 (56)</td>
<td>312 (46)</td>
</tr>
<tr>
<td><strong>Movement time to the right (MT_{right})</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SM</td>
<td>469 (82)</td>
<td>510 (69)</td>
</tr>
<tr>
<td>SF</td>
<td>467 (76)</td>
<td>503 (62)</td>
</tr>
<tr>
<td>MS</td>
<td>475 (75)</td>
<td>504 (58)</td>
</tr>
<tr>
<td>MF</td>
<td>468 (80)</td>
<td>500 (63)</td>
</tr>
<tr>
<td>FS</td>
<td>473 (77)</td>
<td>513 (69)</td>
</tr>
<tr>
<td>FM</td>
<td>475 (85)</td>
<td>512 (62)</td>
</tr>
<tr>
<td><strong>Movement time to the left (MT_{left})</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SM</td>
<td>523 (99)</td>
<td>567 (65)</td>
</tr>
<tr>
<td>SF</td>
<td>525 (89)</td>
<td>560 (64)</td>
</tr>
<tr>
<td>MS</td>
<td>531 (102)</td>
<td>562 (60)</td>
</tr>
<tr>
<td>MF</td>
<td>529 (103)</td>
<td>576 (75)</td>
</tr>
<tr>
<td>FS</td>
<td>534 (103)</td>
<td>576 (62)</td>
</tr>
<tr>
<td>FM</td>
<td>524 (100)</td>
<td>567 (69)</td>
</tr>
<tr>
<td><strong>Limb trajectory</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SM</td>
<td>0.94 (6.18)</td>
<td>0.28 (4.16)</td>
</tr>
<tr>
<td>SF</td>
<td>1.04 (4.43)</td>
<td>0.03 (5.83)</td>
</tr>
<tr>
<td>MS</td>
<td>0.92 (4.23)</td>
<td>0.85 (6.25)</td>
</tr>
<tr>
<td>MF</td>
<td>0.86 (5.19)</td>
<td>-1.78 (4.34)</td>
</tr>
<tr>
<td>FS</td>
<td>-0.59 (5.28)</td>
<td>0.34 (5.48)</td>
</tr>
<tr>
<td>FM</td>
<td>1.50 (4.56)</td>
<td>2.59 (4.72)</td>
</tr>
</tbody>
</table>
4.8.5 Limb trajectory

Limb trajectory assessed the pathway taken by the participants in their hand/finger movement to reach the target (probes) on-screen from the resting home position. Peak trajectory differences (see 3.6.8 Limb trajectory) were used as a proxy for limb trajectory, and were examined for each condition.

4.8.5.1 Hypothesis

The smoking group was expected to have a tendency of directing their limbs towards the smoking or like-smoking images. Because peak trajectory differences were used in the analysis, this could be translated to larger deviations from the filler-filler condition as smokers are directing their movements more towards the smoking and like-smoking images.

4.8.5.2 Peak delta limb trajectory

There was a significant main effect for accimage ($F(1, 25) = 4.60, p < 0.05$, partial $\eta^2 = 0.16$). However, no significant differences were observed for either the group ($F(1, 25) = 0.57, p = 0.46$) or the covariate factors ($F(1, 25) = 0.94, p = 0.34$) (Table 5). A post-hoc analysis assessed for the significant main effect of accompanying images by using paired-samples $t$-test between the two types of images, more-like-smoking and less-like-smoking. There were no significant differences between the two different types of accompanying images ($t(27) = 0.46, p = 0.65$).

Despite the null finding for a group effect, an interesting finding emerged upon further investigation (see Figure 5). When looking at the peak trajectory differences, depending on the smoking status and which accompanying image it was, the direction of the trajectories differed. While the difference was not statistically significant ($F(2, 50) = 1.44, p = 0.25$), it should be noted that when smokers were presented with an accompanying image that was “more like smoking,” their limb trajectory veered towards the accompanying image that was “more like smoking,” presented in Figure 5 by a negative value ($F(1, 25) = 2.46, p = 0.13$). This tendency of directing limb trajectory towards the accompanying image was not observed in non-smokers or when accompanying image was “less like smoking” than the main probed image for both smokers and non-smokers.
**Figure 5.** Figure showing the interaction of limb trajectory and accompanying image. The means of the peak trajectory differences with standard error bars are shown for smokers (n = 15) and non-smokers (n = 13) when accompanying image is more-like-smoking or less-like-smoking. The age covariate is evaluated at age 24.61 in the model.

### 4.9 Stage two: Within-group analysis (smokers)

Analyses of reaction time, movement time, and limb trajectory were examined within the smoking group to assess for differences between smokers.

#### 4.9.1 Data distribution and assumptions

To assess for data distribution, data were collapsed across different conditions, i.e., image pairings, for reaction time, movement time, and limb trajectory. Data were normally distributed for all variables ($D_s(13) = 0.110 - 0.200$, $ps = 0.16 - 0.20$). Shapes of the distributions were assessed with skewness and kurtosis and the values for which ranged from a skewness of 0.05 to 0.68 ($SEs = 0.62$) and a kurtosis range of -0.07 to -1.46 ($SEs = 1.19$).

#### 4.9.2 Analysis model

A series of 3 (probed image [probe]: smoking, matched, filler) x 2 (accompanying image [accimage]: more-like-smoking, less-like-smoking) repeated measures ANOVAs were conducted on the five variables ($RT_{right}$, $RT_{left}$, $MT_{right}$, $RT_{right}$, and limb trajectory).
4.9.3  Reaction time

4.9.3.1  Hypothesis

When examining the smoking group, the same analogy of attentional bias was applied here where smoking images acquire incentive saliency and capture attention. Conditions were grouped based on which image was being replaced, and it was expected that smokers would detect the probe faster, i.e., shorter reaction time, when smoking images were probed versus when the other two images were probed. As a corollary, reaction times for matched image probed when paired with a filler image were expected to be faster than when filler images were probed. When smoking or like-smoking images were replaced by probes, smokers were hypothesized to detect the probes and react faster than when filler images were probed.

4.9.3.2  Probes appearing on the right

There was no observable significant difference for probes ($F(1.4, 16.8) = 0.13, p = 0.88$) or accompanying image ($F(1, 12) = 0.39, p = 0.54$) within the smoking group when controlling for smoking measures. An interaction effect for probe and accompanying image was also not observed ($F(2, 24) = 1.11, p = 0.35$).

4.9.3.3  Probes appearing on the left

There was no observable significant difference for probes ($F(2, 24) = 0.41, p = 0.67$) or accompanying image ($F(1, 12) = 0.66, p = 0.43$) within the smoking group when controlling for smoking measures. An interaction effect for probe and accompanying image was also not observed ($F(1.3, 15.2) = 0.43, p = 0.66$).

4.9.4  Movement time

4.9.4.1  Hypothesis

Similar to reaction time, movement time was expected to be shorter, i.e., faster, when smoking and like-smoking images were probed compared to filler images. Because of image salience, the attention of smokers would already be oriented towards the smoking images when they are replaced by probes and these participants would be more prepared to enact and aim for the probe.
4.9.4.2 Probes appearing on the right

There were no observable significant effect for accompanying image \((F(1, 12) = 1.75, p = 0.21)\) or for the interaction between probe and accompanying image \((F(2, 24) = 0.23, p = 0.80)\). There was, however, a slight trend for probe \((F(2, 24) = 2.09, p = 0.15)\).

4.9.4.3 Probes appearing on the left

There were no observable significant main effects for probe \((F(2, 24) = 0.93, p = 0.41)\) or for accompanying image \((F(1, 12) = 0.03, p = 0.87)\). There was, however, a trend for the interaction of probe and accompanying image \((F(2, 24) = 2.67, p = 0.09)\).

4.9.5 Post-hoc analysis

Post-hoc analysis for movement time was considered given (a) the trends discovered here and (b) the sensitivity of movement time for between-group analysis in part one. Post-hoc was assessed by a series of paired samples t-tests to assess which image pairing significantly differed the most. Paired samples t-tests were conducted for both movements to the right and to the left as they may benefit from further analysis. Each condition was paired with its alternate in a paired samples t-test. For instance, a condition of a smoking image and a filler image where the former image was probed was tested against the same image pairing but when the filler image was probed. A series of paired samples t-tests were done for the following image pairings: smoking-matched, smoking-filler, and filler-matched. Recall that the picture notations are as such, S for smoking image, M for matched image, and F for filler image. The first letter of the pairing denotes the image that was probed, i.e., SF would be a smoking and filler pairing where smoking image was probed.

4.9.5.1 Movement time for probes appearing on the right

Paired samples t-tests found a trend for conditions with smoking and filler pairings \((t(12) = 2.19, p = 0.05)\), after Bonferroni correction with \(\alpha = 0.017\), where \(MSF = 503\) ms \((SD = 62)\) and \(MFS = 513\) ms\((SD = 70)\) (Figure 6).
4.9.5.2 Movement time for probes appearing on the left

Paired samples t-tests found a trend for conditions with smoking and filler pairings ($t(12) = 2.49, p = 0.03$), after Bonferonni correction with $\alpha = 0.017$, where $MSF = 560$ ms ($SD = 64$) and $MFS = 576$ ms ($SD = 62$) (see Figure 6).

4.9.6 Limb trajectory

4.9.6.1 Hypothesis

For conditions where probes replaced smoking images or like-smoking images (when paired with a filler image), smokers were expected to make more direct movements towards these images. When assessing the peak trajectory differences, deviations from the neutral condition with filler-filler image pairing were expected to be greater for conditions wherein smoking or like-smoking images were probed.
4.9.6.2 Peak trajectory differences

There were no significant differences for probes \(F(2, 24) = 1.92, p = 1.7\), or for accompanying image \(F(1, 12) = 0.05, p = 0.83\). There was, however, a trend for the interaction of the two \(F(2, 24) = 2.54, p = 0.10\) within the smoking group. Refer to Table 6 for a list of the main effects for each variable.

Table 6

Main effects and significant interactions of probe and accompanying image of just the smokers for each variable

<table>
<thead>
<tr>
<th>Condition</th>
<th>df</th>
<th>F-statistic</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaction time to the right (RT(_{\text{right}}))</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Probe</td>
<td>(1.4, 16.8)</td>
<td>0.13</td>
<td>0.88</td>
</tr>
<tr>
<td>Accompanying image</td>
<td>(1, 12)</td>
<td>0.39</td>
<td>0.54</td>
</tr>
<tr>
<td>Probe*accompanying image</td>
<td>(2, 24)</td>
<td>1.11</td>
<td>0.35</td>
</tr>
<tr>
<td>Reaction time to the left (RT(_{\text{left}}))</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Probe</td>
<td>(2, 24)</td>
<td>0.41</td>
<td>0.67</td>
</tr>
<tr>
<td>Accompanying image</td>
<td>(1, 12)</td>
<td>0.66</td>
<td>0.43</td>
</tr>
<tr>
<td>Probe*accompanying image</td>
<td>(1.3, 15.2)</td>
<td>0.43</td>
<td>0.66</td>
</tr>
<tr>
<td>Movement time to the right (MT(_{\text{right}}))</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Probe</td>
<td>(2, 24)</td>
<td>2.09</td>
<td>0.15†</td>
</tr>
<tr>
<td>Accompanying image</td>
<td>(1, 12)</td>
<td>1.75</td>
<td>0.21</td>
</tr>
<tr>
<td>Probe*accompanying image</td>
<td>(2, 24)</td>
<td>0.23</td>
<td>0.80</td>
</tr>
<tr>
<td>Reaction time to the left (MT(_{\text{left}}))</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Probe</td>
<td>(2, 24)</td>
<td>0.93</td>
<td>0.41</td>
</tr>
<tr>
<td>Accompanying image</td>
<td>(1, 12)</td>
<td>0.03</td>
<td>0.87</td>
</tr>
<tr>
<td>Probe*accompanying image</td>
<td>(2, 24)</td>
<td>2.67</td>
<td>0.09†</td>
</tr>
<tr>
<td>Limb trajectory</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Probe</td>
<td>(2, 24)</td>
<td>1.92</td>
<td>1.7</td>
</tr>
<tr>
<td>Accompanying image</td>
<td>(1, 12)</td>
<td>0.05</td>
<td>0.83</td>
</tr>
<tr>
<td>Probe*accompanying image</td>
<td>(2, 24)</td>
<td>2.54</td>
<td>0.10†</td>
</tr>
</tbody>
</table>

† \(p \leq 0.15\)

4.10 Cravings and attentional bias

Cigarette cravings were assessed with desire to smoke (DtS) and strength of desire to smoke (SoD). Reaction time and movement time were collapsed across each condition. Correlational analyses were done to assess for relationship between cigarette cravings and time assessments. Total time, the time elapsed from probe detection to movement end, i.e., total time = reaction time + movement time, was also included in the analysis as an additional measure of performance.
4.10.1 Hypothesis

According to Incentive-Sensitization theory (Robinson & Berridge, 1993), the neural system that mediates craving is also responsible for attributing incentive saliency to substance-related stimuli. Craving could be considered to arise from excessive activity in the sensitized system (Robinson & Berridge, 1993), and as such, the correlate of incentive salience (Waters et al., 2003b). Incentive salience, or attentional bias, was measured with reaction time, movement time, and as a result total time, and they were hypothesized to correlate negatively with measures of craving, since greater bias is indicative of shorter times.

4.10.2 Data distribution

Desire to smoke and strength of desire were based on a 7-point Likert scale and since their data were not normally distributed ($D(13) = 0.29, p < 0.05$ and $D(13) = 0.25, p < 0.05$ respectively), Kendall’s Tau was used for correlational analyses.

4.10.3 Craving and attentional bias

Correlational data of desire to smoke and strength of desire with reaction time, movement time, and total time are presented in Table 7. As expected, the two craving measures positively correlated with each other ($\tau(13) = 0.84, p < 0.01$). Also as expected, total time was positively correlated with reaction time and movement time since it was the summation of the two time measures ($\tau(13) = 0.67$ and $0.69$ respectively, $ps < 0.01$). There were significant linear relationships for both measures of smoking cravings and time assessments, with the exception of movement time and strength of desire. There was a trend of a linear relationship for movement time and strength of desire with $p = 0.084$. In all cases, the relationships were negative. This signified that as cravings increased, there was a corresponding decrease in reaction time, movement time, and total time. When put into context, participants reacted faster to the probe (smaller reaction time) and reached the target faster (smaller movement time) when they were experiencing higher levels of craving.
4.11 Summary of findings

The experimental protocol had three main variables that assessed attentional bias – reaction time ($RT_{\text{right}}$ and $RT_{\text{left}}$), movement time ($MT_{\text{right}}$ and $MT_{\text{left}}$), and limb trajectory. To keep the source of data consistent, reaction time and movement time data detected by Optotrak Certus were used, as opposed to the data from the button and touch screen monitor. Participants were divided into two groups – non-smokers ($n = 15$) and smokers ($n = 13$). These two groups did not differ in gender representation or BMI, but the smokers were significantly older than the non-smokers. Moreover, there was also the expected difference in smoking status measures between the groups as measured by baseline breath carbon monoxide level. In addition, smokers had significantly lower breath carbon monoxide level at the testing session than at baseline (screening) as a result of the required three hour smoking abstinence. As another manipulation check, movement time for contralateral movements to the left was larger, i.e., took longer, than the ipsilateral movements to the right. Furthermore, there were six conditions to each variable and there was high reliability between the conditions for all variables.

Data analyses were approached from three stages: (i), between-subjects effect, (ii) effects within the smokers, and (iii), correlation between cravings and time measurements within the smokers. There were no significant differences between the two groups on all five variables. However, trends were observed in movement time for movements to the left where smokers tended to reach their target slower than non-smokers, while controlling for age. There was also a significant main effect for accompanying image when assessing limb trajectory. Although, differences could not be found in the post-hoc analysis, an interesting pattern emerged where smokers tended to deviate their limb trajectory towards the accompanying image when the image

<table>
<thead>
<tr>
<th></th>
<th>DtS ($n = 13$)</th>
<th>SoD ($n = 13$)</th>
<th>Reaction time ($n = 13$)</th>
<th>Movement time ($n = 13$)</th>
<th>Total time ($n = 13$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desire to Smoke (DtS)</td>
<td>-</td>
<td>0.84**</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Strength of Desire (SoD)</td>
<td>- 0.48*</td>
<td>- 0.48*</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Reaction Time</td>
<td>- 0.51*</td>
<td>- 0.39</td>
<td>0.36</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Movement Time</td>
<td>- 0.61**</td>
<td>- 0.54*</td>
<td>0.67**</td>
<td>0.69**</td>
<td>-</td>
</tr>
</tbody>
</table>

* $p < 0.05$; ** $p < 0.01$
was more-like-smoking when compared to the probed image. When conducting analyses on just
the smoking group, there were a few trends for movement time and limb trajectory. Movement
time data was further examined given its sensitivity in between-group assessments using paired-
samples t-tests. Upon this further analysis, trends were observed, after Bonferroni correction, for
the filler-smoking image pairing for both movement time to the right and movement time to the
left. Movement time was lower when the smoking image of the pair was probed than when the
filler was probed and this was observed for both directionalities. In the final stage of analysis,
measures of craving, desire to smoke and strength of desire, were correlated with measures of
time (reaction time, movement time, and total time). Using Kendall’s Tau, significant negative
linear relationships were found for all measures of craving and time assessments, with the
exception of strength of desire and movement time. When there was an increase in craving, an
observable decrease could be found in reaction time, movement time, and total time, which may
be reflective of greater attentional bias. Namely, when the smokers experienced greater cigarette
cravings, they reacted and took less time to direct their finger to aim at the images.
Chapter 5
Discussion

5.1 Overview

The use of manual aiming for assessing attentional bias gave rise to two new variables in addition to reaction time, including movement time and limb trajectory. It was hypothesized that, because of attentional bias for smoking cues, smokers would have shorter reaction time and movement time, as well as a more direct limb trajectory on trials where more-like-smoking images were probed. Although no evidence of attentional bias could be found for reaction time and limb trajectory, there was a near-significant trend in movement time for smokers opposite to hypothesis. The lack of between-group differences may be the result of the effects of nicotine deprivation or a depletion of self-control resources. The trend for movement time may be more pronounced in a larger sample with more dependent smokers. Overall, there is some tentative evidence to suggest manual aiming is a feasible method for assessing attentional bias, particularly in terms of movement time. This method may even be sensitive to measures of attentional bias that cannot be detected by an immediate response such as reaction time. Future studies are required to address current limitations and to confirm the implications of manual aiming for assessing attentional bias.

5.2 Movement time and the smoking group

Between-group analysis found no significant group or condition by group differences for any of the five variables; however, after controlling for age, the smoking group had an unexpected, near-significant larger movement time than the non-smoking group. The smoking group, on average, took more time to complete the manual aiming movement than the non-smoking group. This trend was observed irrespective of image pairing or the type of image the probe replaced. Smoking abstinence could have affected this group’s performance, in terms of a greater movement time, due to the effects of nicotine deprivation and the depletion of self-control strength.
5.2.1 Nicotine withdrawal

Nicotine is an addictive psychoactive substance with associated withdrawal symptoms. It has an effect on not only the central nervous system, but also the periphery nervous system (Bates et al., 1994). A review done by Heishman, Taylor, and Henningfield (1994) examined the effects of nicotine on human performance. They remarked that the American Psychiatric Association has included impaired performance as part of the nicotine withdrawal syndrome and impairments can be observed within 4 to 12 hours of nicotine abstinence. In the present study, the smoking group was required to abstain from smoking for at least 3 hours but, they had abstained for, on average, 5 hours and this abstinence period could have affected performance.

It should be noted that while an enhancement in performance can be observed for non-smokers when administered nicotine, this effect is different than the enhancement observed in experienced smokers after smoking abstinence. For non-smokers, the effect of nicotine administration has implications with smoking initiation whereas for smokers, the implication is with smoking maintenance (Heishman et al., 1994). Smoking abstinence may result in performance deficit and any improvement in performance with nicotine administration could be the removal of that deficit (Tait et al., 2000). Although, to our knowledge, there are no past studies on the performance of manual aiming tasks between smokers and non-smokers, Tait and colleagues used a visual search memory cognition task that could be devised to examine both reaction time and movement time. Similar to the present study, participants were required to press down on a home position until they were ready to make a selection for the probe – which was termed, decision time – and at which point, they were instructed to release the home position and to press down on a target key – movement time. In their study, after a required abstinence of 12 hours, the heavy smoking group (those who smoked more than 20 cigarettes per day), had significantly slower movement time than non-smoking controls. Moreover, this performance deficit was removed after the smoking group was given a smoking break (Tait et al., 2000). As such, for experienced smokers, nicotine administration leads to withdrawal/deficit removal and not performance enhancement, as can be observed for non-smokers.

Most studies have examined the effects of nicotine administration and nicotine withdrawal on reaction time. Two additional studies explored their effects on the periphery nervous system by assessing movement time (Bates et al., 1994; Marzilli & Shea, 2000) with an abstinence period
of 2 and 12 hours respectively. Bates and colleagues (1994) found a facilitating effect, i.e., decreased reaction time, with nicotine administration while no differences were observed in movement time. Accordingly, Marzilli and Shea (2000) found no differences in movement time when the task was simple; however, when the task became more complex and required information processing, participants performed significantly better in the nicotine administration condition than the abstinent one. It was concluded that smoking abstinence had an impairment effect on psychomotor performance for tasks requiring information processing (Marzilli & Shea, 2000). Cigarette smoking increases information processing rate thereby making the central information processing mechanism that is required for successful movement completion more efficient. This efficiency can be observed as a decrease in movement time for the same task when comparing nicotine administration to a nicotine withdrawal condition.

While the movement task between this study and the two aforementioned studies differed, one can argue that the task involved in this study is of a complex nature requiring information processing. Recall that in this task, participants were first asked to focus on the fixation point and to disregard the images present despite the nature and content of the images were being processed in their peripheral visual field. They then had to detect between two locations where the probe appeared and to make a choice selection to manually aim for that target. The near-significant trend of the increase in movement time of the smoking group, who had abstained on average of 5 hours, when compared to the non-smoking group, was also consistent with the review suggesting the effect of nicotine deprivation on psychomotor performance for tasks requiring information processing (Heishman et al., 1994).

5.2.2 Self-regulation theory

Another explanation as to why the smoking group overall took longer to complete a manual aiming movement is self-regulation theory. The psychology behind self-regulation is concerned with the “regulation of self by the self” (Forgas et al., 2009, p.4). It can be regarded as a limited strength model. In this model, self-control strength, which is required to self-regulate, is a limited resource that can be depleted over time (Muraven & Baumeister, 2000). Due to the finite nature of self-control strength, studies that require participants to perform two or more tasks can observe a decrease in performance in subsequent tasks following the first one (Baumeister et al., 1994; Muraven, Tice, & Baumeister, 1998). Given this tenet, when the smoking group was asked
to abstain from smoking, they were engaging in a challenging feat where they had to self-regulate and self-control. In accordance with the limited strength model, after a period of smoking abstinence, participants were in a depleted state when they were asked to complete a series of manual aiming tasks, and thus, they were not performing optimally. As such, their impaired manual aiming performance (second task) after abstaining from smoking (first task) was reflected by the longer movement time than the non-smoking group, who did not have to exercise self-control when asked to refrain from smoking.

5.3 Within-group analysis (smoking group)

Given the role of attentional bias in the saliency of smoking and matched\(^1\) images to the smoking group, it was hypothesized that conditions where the location of salient images was probed, there would be shorter reaction time and movement time. In terms of limb trajectory, it was hypothesized that the peak trajectory differences would be larger for conditions where “more-like-smoking” images were probed because of deviations towards the locus of attention, which would have been biased towards the cued smoking-related images. In this stage of analysis, a series of 3 (probe) x 2 (accimage) repeated measures ANOVAs was conducted to assess for conditional differences and found trends for movement time. Post-hoc analyses also found trends where participants completed manual aiming movements in a shorter time when smoking images were probed with the accompanying image as fillers than the reverse condition, i.e. probed filler images when accompanied by smoking images. This trend was observed for both directions.

The smoking-filler condition was the most noticeably different pairing of the three possible image pairs (smoking-matched, matched-filler, and smoking-filler). This is because a smoking image was the “most like smoking” in comparison to the other two, while the filler image was the “least like smoking”. As such, it was anticipated that if any differences were to emerge, it would be for the smoking-filler image pairing condition. This finding was consistent with the hypothesis of attentional bias such that when a probe replaced an already attended location, movement time would be smaller. In a probed smoking-filler condition, theoretically, the smoking group would direct their attention towards the smoking images as opposed to the filler,

\(^1\) Probed matched images were expected to show attentional bias for smokers only when they are paired with “less-like-smoking” images, i.e., filler ones.
neutral images. Thus, once the probe onset replaced the smoking image participants were more prepared to direct a manual aiming movement toward the probe, since there was an attentional bias towards that particular visual field, and this resulted in a smaller movement time.

5.4 Correlation of cravings and attentional bias

In the final stage of analysis, the relationship between cravings and time measurements were assessed. Incentive-Sensitization theory suggested an intricate relationship between cravings and attentional bias as they seem to originate from a common source (Robinson & Berridge, 1993). The underlying neural system for experiencing cravings is also thought to play a role in attributing saliency to substance-related stimuli. This relationship has been shown in the past for smoking (Mogg et al., 2005).

Craving measures were assessed via questionnaires administered to the participants immediately prior to undertaking the manual aiming protocol. Two commonly used questionnaires, desire to smoke and strength of desire, provided two craving scores for each participant. However, only data from the smoking group was used in this analysis as the non-smoking group reported no cigarette cravings and the latter group was also not expected to exhibit any attentional bias. Reaction time, movement time, and their summation, total time (total time = reaction time + movement time), were assessed against cravings. Smaller reaction time, movement time, and total time were expected with greater cravings. Because biases towards smoking-related images would result in smaller reaction time and movement time, and accordingly total time, there should be a negative relationship between the measures, i.e., as cravings increase, reaction time, movement time, and total time decrease.

Using Kendall’s Tau, significant negative linear relationships were found for all measures of craving and time assessments, with the exception of the relationship between craving strength (strength of desire) and movement time. This finding lends support to Robinson and Berridge’s Incentive-Sensitization theory (1993) because their relationship suggests when smokers experience greater cravings, they will take less time to respond and move to the target. Participants’ performance may have been affected, in terms of shorter reaction time, movement time, and total time, because of attentional bias to salient cues, which can be attributed to an over-activity in the sensitized system leading to feelings of craving and increased saliency to smoking-related cues. The relationship between attentional bias and cravings is of a mutual
cyclical nature where greater attentional bias leads to increased saliency of substance-related cues, which leads to greater cravings, which in turn further increase the saliency of substance-related cues (Robinson & Berridge, 1993). It is unclear from the present study whether smoking abstinence increased cravings and thus, affecting performance or whether the smoking abstinence caused the participants to be more perceptive to smoking-related cues, which then increased their cravings. However, this correlational analysis does demonstrate the relationship between cravings and reaction time, movement time, and total time.

5.5 Reaction time

In this study, no group or conditional differences were observed for reaction time. It was initially hypothesized that the smoking group would have a shorter reaction time to the probe onset due to attentional bias; however, this was not observed. Even within the smoking group, it was hypothesized that shorter reaction time would ensue for conditions where the probes replaced images that were smoking-related versus those that did not. The hypotheses were in line with past studies that investigated attentional bias using visual dot-probe between smokers, non-smokers, and former smokers (Erhman et al., 2002) and just within the smokers (Hogarth et al., 2003). However, this study did not find any evidence of attentional bias, as reflected by reaction time, in the smoking group.

One possible explanation for a null finding could be the set-up of the image presentation. In a typical visual dot-probe paradigm, the screen begins with a fixation point, followed by an image pair, and a probe onset at the location of one of the two images. The difference in this paradigm was that the fixation point remained onscreen until probe onset. The decision of maintaining a fixation point was made to ensure a maintained gaze on the centre of the screen throughout image presentation. Because participants’ eye movements were also being monitored throughout the session, trials in which fixation was not maintained during image presentation were repeated. In addition to having control over participants’ direction of gaze during image presentation, the fixation point was also not removed in order to examine the concept of attentional bias being an unconscious process. Attentional bias, through incentive sensitization, should be strong enough to induce substance-seeking behaviours without consciousness (Robinson & Berridge, 1993). Given the unconscious nature of attentional bias, it was hypothesized that attentional bias would be present, in the form of a smaller reaction time, even if participants were not able to
consciously process the context of the images presented. This, however, was not the case as no differences were observed in reaction time between the groups or the conditions.

Another possible reason as to why reaction time differences were not observed could be that the smoking group may not have been heavy enough smokers. To be included in the study, smokers had to meet a smoking criterion of ten or more cigarettes per day, which is confirmed by an expired baseline breath carbon monoxide level of at least 10 ppm, which was a common eligibility requirements for other studies examining smokers (Field et al., 2004; van Rensburg et al., 2009; Faulkner et al., 2011). This resulted in a group who, on average, smoked 13 cigarettes a day, and with a baseline breath carbon monoxide reading of 18 ppm and a nicotine dependence score of 3.9 (out of 10) on the Fagerström Test for Nicotine Dependence. These smoking characteristics translated to a moderate to heavy smoking group with low to moderate nicotine dependence (Fagerström, Heatherton, & Kozlowski, 1990; Health Canada, 2008; Bedfont Scientific, USA). Inherently, attentional bias is a result of a neuroadaptation from repeated use of a particular substance, and thus, is exhibited by seasoned users. As such, the degree of attentional bias can be influenced by the level of dependency. There is some evidence to suggest that less dependent smokers do not display attentional bias at the level of more dependent smokers and in fact, the less-dependent smoker’s level of attentional bias is on par with that of non-smokers (Vollstädt-Klein et al., 2011). Thus, smokers in the group who were less dependent on nicotine could have prevented reaction time differences from emerging. Future studies should consider only including heavy smokers with moderate to high nicotine dependency, e.g., those who consume more than 20 cigarettes per day, have a nicotine dependence score of over 5, and a breath carbon monoxide reading of at least 15 ppm.

5.6 Limb trajectory

There were no group or conditional differences in limb trajectory between smokers and non-smokers or within the smokers respectively. It was originally hypothesized that smokers would have larger peak trajectory differences as they would make greater deviations than the non-smoking group. It was also believed that within the smokers, they would deviate upper-limb movements towards the probed smoking images in comparison to probed non-smoking images. However, mixed-model ANCOVA did find a significant main effect for accompanying image. Although significant differences did not persist past post-hoc analyses, a pattern emerged where
the smoking group made deviations in their movements towards the visual field of the image presented that was “more like smoking”.

5.6.1 Limb trajectory and the smoking group

Although the finding was not significant, the smoking group were making deviated movements towards the accompanying image (as opposed to the probed image), when it was "more like smoking", i.e., an un-probed smoking image or an un-probed matched image when paired with a probed filler image. When the accompanying image was “less like smoking”, the smoking group was nearly deviating their trajectory towards the probed images. This pattern of deviations is in comparison to the non-smoking control group who made deviated movements towards the probed image, regardless of the nature of the accompanying image (see Figure 5). The behaviour of the smoking group was found to be consistent with the concept that reaching movements are reflective of the locus of attention (Song & Nakayama, 2009) and Welsh’s study on attentional capture and manual aiming (2011). Welsh observed deviations in trajectory for congruent cued-target conditions and the deviations were made towards the cued location (Welsh, 2011). That is to say, participants had directed their movements towards the locus of their attention.

In this study, for the smoking group, the cue could be considered as the smoking-related image and the target was the probe. This is in contrast to Welsh’s study where the cue properties matched that of the target stimuli because the two stimuli would be of the same attentional set and only then would the cue be able to capture attention (Welsh, 2011). It can be argued that although not identical and not belonging to the same attentional set as the target probe, the cues, i.e., smoking-related images, were capable of capturing attention due to attentional bias. For the purpose of this study, congruent cued-target conditions can be thought of as when the probe replaced a “more-like-smoking” image, i.e., accompanying image was “less-like-smoking”. In the congruent cued-target conditions, the smokers deviated their movements towards the probe that had replaced a smoking-related image. Conversely, in an incongruent condition where the probed image was “less-like-smoking” and the accompanying image was smoking-related (the cue), it was observed that smokers made deviations towards the cue. Although Welsh (2011) did not find trajectory deviations in an uncued trial, i.e., mismatched cue and target locations, deviations were observed in this study, however in the opposite direction as the probe. When deviations are made towards a non-target, i.e., an unprobed image, then the non-target response,
i.e., the accompanying image, can be thought of as active (Welsh, 2011). If deviations and
trajectory pathways are reflective of locus of attention, then it would follow that the smoking
group made trajectory deviations towards the visual field of accompanying images because they
were “more-like-smoking” and thus, they were biasing their attention towards that location. The
smoking group shifted their attention towards the smoking-related cue due to attentional bias and
when asked to perform manual aiming movements towards the target, they deviated towards the
cue as that was their locus of attention. Their attentional bias was reflected by the direction of
their trajectory deviations. As a result of attentional bias, smoking participants’ locus of attention
was shifted towards the salient “more-like-smoking” images, and thus, their trajectories deviated
towards the location where these images had once appeared.

An important thing to bear in mind is that limb trajectory results were not significantly different
between the groups. The interpretation here mainly focuses on the direction of the trajectory
deviations, and not on the magnitude. Admittedly, it was interesting to observe the different
directions of deviations for the smoking group based on the nature of the accompanying image.
Unfortunately, this difference in opposite directions did not reach significance and could be of
little importance. Due to the limited nature of addiction research in the field of limb movements,
it is only speculative that perhaps the pictures presented were insufficient to capture enough
attention to affect limb trajectory since they were different from the target and did not belong to
the same attentional set.

5.7 Commentary on attention and the measures

Attentional bias can be thought to be comprised of two components: initial shifts in attention and
maintained attention. Initial shifts in attention can be assessed when the image pair is presented
for 500 ms or less and the latter, when it is presented for a longer period (Mogg et al., 2003).
These are the two measures that are consistently explored in eye-tracking studies as direction of
initial gaze or initial fixation (initial shifts in attention) and dwell time/duration (maintained
attention) (Mogg et al., 2003; Kwak et al., 2007; van Rensburg et al., 2009). In this study, the
component captured by the experimental set-up was maintained attention since the pictures were
presented for 1000 ms.

With eye-tracking, maintained attention can be assessed with dwell time/duration as picture
presentation prolonged past 500 ms. In this paradigm, even though the direction of eye
movements was monitored with the use of an electro-oculogram (EOG), because participants were instructed to focus their gaze on the fixation point throughout image pair presentation, maintained attention on the images cannot be assessed during their presentation. Instead, maintained attention was represented by attentional biases that would have been observed in reaction time data. For instance, if a probed smoking-related image had a shorter response time than a probed non-smoking related image, then this could be assumed to be the result of attentional bias and there was presumably maintained attention on the smoking-related image.

The theory behind attentional bias and reaction time for the visual-dot probe paradigm is that when there is a bias in attention and one field is attended to preferentially over the other, participants will be quicker to detect changes to the field, i.e., probe/target presentation, than when it occurs in the opposite field. Because images were presented for more than 500 ms, if participants were exhibiting attentional bias, they would be preferentially and unconsciously attending and maintaining their attention to one side over the other. An attentional bias score can be derived with reaction time data wherein the reaction times between two complementary conditions, e.g., a smoking-filler pairing with the smoking image probed and its complementary condition of the same pairing, but with the filler image probed, can be compared and subtracted. The greater the difference between reaction time would result in a greater attentional bias score. However, because no differences were found in reaction time data for group differences or within the smoking group, attentional bias score was not calculated for this study.

While no significant differences were observed for maintained attention, an interesting component of this study was the use of movement time and limb trajectory. Because reaction time is an extremely quick response, other variables like movement time and limb trajectory may potentially offer additional information that could not be captured by reaction time. This was observed in this study when near-significant trends for movement time can be found for both group differences and within the smoking group, despite a null finding for reaction time. In terms of limb trajectory, because trajectories are reflective of the current locus of attention, an additional concept of attention, attentional shifts can be monitored with trajectory data and the direction of a curved trajectory can be reflective of attention (Song & Nakayama, 2009). In this study, although not significant, the pattern found for peak trajectory differences suggests that the smoking group were attending to the un-probed visual field for conditions where the accompanying images were “more like smoking” than the probed images. As such, movement
time and limb trajectory may be assessing different kinds of attention, including attentional shifts, as movement progresses, and they are sensitive to attentional bias measures that cannot be found by reaction time alone.

5.8 Limitations

Given the novelty of this attentional bias and manual aiming research, it was unclear what the appropriate sample size would be to detect a significant difference. As such, a main limitation to the study is sample size. Additionally, there were various unforeseen limitations to the study that could have affected the outcome and these revolved around the execution of testing and characteristics of participants. There was also a physical limitation to the experimental set-up that can be corrected in future replication studies.

5.8.1 Sample size and power analyses

The total sample size for this study was originally proposed to be 30 people, consisting of 15 smokers and 15 non-smokers. Because no research had been done on attentional bias and manual aiming to the best of our knowledge, this sample size was entirely based on several factors from various studies.

A past manual aiming study with a similar set-up with the infrared diode (IRED) attached to participants' index finger while the Opotrak Certus monitored limb movements had a sample size of eight (Kennedy, 2011). Studies analyzing the impact of exercise on attentional bias amongst smokers employed sample sizes from 10 to 23 smokers (van Rensburg et al., 2009; Thompson & Taylor, 2009; Oh & Taylor, 2011; Hassova & Taylor, 2012) and these had a small effect on reducing attentional bias. Moreover, the purpose of this study was to establish the manual aiming protocol to measure attentional bias for use in smoking and exercise research. Given the novelty of this paradigm, results from this study can be used to inform future studies on an appropriate sample size of a similar protocol. Past studies on the effect of exercise on cigarette cravings (Daniel et al., 2004; Taylor & Katomeri, 2006), had indicated a sample size of fifteen was adequate for identifying differences in cravings based on the exercise condition with a power of 0.8. As such, a target sample size of fifteen smokers and fifteen non-smokers was thought to be appropriate and feasible for the purpose of this study. Although the target sample size was set to be 30, the analysis consisted of a total of fifteen non-smokers and thirteen smokers. Two
smokers were excluded due to failure to follow instruction \((n = 1)\) and being an outlier for the majority of the measures \((n = 1)\).

### 5.8.1.1 Group differences

With a total sample size of 28 \((n_{\text{Smokers}} = 13; n_{\text{Non-Smokers}} = 15)\) and using a repeated-measures mixed design, there were no significant between-group effects. However, there were trends \((ps = 0.06)\) for a between group effect for both movement time when probes replaced the right side and the left side, after controlling for age, with partial \(\eta^2 = 0.13\) and 0.14 respectively.

To assess for an appropriate sample size to inform future studies, a sample size calculation was done using \(G^*\text{Power 2.0}\) program (Faul & Erdfelder, 1992). To convert partial \(\eta^2\) to Cohen’s \(d\), the following equation can be used (Cohen, 1988), and where \(d = 2f\)

\[
\eta^2 = \frac{f^2}{1 + f^2}
\]

\[
f^2 = \frac{\eta^2}{1 - \eta^2}
\]

Using the above equations, the effect size, expressed as Cohen’s \(d\), are 0.77 and 0.81 respectively for between group differences in movement time for probes appearing to the right and probes appearing to the left. Given these effect sizes, an appropriate total sample size to find significant group differences in a two-tailed analysis, with an adequate power of 0.80 and \(\alpha = 0.05\), would be 50 to 56 people. Thus, a total sample size of 56, with 28 smokers and 28 non-smokers, would be sufficient to detect a significant difference in movement time, at \(\alpha = 0.05\) level and with a power of 0.80.

Using \(G^*\text{Power}\), a post-hoc power analysis can also be done with movement time. Movement time analyses with near-significant trends \((ps = 0.06)\) with large effect size \((d = 0.77 \text{ and } 0.81)\), when probes replaced either side of the screen, for group differences with \(n_{\text{Smokers}} = 13\) and \(n_{\text{Non-Smokers}} = 15\), resulted in powers ranging from 0.50 to 0.54. As determined by an a priori sample size calculation for future studies, to obtain a significant finding at \(\alpha = 0.05\) level and an adequate power of 0.80, the sample size should be nearly doubled, consisting of 28 smokers and
28 non-smokers. This study, as it stands, was under-powered to detect significant group differences

5.8.1.2 Condition differences

Effect sizes for the trends of condition differences observed between FS and SF trials within the smokers for movement time were $d = 0.61$ for movements to the right and $d = 0.69$ for movements to the left. Cohen’s d values of around 0.6 to 0.7 can be considered to have medium effects. Using G*Power to assess for the power in this study with 13 smokers, it was found that these results had power ranging from 0.32 to 0.39. Additionally, in order to assess for a more liberal sample size to ensure significance can be found for future studies in both directions, the smaller effect size was used. As determined by an a priori sample size calculation for future studies, to obtain significant findings at $\alpha = 0.05$ level and an adequate power of 0.80 for movement time within the smoking group, the total sample size should be 88 participants. However, because this was a repeated measures design, a study with 44 smokers would be required to detect a significant difference in movement time. This study, as it stands, was under-powered to detect significant condition differences within the smoking group.

5.8.2 Timing of testing

Because of the stringent eligibility criteria for the smoking group and the initial strategy of recruiting within the university’s community, these caused group testing to become dichotomized. In other words, the non-smoking group was tested first and then the smoking group. There were challenges with recruiting regular moderate to heavy smokers who consumed more than ten cigarettes per day on average within the university community. As such, smokers were recruited from external sources, i.e., online and local newspapers classifieds, which was put in place if the primary one of advertising within the university community had been exhausted. Although the experimental set-up and study protocol remained identical, there may be differences unaccounted for due to the timing of testing. Ideally, testing should be randomized and there should not be an order for which group was tested first. The timing of testing was not perfectly counterbalanced and randomized for the groups.
5.8.3 Between-group covariate

Additionally, because of the smoking eligibility criteria and the initial recruitment strategy, there was a significant age difference between the groups with the smoking group being older than the non-smokers. Although age was entered into the analyses as a covariate, it may have had some effect on performance, particularly for temporal measures as reaction time and movement time. Although the magnitude of a 5 years age difference is not large, the non-smoking group can be classified as being in their early-twenties, while the smoking group in their late-twenties. Performance at around age 20 had been shown to be at its optimal in terms of reaction time and movement time, while consistency is observed around age 30 (Pierson & Montoye, 1958). Additionally, performance can also be modulated by physical activity levels (Waneen & Phillip, 1978). Physical activity level was not assessed in this study and it should be considered for future studies.

5.8.4 Physical constraint

One individual was excluded from analysis due to failure to follow instructions properly and complete the study. This was to no fault of the individual because of physical constraints with the experimental set-up that had prevented study completion. The monitor, head-and-chin rest, and the home position button were set-up on a modest-sized table that could be restrictive to wide movements. Based on physical characteristics, it could be uncomfortable and challenging to reach the target without jeopardizing the experimental set-up, e.g., by moving the monitor closer. The physical constraint of this study was unanticipated and future studies should consider adapting the experimental set-up to be more inclusive.

5.9 Future directions

Attentional bias can be assessed behaviourally via cognitive tasks, including modified Stroop and visual dot-probe tasks and more recently, through eye-tracking technology. Although the latter method is more direct as it assesses location of eye gaze and duration of dwell time, it has several limitations that should be addressed. Due to its expensive and time-consuming operation, along with its restrictive sampling requirement, other more practical methods of attentional bias assessment would be beneficial.
The proposed methodology in this study employed manual aiming with a modified visual dot-probe paradigm while eye-movements and the finger’s location in space were monitored and tracked. In addition to addressing the limitations of eye-tracking, manual aiming is also advantageous to the typical visual dot-probe paradigm as it bypasses the arbitrary key-press response by integrating an aiming component that would have implications with goal-directed limb movements. Furthermore, imaging study using smoking cues have shown activation in neural correlates of premotor regions and this may reflect motor preparation for the drug-taking behaviour (Smolka et al., 2006). Thus, manual aiming may provide unprecedented insight into attentional bias and addiction. To our knowledge, this is the first study of its kind to examine attentional bias in addiction with the use of manual aiming. Because the concept of using manual aiming to assess for attentional bias is novel and still in its infancy, future studies should first aim at further establishing its validity.

5.9.1 Study replication

If the study is to be repeated, changes to the study protocol and participants eligibility should be considered. For the modified visual-dot probe paradigm, consideration should be made in removing the fixation point during image presentation to ensure adequate attentional bias. Moreover, because there is evidence to suggest deviations in trajectories for congruent cue-target trials where the cue and target are identical and belong to the same attentional set, the same principle should be adopted. Moreover, future studies should consider including smokers who are heavily dependent on nicotine, e.g., individuals who smoke more than 20 cigarettes a day. To avoid abstinence and withdrawal effects on performance, considerations can be made to minimize the abstinence period but still be sufficient to heighten and elicit cravings when presented with smoking-related cues.

Once manual aiming for assessing attentional bias has been sufficiently validated where smokers reliably demonstrate shorter reaction time and movement time for probed smoking cues, further studies can be conducted to examine the implications and practical nature of manual aiming. Manual aiming may be utilized as a tool to examine the mechanism behind craving reduction of exercise. Additionally, because manual aiming involves goal-directed limb movements, studies can be done to explore grasping and reaching movements involved in substance consumption and to utilize this movement for attentional bias modification.
5.9.2 Exercise and smoking

A bout of exercise has repeatedly been shown to be effective in reducing cravings in abstinent smokers (Ussher et al., 2008). However, the mechanism underlying craving and withdrawal symptom reduction remain unknown. It has been previously demonstrated that a bout of exercise can reduce the attentional bias of smokers in terms of initial direction of gaze and percentage of dwell time (van Rensburg et al., 2009). However, few studies have explored the relationship between attentional bias and exercise in the field of nicotine addiction. Effects of exercise on other measures of attentional bias, namely movement time and limb trajectory, should be explored.

5.9.3 Attentional bias modification

Because attentional bias has implications for cravings and plays an important role in substance consumption and relapse, it is thought that an effective method of treating addiction would be to reduce attentional bias. Using manual aiming and the modified visual dot-probe paradigm in this study, a program can be developed and built into a personal technological device, such as a tablet, where participants can engage in attentional bias modification without the confines of a lab setting.

5.9.3.1 Goal directed movement – reaching

One advantage of manual aiming over the typical visual dot-probe paradigm for attentional bias modification would be the extended upper limb movement. The attention system was developed over time for goal-directed limb movements, including aiming, and not single key-press responses (Allport, 1987) which are pervasive for the typical visual dot-probe paradigm used in attentional bias modification. Because neural correlates of premotor regions are activated upon viewing smoking cues (Smolka et al., 2006), attentional bias modification via manual aiming may provide external validity since it would mimic the reaching behaviour required for drug consumption.

5.10 Conclusion

Attentional bias has implications in addiction maintenance and relapse and given the methodological limitations of current tools for assessing attentional bias, a novel approach was proposed by using manual aiming. The purpose of this study was to investigate the feasibility of
manual aiming for assessing attentional bias in moderate to heavy smokers when compared to non-smoking controls. To do so, three variables were derived to examine group and conditional differences – reaction time, movement time, and limb trajectory. With a sample of 15 non-smokers and 13 smokers, no significant group differences were observed in reaction time and limb trajectory, but there was a near-significant trend in movement time with the smoking group taking a longer time to complete the aiming movement than the non-smokers. This finding was contrary to the hypothesis, but may be explained by the smoking abstinence period leading to performance deficit and depletion of self-control resources. Conditional testing within the smoking group found near-significant differences in attentional bias for filler-smoking conditions when probes replaced smoking images versus filler images. Additionally, correlational analyses confirmed a negative-linear relationship between cravings and reaction time, movement time, and total time.

Overall, findings were not as favourable as initially hypothesized and given study limitations, it is not possible to confirm definitively the exact role of manual aiming in assessing attentional bias. However, there is some tentative evidence to suggest that attentional bias may also include properties that are reflected by movement time. Further exploration is needed with larger samples, as well as a more-dependent smoking population.
References


Appendix A

Flowchart of database and keywords used to find attentional bias in smoking articles.

Database: PsycINFO
Keywords: "attentional bias", "smoking", & "craving"

32 English articles
• 3 article whose focus is on attentional bias modification

29 articles
• 5 review articles

24 articles
• 13 irrelevant articles for the purpose of this literature review (see below)

11 articles
• employed some sort of task or technology to measure AB without any further manipulation to attentional processes other than using tobacco smoking-related cues
• eight articles used an indirect measurement (visual dot-probe, modified Stroop, and visual search paradigm) and three used eye-tracking technology
Flowchart of databases and keywords used to find articles related to the effect of physical activity on attentional bias of smoking.

Databases: PubMed, Medline, & Proquest Dissertations & Theses Databases
Keywords: "smoking", "attentional bias", AND "acute exercise" OR "physical activity"

76 articles

Screening process - include only if:
- used a bout of exercise as the intervention &
- assessed attentional bias as an outcome measure

4 articles met inclusion criteria
Appendix B

All the images pair presentations used in this study. Note that each image pair could be presented in two ways, e.g., a smoking and a matched image pair can be presented as (i) smoking on the right and matched on the left, and (ii) matched on the right and smoking on the left. Only one representation is shown here. Also not presented here are a set of a five Filler-Filler images for practice purposes.

<table>
<thead>
<tr>
<th>Matched-Smoking</th>
<th>Filler-Matched</th>
<th>Filler-Smoking</th>
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<td><img src="image3" alt="Image" /> + <img src="image4" alt="Image" /></td>
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<td><img src="image9" alt="Image" /> + <img src="image10" alt="Image" /></td>
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<td><img src="image17" alt="Image" /> + <img src="image18" alt="Image" /></td>
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<tr>
<td>Matched-Smoking</td>
<td>Filler-Matched</td>
<td>Filler-Smoking</td>
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Appendix C

Independent of whether reaction time data originated from the button or Optotrak Certus, the group effect on reaction time remained the same. 3 (probe: smoking, matched, filler) x 2 (accompanying image: more-like-smoking, less-like-smoking) x 2 (group: control, smokers) repeated measures ANCOVA, controlling for age, was used for the analysis.

<table>
<thead>
<tr>
<th>Group differences in reaction time</th>
<th>Button</th>
<th>Optotrak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movements to the right</td>
<td>$F(1, 25) = 0.69, p = 0.41$</td>
<td>$F(1, 25) = 1.31, p = 0.26$</td>
</tr>
<tr>
<td>Movements to the left</td>
<td>$F(1, 25) = 1.26, p = 0.27$</td>
<td>$F(1, 25) = 1.49, p = 0.23$</td>
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