Inhibitory control dysfunction in nicotine dependence and the influence of short-term abstinence

Kathleen Charles-Walsh[a], Liam Furlong[a], David G. Munro[a], Robert Hester[a].

[a] Melbourne School of Psychological Sciences, University of Melbourne, Melbourne, Australia

Correspondence should be addressed to:
Robert Hester
Melbourne School of Psychological Sciences,
University of Melbourne,
Parkville, Victoria, 3010
Australia.
Ph: +61 3 83440222
Fax: +61 3 9347 6618
E-mail: hesterr@unimelb.edu.au

Highlights

- Nicotine dependent participants had impaired stop-signal task performance
- The impairment was evident after 10 hours, but not 3 hours, of abstinence
- Cognitive control studies in nicotine dependence need to consider abstinence carefully

ABSTRACT

*Background***:** Although the majority of substance use disorders depict reliable deficits in inhibitory control (IC), similar deficits are not consistently found in nicotine dependence. The mixed results of past research may have been due to confounding variables known to independently influence IC function, including age, concurrent drug use and particularly, length of nicotine abstinence. *Methods:* A Stop Signal Task was used to examine Stop Signal Reaction Time (SSRT), a typical measure of IC, in nicotine dependence across two studies that attempted to closely control for IC confounds. Study 1 compared the SSRT of 37 dependent cigarette smokers (11 female) to 36 non-smokers (13 female), following 3-hours of nicotine abstinence. Study 2 compared 22 dependent cigarette smokers' (11 female) SSRT scores when satiated on nicotine to their performance following 10-hours of nicotine abstinence. *Results:* Nicotine dependent individuals did not differ from controls in SSRT performance following 3-hr abstinence, but showed a significant decline in performance following 10-hr abstinence, when compared to nicotine satiation. *Conclusions:* During shorter abstinence periods, the acute benefits of nicotine satiation appear to facilitate inhibitory control, however IC was poorer during extended periods of nicotine abstinence. In

turn, this suggests that the reliability of IC dysfunction in nicotine dependence varies according to abstinence length and needs to be carefully considered for future behavioural and neuroimaging examination of IC within this population.

KEYWORDS: Nicotine, inhibitory control, abstinence, response inhibition, stop-signal

1. INTRODUCTION

Current models of substance dependence suggest that deficits in executive control are critical to ongoing drug use (Jentsch and Taylor, 1999). In particular, inhibitory control (IC), which is the ability to inhibit a pre-potent response, may be especially involved in maintaining drug dependence (Goldstein and Volkow, 2002; Lubman et al., 2004). IC impairment is prevalent within varying forms of drug-dependence, including alcohol, methamphetamine and cocaine dependence (Fillmore and Rush, 2002; Li et al., 2009; Lubman et al., 2004; Monterosso et al., 2005). The reliability of IC dysfunction in individuals dependent on substances with widely differing neurochemical profiles suggests IC dysfunction is a common feature of addiction and would therefore feature similarly in nicotine dependence.

Research examining IC performance in nicotine dependence has to date yielded a varied set of findings. Nicotine dependent individuals demonstrate impaired performance on measures of impulsivity, such as delay discounting tasks, in which smaller immediate monetary rewards are favoured over larger but delayed rewards (Bickel et al., 1999; Mitchell, 1999; Reynolds et al., 2004); and risky financial decision making, in which potentially higher pay-offs are chosen while accepting the increased risk of losing everything (Lejuez et al., 2003). For example, Yakir et al. (2007) reported a selective deficit in impulsivity within both current and past smokers when compared to controls. However, studies measuring IC over a pre-potent motor response using the Go/No-go and Stop Signal tasks (Dinn et al., 2004; Spinella, 2002; Yakir et al., 2007) have not reliably demonstrated IC impairment in comparison to control populations. For example, Spinella (2002) found that IC performance on a Go/No-go task was negatively correlated with smoking behaviour, where levels of IC deficit were proportional to smoking severity. In contrast, Dinn et al. (2004) also

administered the Go/No-go task and found no difference in performance between smokers and non-smokers.

The mixed findings of past research may be due to factors that independently affect IC function. Demographic variables that influence IC, such as age (Kramer et al., 1994) have not always been controlled. For example, Spinella's (2002) sample varied in cigarette use (levels not reported in the paper) and age (range = 19-70 years, mean = 31.1 SD = 16.7), with the latter variable not used as a covariate in the correlation between nicotine use and IC performance. Similarly, because most of these studies have recruited college or community samples, they have not always screened for IC confounds such as history of traumatic brain injury (Dimoska-Di Marco et al., 2011) or other types of drug abuse (Fillmore and Rush, 2002; Li et al., 2009; Monterosso et al., 2005).

IC performance also appears sensitive to variation in the duration of nicotine abstinence prior to cognitive testing. In other dependent populations, administration of a drug of dependence (e.g., cocaine or heroin) reduces levels of IC deficit otherwise present in dependent individuals, with short-term abstinence inducing the opposite effect (Goldstein and Volkow, 2011). In parallel to these findings, acute nicotine administration reverses otherwise prevalent IC deficits in ADHD (Potter and Newhouse, 2004) and abstinence from cigarettes in an otherwise healthy population has been associated with decreased IC performance (Harrison et al., 2009). As such, satiated smokers may have acutely elevated IC performance that masks underlying IC deficits (Dawkins et al., 2007). However the influence of nicotine abstinence on the presence/absence of IC deficits in past studies remains unclear, as few have approached abstinence as an independent factor interacting with IC ability.

Given the small number of studies and mixed findings, the aim of the present study was to examine IC function in nicotine dependence whilst controlling for demographic and drug use confounds. To examine the influence of nicotine abstinence on IC dysfunction we

also conducted a within-subject comparison between nicotine satiation and short-term, 10-hour abstinence.

Study 1 compared a group of dependent smokers to a control group of non-smokers on IC performance using a Stop Signal Task (Logan et al., 1997). To limit acute effects of nicotine, dependent smokers completed the SST following 3-hours of nicotine abstinence. It was hypothesised that after controlling for variables that had confounded previous studies (demographics, other drug use, brain injury), nicotine dependence would be associated with poorer IC in comparison to controls, indicated by higher Stop Signal Reaction Time (SSRT). Study 2 examined the influence of nicotine abstinence on IC performance by comparing dependent nicotine smokers' SSRT after a 10-hour period of abstinence to performance at nicotine satiation. It was hypothesised that in dependent smokers inhibitory performance would be significantly poorer following prolonged nicotine abstinence than at satiation.

2. METHODS

2.1 Study 1

2.1.1 Participants. 37 dependent cigarette smokers (11 female; mean age 23.70; SD = 4.32) and 36 non-smokers (13 female; mean age 23.14; SD = 4.85) were recruited for the study. Inclusion in the smokers group required smoking 15 or more cigarettes a day for a minimum of two years. Non-smoking participants had each consumed less than 10 cigarettes in their lifetime. Exclusion criteria for both groups included a history of neurological or psychiatric disorders, current use of psychotropic medication or any medication known to affect heart rate or respiration, and current substance abuse or dependence (other than nicotine for the smoking group). The groups did not significantly differ on the variables of age, education or gender (see Table 1). Participants were recruited via advertisements at the University of Melbourne. All provided written informed consent prior to participation, approved by the human ethics committee at the University of Melbourne.

To limit both acute and withdrawal effects of nicotine, maximum time since participants' last cigarette at task completion was limited to 3-hours by instructing participants to consume their last cigarette 2-hours prior to testing. All participants were also asked to abstain from illicit drug use for 48-hours prior to testing and not consume alcohol or caffeine for 10 or 1 hours, respectively, prior to participation.

2.1.2 Measures. Non-nicotine drug use behaviour was measured using the Alcohol Use Disorders Identification Test (AUDIT; Saunders et al., 1993) and the Drug Abuse Screening Test (DAST; Skinner, 1982). Smokers' breath carbon monoxide (CO) concentrations were monitored using a calibrated Micro+Smokerlyzer (Bedfont Scientific Ltd., Rochester, UK). In addition, smokers completed the Fagerström Test for Nicotine Dependence (FTND; Heatherton et al., 1991) to measure nicotine dependence. Mean values for each measure are displayed in Table 1.

Stop Signal Task. Participants performed 300 trials of the stop-signal paradigm, in which the go-stimuli were the letters O and X mapped to corresponding button press responses, respectively. The stop-signal was a red box that surrounded the go-stimulus on 25% of trials. The delay between the onset of the go-stimulus and the onset of the stop-signal (stop-signal delay, SSD) was initially set to 250ms and was thereafter adjusted dynamically in increments of 50ms contingent upon the performance of the participant. Successful inhibitions resulted in an increase of the SSD, making inhibition more challenging on the following trial, whereas failed inhibitions resulted in a reduction of the SSD, thereby facilitating inhibitory success. This procedure ensured that on average each participant in each session had a probability of successful inhibition approaching 50%. Stop-signal reaction time (SSRT) was derived as the mean reaction time to go-stimuli (MRT) minus the SSD for the 50% inhibition threshold (SSRT = MRT - SSD) (Logan et al., 1997). This measure corresponds to inhibition latency, whereby higher SSRTs indicate poorer inhibition abilities. Participants with stop accuracy

below 40% or above 60% were removed from the analysis, in accordance with the conservative criteria of Congdon et al. (2012).

Upon arrival, all participants completed the questionnaires and their expired CO levels were measured to confirm patterns of cigarette use. Following this, they undertook the SST.

2.1.3 Results. Smokers and non-smokers differed on measures of dependence and cigarette consumption, with smokers scoring significantly higher than non-smokers on number of cigarette's consumed per day ($t(36) = -34.94$, $p<.01$) and level of nicotine dependence ($t(36) = -10.92$, $p<.01$), following adjustment for unequal variance. Descriptive statistics for both groups are provided in Table 1.

SST performance did not differ between groups for SSRT ($t(71) = .40$, $p = .69$, $d = .08$) go trial RT ($t(71) = .06$, $p = .96$, $d = .02$) or stop trial accuracy ($t(71) = -.11$, $p = .92$, $d = .03$). The descriptive statistics for SST performance for both groups are reported in Table 2. There was no significant effect of gender on SSRT in either group $F(1)= .13$, $p = .72$.

As the use of other drugs could moderate SST performance, independent t-tests examined group differences in self-reported illicit drug use (DAST) and alcohol consumption (AUDIT) that fell below criterion for dependence or abuse. After adjusting for unequal variance, independent t-tests revealed significant differences between the smoking and non-smoking groups on both DAST $t(41) = -5.14$, $p<.001$, and AUDIT scores $t(52) = -5.89$. $p<.001$; with drug and alcohol use significantly higher in the smoking than non-smoking group (see Table 1). In spite of these differences, SSRT performance did not significantly correlate with DAST scores, $r_s = -.12$, $p = .31$, or AUDIT scores $r_s = -.02$, $p = .85$, nor did the absence of SSRT group differences change when DAST and AUDIT scores were used as covariates.

Within the smoking group IC performance was not related to measures of nicotine use and dependence. Individual SSRTs were not significantly correlated with the number of cigarettes consumed per day, r_s = -.12, n = 37, p = .46. or FTND scores, r_s = .13, n = 37, p = .45. Thus, when controlling for important possible confounds, the first study did not provide support for differences in IC performance between smokers at 3-hour abstinence and non-smokers.

2.2 Study 2

2.2.1 Participants: 22 dependent cigarette smokers (11 female; mean age 25.9; SD = 3.5), mean education 16.2 (SD = 2.3), met the same inclusion and exclusion criteria outlined in study 1.

2.2.2 Design: This study used a test-retest paradigm with two counterbalanced conditions – cigarette abstinence and satiation. In the abstinence condition, individuals were tested the morning proceeding 10-hours of overnight nicotine abstinence. In the satiation condition, individuals were tested after no more than 5 hours of ad libitum smoking and their last cigarette no more than half an hour prior to testing. Participants were randomly assigned to complete either the abstinence condition first (AB-SAT, n = 12) or the satiation condition first (SAT-AB, n = 10). Those assigned to the AB-SAT group completed the two sessions over the course of one day, whilst those in the SAT-AB group undertook the two sessions across two days.

As in Study 1, participants were instructed to abstain from alcohol 10-hours prior, caffeine 1-hour prior and illicit drugs 48-hours prior to participation in each condition. In both the satiation and abstinence sessions, participants first completed demographic surveys and other questionnaires and indicated time since last licit and illicit drug use. Within the satiation condition, participants also indicated number of cigarettes consumed ad libitum prior to the experimental session. Expired CO concentrations were then measured, prior to

undertaking the SST. The SST was completed in both sessions according to the paradigm outlined in study 1. In total, each session took no more than 90 minutes to complete.

2.2.3 Measures: As in Study 1, a self-report questionnaire ascertained basic demographic and exclusion criteria, a Micro+Smokerlyzer measured CO concentrations and the FTND measured level of nicotine dependence. Additional self report measures were also used; non-nicotine drug use behaviour was assessed using the Psychoactive Drug History Questionnaire (PDHQ; Sobell et al., 1995); a Smoking History Survey that ascertained information regarding total years smoking, age of uptake, total previous quit attempts and average number of daily cigarettes.

To control for withdrawal effects at 10-hour abstinence, craving, mood and anxiety, all symptoms of nicotine withdrawal (Hughes, 2007; Baker et al., 2012), were examined using the following measures: cigarette craving was assessed using the Brief Questionnaire of Smoking Urges (QSU-Brief; Cox et al., 2001); positive and negative affect were measured using the Positive and Negative Affect Schedule (PANAS; Watson et al., 1988); subjective state feelings of anxiety were measured by the State-Tait Anxiety Inventory-X Form (STAI-X; Spielberger, 1983).

2.2.4 Results

Descriptive statistics for pre-test drug use variables presented in Table 3, show all participants' licit drug use accorded with participation instructions. No participants reported smoking within 10-hours prior to testing in the abstinence condition. In the satiation condition, all participants reported smoking prior to testing, but not within half an hour of the session. Compared to satiation, the abstinence condition was associated with significantly lower CO levels consistent with the reported abstinence, $t(21) = -7.81$, $p < .01$.

SST performance is outlined in Table 4. A within subjects t-test found mean SSRT at abstinence was significantly higher than at satiation, $t(21) = 4.12$, $p < .001$, $d = .97$ (see Figure

1), and this did not significantly differ between the SAT-AB and AB-SAT groups $F(1)=2.57$, $p=.13$. SSRT at satiation was significantly shorter than abstinence in both the SAT-AB, $t(9) = 2.43$, $p < .05$, and AB-SAT groups, $t(11) = 3.70$, $p < .01$, further indicating a condition effect that did not differ with order of condition administration. This effect was not significantly associated with gender $F(1)= .28$, $p = .61$.Within subject t-tests found no difference between abstinence and satiation on Go trial reaction time, $t(21) = -1.04$, $p=.31$, or Stop trial accuracy, $t(21) = -1.19$, $p = .25$, indicating decreased SST performance at abstinence was specific to IC.

Other moderating variables were also examined for interactions with SSRT performance. Higher levels of dependence, indicated by higher FTND scores, were significantly associated with poorer SSRT performance at abstinence ($r = .43$, $p = .05$) (see Figure 2); but this association didn't hold for individual SSRT differences between satiation and abstinence ($r = .23$, $p = .30$). SSRT performance at satiation was not associated with measures of cigarette use prior to testing, such as time since last cigarette or number of cigarettes smoked prior to testing ($r = -.16$ to $.17$).

Because SSRT was poorer following abstinence, measures of withdrawal were examined to test whether decreased performance was directly related to withdrawal effects. For this, QSU-Brief, PANAS and STAI-X were examined. There was a significant difference between satiation and abstinence in craving $t(21) = 9.5$, $p<.01$, positive affect $t(21) = -4.5$, $p<.01$, negative affect $t(21) = 3.86$, $p<.01$, and anxiety $t(21) = 4.81$, $p<.01$, whereby positive affect decreased and negative affect, craving and anxiety increased at abstinence, indicating an overall increase in withdrawal symptoms at abstinence compared to satiation (Table 3). Of these measures, only changes in positive affect correlated negatively with SSRT performance at abstinence ($r = -.51$, $p< .05$) and with individual changes in SSRT between satiation and abstinence ($r = -.42$, $p< .05$). Individual changes between satiation and abstinence in negative

affect (r = .38, p = .08), anxiety (r = .33, p = .14) and craving (r = -.35, p = .12) were not associated with SSRT at abstinence, or with differences in SSRT between satiation and abstinence (negative affect r = .14, p = .53; anxiety r = .10, p = .66; craving r = -.06, p = .80).

3. DISCUSSION

Study 1 compared inhibitory control performance of nicotine dependent and matched non-dependent controls using a stop signal task (SST), with the nicotine dependent group abstaining from nicotine for 3-hours prior to testing. Contrary to our hypothesis, IC performance did not significantly differ between the groups. Using the same SST task, study 2 compared IC performance in nicotine dependent individuals following a period of 10-hour abstinence with nicotine satiation. Consistent with our hypothesis, IC performance was significantly poorer following 10-hour nicotine abstinence.

Previous studies investigating IC performance in nicotine dependence have not consistently controlled for variables that potentially influence IC performance, for example age, concurrent drug abuse, recent licit drug use and abstinence length. Small sample sizes have also limited the replicability of some findings. The current attempt to control for these variables suggests chronic nicotine users have significantly poorer IC following a long (10-hour) but not short (3-hour) abstinence from nicotine.

Study 1 showed nicotine dependent participants did not differ from controls in inhibitory performance following 3-hour abstinence. This finding runs contrary to previous evidence of poor go/no-go stop accuracy in a small sample of satiated dependent smokers compared to controls (Nestor et al., 2011), but is consistent with a larger corpus of studies demonstrating no IC performance difference between nicotine dependent and non-dependent groups (de Ruiter et al., 2012; Dinn et al., 2004; Domier et al., 2007; Luijten et al., 2013). Given these studies used nicotine dependent samples that were intentionally and acutely satiated on nicotine, and study 1 used intentional abstinence, the similarity in findings

suggest IC performance is indistinguishable between states of short 3-hour abstinence and acute satiation. This similarity may be consistent with nicotine's 2-hour half life which causes nicotine to remain pharmacologically active up to 6-8 hours post nicotine cessation (Benowitz, 2008; Hukkanen et al., 2005), subsequently prolonging acute nicotinic benefits or the delaying the negative effects of withdrawal.

One such benefit may be an acute nicotinic effect on inhibitory ability that compensates for, and subsequently masks, underlying IC deficits. Acute nicotine administration has been shown to lessen the severity of pathological IC deficits in ADHD in a group of non-smoking adolescents (Goldstein and Volkow, 2011; Potter and Newhouse, 2004), suggesting acute nicotine satiation may temporarily improve baseline IC capabilities. Similarly, within a nicotine dependent sample, acute nicotine administration was argued to ameliorate otherwise poor IC performance (Dawkins et al., 2007). Despite these enhancements in behavioural performance, recent neuroimaging findings examining acute nicotine satiation within chronic nicotine users have demonstrated aberrant neural and functional correlates of IC (de Ruiter et al., 2012). In particular, Luijten et al. (2013) found neural activity indicative of greater cognitive 'effort' on an inhibitory task within satiated dependent individuals, whilst behavioural performance did not differ from controls. Nicotine satiation may therefore mask the behavioural manifestation of underlying neurocognitive differences between dependent and non-dependent groups in inhibitory ability. Hence within study 1, a maintained state of satiation at 3-hour abstinence may account for behavioural performance similarities between the dependent and control groups and does not preclude underlying functional disparities between the two groups.

Differences in IC performance during nicotine satiation and abstinence were found in study 2, where IC performance decreased in a nicotine dependent sample following 10-hour abstinence compared to performance when satiated. Previous studies examining abstinence

duration ranging from 5 – 25 hours (majority between 13 – 17hrs) have also reported decreased IC performance, with the severity of IC deficits often proportionate to abstinence length (Atzori et al., 2008; Domier et al., 2007; Mendrek et al., 2006; Schlienz et al., 2013). Given study 2 implemented an abstinence period of 10-hours, both acute and cumulative effects of nicotine (seen in most active smokers) were limited (Benowitz, 2008), and the likely absence of, or decrease in, nicotine at 10-hour abstinence may have revealed a lower level of baseline IC ability within dependent cigarette smokers. The current findings might also indicate enhanced inhibitory performance at satiation rather than an inhibitory deficit at abstinence. The study was not designed to investigate this possibility, as previous research mostly indicates a decompensation of inhibitory function during nicotine abstinence. Nonetheless, delineating the direction of this effect remains a possible avenue for future research.

The increase in withdrawal symptoms that accompanied the longer 10-hour abstinence period during Study 2 might also have influenced IC performance. Several symptoms of withdrawal were heightened at 10-hour abstinence, including positive and negative affect, craving and anxiety. Individual differences in positive affect between abstinence and satiation were associated with SSRT performance. However, individual changes in the majority of withdrawal measures examining negative affect, craving and anxiety were not associated with inhibitory performance at abstinence and no other task component, such as accuracy or reaction time, differed between abstinence and satiation. Withdrawal-related impairments within the task domain appear to be confined to inhibitory abilities, although some aspects of the withdrawal syndrome may likely interact with nicotine abstinence to influence inhibitory control performance.

The suggested distinction between nicotine dependent IC performance over longer (10-hour) and shorter (3-hour) abstinence lengths supports similar findings examining

differences between states of satiation and abstinence. For example, Domier et al. (2007) found smokers' performance on a Stroop task was comparable to controls following ≤1hour of abstinence but decreased significantly at 13-hour abstinence. Similarly, Dawkins et al. (2007) found IC over antisaccadic eye movements was poorer following continued abstinence than when subsequently satiated on nicotine. A suitable period of abstinence may therefore be an important precondition to examining IC dysfunction within nicotine dependence. It is important that future cognitive and neuroimaging studies recognise the potential role of abstinence length in determining inhibitory performance, which should factor into future task designs.

Our studies indicate utility in using abstinence as a paradigm for investigating IC deficits within nicotine dependence, suggesting behavioural manifestations of IC deficits become increasingly apparent with increased abstinence, with the severity of these deficits proportionate to dependence severity. Current models of drug dependence propose that the failure to control or inhibit pre-potent urges and responses to drug stimuli become heightened with increased periods of abstinence, with subsequent failings of IC promoting continued drug use (Goldstein and Volkow, 2002; Lubman et al., 2004; Goldstein and Volkow, 2011). Interestingly, unlike other drugs, a typical pattern of nicotine use results in cumulative, 24-hour a day nicotine exposure (Benowitz, 2008), meaning that unlike some forms of dependence, the contribution of IC dysfunction to nicotine dependence may not be of clinical significance until the decision to quit or abstain from nicotine. Hence focusing on the interaction between IC and abstinence may be critical to improving clinical outcomes within this population. Due to sampling differences, one limitation of this investigation was the inability to statistically compare performance of nicotine dependent individuals across study 1 and 2. In turn an explicit distinction between nicotine related performance across 3-hour

abstinence, 10-hour abstinence and satiation in comparison to control performance was not possible and should be considered an aim of future research.

In conclusion, our findings indicate abstinence length within nicotine dependence has an important relationship with IC function. When strictly controlling for variables that independently alter IC function a nicotine dependent sample showed no difference in inhibitory performance to matched controls at 3-hour abstinence, however showed a significant decline in inhibitory function following 10-hour abstinence. This appears to indicate a scale of dysfunction varying in proportion to abstinence length; whereby inhibitory dysfunction is not evident at lower abstinence lengths, however does emerge over longer abstinence periods. These findings suggest the importance of future studies controlling for abstinence alongside other confounding variables. By accounting for abstinence as an important factor of behavioural IC performance, the relationship between inhibitory control and nicotine dependence may be better delineated, with important potential implications for understanding long-term abstinence outcomes.

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FIGURE LEGENDS

Figure 1. Mean Stop Signal Reaction Time (SSRT) within 10-hour abstinence and satiation conditions. *Note*: Higher SSRT accords with poorer inhibitory performance. ** p<.001

Figure 2. Association between Fagerström Test for Nicotine Dependence (FTND) and Stop Signal Reaction Time (SSRT) following 10-hour abstinence

Table 1: Mean demographic and questionnaire data for smoking and non-smoking groups

Questionnaire variables	**Smokers**	**Non Smokers**
Age	23.70	23.14
Gender (male/ female)	26 / 11	23 / 13
Years of education	14.81	15.25
No. of Cigarettes (per day)	16.86**	0
CO levels (ppm)	7.59	-
AUDIT	12.84**	4.67
DAST	2.46**	.39
FTND	3.73**	0

Note: CO levels = carbon monoxide levels measures in parts per million (ppm).
** p <.001, refers to corresponding independent samples t-test

Table 2. Mean stop-signal reaction time, mean correct 'go' reaction times and stop-signal accuracy for smoking and non-smoking groups.

SST Measure	**Smokers**		**Non-smokers**	
	M *(Range)*	**SE**	**M *(Range)***	**SE**
SSRT (ms)	199.27	7.80	203.50	7.04
MRT (ms)	557.16	21.88	558.97	24.94
Stop Accuracy (%)	51.77 *(48 – 58.67)*	0.46	51.69 *(48 – 58.67)*	0.47

Note: SSRT = stop-signal reaction time; MRT = mean correct go reaction time; Stop Accuracy = percentage of successful inhibitions on stop trials

Table 3. Descriptive statistics for pre-test questionnaire measures in the abstinence and satiation conditions

	Abstinence		**Satiation**	
	M (*Range*)	**SE**	**M** (*Range*)	**SE**
Time since last cigarette (hrs)	13.57 (*10-24*)	.73	.84 (*.5-1.5*)	.08
Time since last alcohol (hrs)	16.39 (*10-36*)	1.60	18.86 (*12-42*)	1.62
Time since last caffeine (hrs)	8.57 (*1-24*)	1.81	2.46 (*1-8*)	.34
Number of cigarettes pre-test	-	-	8.59 (*2-23*)	1.25
CO levels (ppm)	7.14**	.75	26.18	2.70
QSU-Brief	50.18**	2.7	25.82	2.36
STAI	10.91**	6.18	.45	5.48
PANAS (PA)	19.45**	1.24	27.86	1.74
PANAS (NA)	17.55**	1.43	13.82	.87

Note: CO levels = carbon monoxide levels measures in parts per million (ppm); QSU-Brief = Brief Questionnaire of Smoking Urges, scores may range from 7- 70.
**$p<.01$, refers to corresponding within-subjects t-test

Table 4. Mean stop-signal reaction time, correct 'go' reaction times and stop-signal accuracy for abstinence and satiation conditions.

SST Measure	**Abstinence**		**Satiation**	
	M *(Range)*	**SE**	**M *(Range)***	**SE**
SSRT (ms)	203.23	6.32	177.27	5.92
MRT (ms)	449.76	19.92	458.61	20.55
Stop Accuracy (%)	49.51 *(44.0 – 53.33)*	.43	50.00 *(48.0 – 52.0)*	.27

Note: SSRT = mean stop-signal reaction time; MRT = mean correct go reaction time; Stop Accuracy = percentage of successful inhibitions on stop trials

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Contributors

R.H., L.H., & D.G.M designed the study and developed the protocol, K.C-W. and R.H. undertook data analysis and wrote the paper, L.H. and D. G. M. recruited participants, administered cognitive tests and assisted in literature revision. All authors contributed to drafts of the manuscript.

Conflict of Interest

No conflict declared

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Figure 1

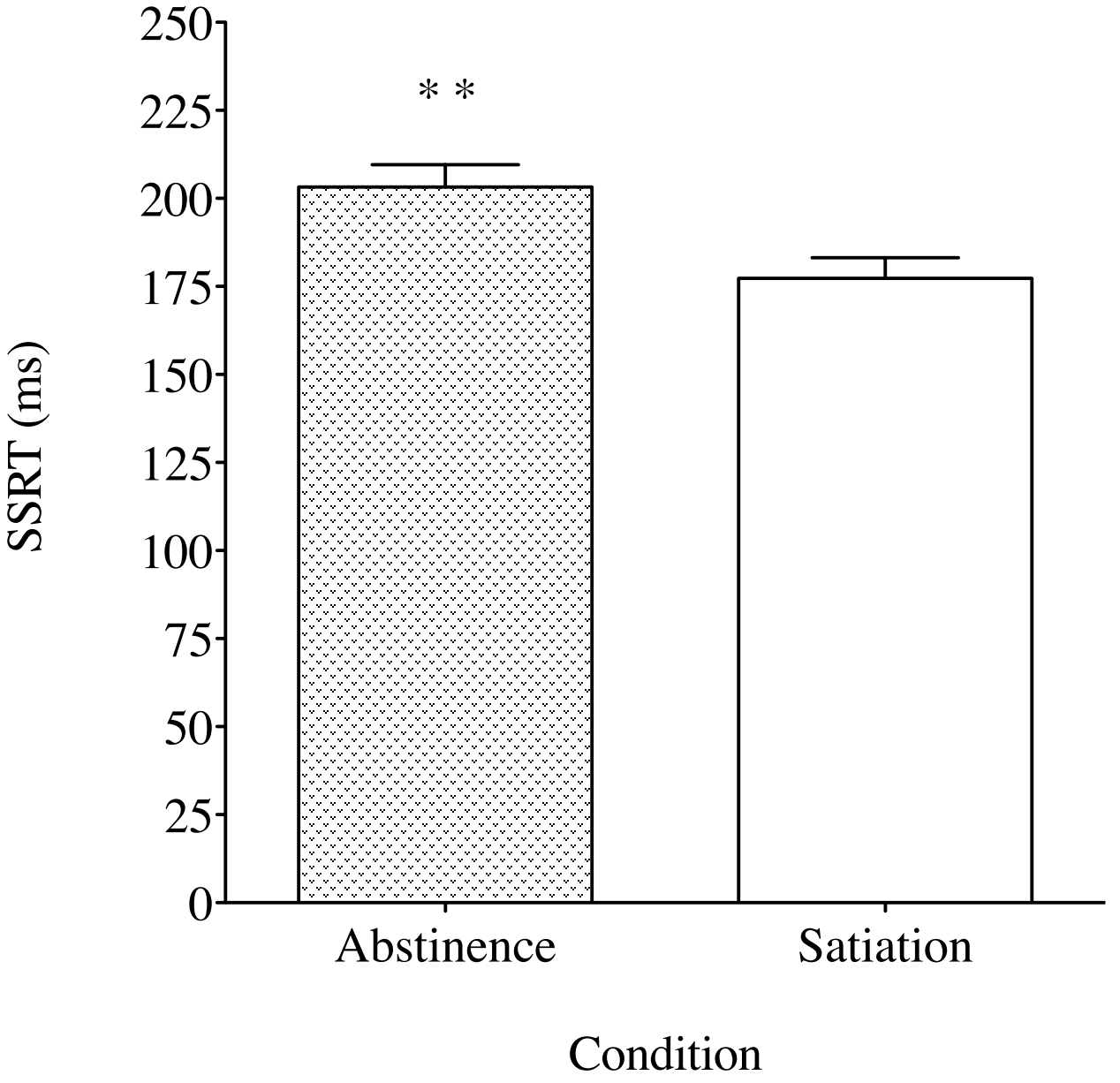
250
225
200
175
150
125
100
75
50
25
0
SSRT (ms)
* *
Abstinence
Satiation
Condition

Figure 2