

Patterns of change in withdrawal symptoms, desire to smoke, reward motivation and response inhibition across 3 months of smoking abstinence

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ABSTRACT

Aims We have demonstrated previously that acute smoking abstinence is associated with lowered reward motivation and impaired response inhibition. This prospective study explores whether these impairments, along with withdrawal-related symptoms, recover over 3 months of sustained abstinence. **Design** Participants completed a 12-hour abstinent baseline assessment and were then allocated randomly to quit unaided or continue smoking. All were re-tested after 7 days, 1 month and 3 months. Successful quitters' scores were compared with those of continuing smokers, who were tested after *ad libitum* smoking. **Setting** Goldsmiths, University of London. **Participants** A total of 33 smokers who maintained abstinence to 3 months, and 31 continuing smokers. **Measurements** Indices demonstrated previously in this cohort of smokers to be sensitive to the effect of nicotine versus acute abstinence: reward motivation [Snaith–Hamilton pleasure scale (SHAPS), Card Arranging Reward Responsivity Objective Test (CARROT), Stroop], tasks of response inhibition [anti-saccade task; Continuous Performance Task (CPT)], clinical indices of mood [Hospital Anxiety and Depression Scale (HADS)], withdrawal symptoms [Mood and Physical Symptoms Scale (MPSS)] and desire to smoke. **Findings** SHAPS anhedonia and reward responsivity (CARROT) showed significant improvement and plateaued after a month of abstinence, not differing from the scores of continuing smokers tested in a satiated state. Mood, other withdrawal symptoms and desire to smoke all declined from acute abstinence to 1 month of cessation and were equivalent to, or lower than, the levels reported by continuing, satiated smokers. Neither group showed a change in CPT errors over time while continuing smokers, but not abstainers, showed improved accuracy on the anti-saccade task at 3 months. **Conclusion** Appetitive processes and related affective states appear to improve in smokers who remain nicotine-free for 3 months, whereas response inhibition does not. Although in need of replication, the results suggest tentatively that poor inhibitory control may constitute a long-term risk factor for relapse and could be a target for intervention.

Keywords Abstinence, recovery, response inhibition, reward motivation, smoking, withdrawal symptoms.

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Submitted 31 March 2008; initial review completed 5 September 2008; final version accepted 19 December 2008

INTRODUCTION

Acute abstinence from regular smoking is associated with somatic symptoms, low mood [1,2], motivational and cognitive disturbance [3–7] and impaired inhibitory control [8–10]. Which of these dysfunctions develop as a consequence of smoking, or are constitutional deficits that predate regular smoking, remains uncertain. If the former is the case, and if neuroadaptations are reversible,

then such impairments should normalize with continuing abstinence; if the latter is the case, they would not be expected to improve even with protracted abstinence. Because the time-course and trajectory of such impairments may affect the ability of the smoker to maintain abstinence, it is useful to chart their natural history.

Very few prospective studies have included measures of cognition. In one recent study in which mental arithmetic was assessed post-cessation [11], scores returned to

baseline (pre-quit) levels within 10 days of quitting. However, Gilbert and colleagues [12] noted reduced accuracy on the rapid visual information processing (RVIP) task and electroencephalogram (EEG) deactivation in abstinent smokers which failed to return to either pre-quit baseline or smoking control levels after 31 days.

A handful of cross-sectional studies have compared current, ex and non-smokers on indices of reward motivation and cognition; in some, impairments were demonstrated by current smokers but not ex-smokers [13,14], while in others the opposite was found [15]. While this may reflect the particular tests used, a recent EEG study [16] found hypoactivation of the pre-frontal cortex and anterior cingulate in smokers who had been abstinent for a mean of 11 years.

With respect to abstinence-related affective and somatic symptoms, nicotine withdrawal is characterized by anxiety, depression, irritability, restlessness, difficulty concentrating and desire to smoke [1,2]. Early studies suggested that such symptoms recover within a few weeks [17–19]; however, reported durations in recent studies have ranged from less than 2 weeks [11,20] to more than a month [21–23]. In one of very few studies which have tracked withdrawal symptoms for longer periods, Piasecki and colleagues [24,25] found considerable heterogeneity in the profiles of symptoms presented by different individuals (75% of whom used a nicotine patch), and approximately 40% showed an *increase* in the severity of withdrawal symptoms after 30 days of abstinence, [24]. In a related study they found comparable levels of depression, anhedonia and somatic features (e.g. decreased appetite, lack of motivation, impaired sleep) in both current and ex-smokers (abstinent for at least 6 months) relative to never-smokers [25].

Prospective studies exploring the time-course of abstinence-related responses are, however, methodologically complex [22,26]; a major weakness is selective dropout, which can bias conclusions seriously. For example, high relapse rates may distort mean scores in the residual sample if relapse is more likely in those who experience the greatest severity of symptoms or cognitive impairment in the early stages of abstinence. Relatedly, successful abstainers may be characterized by atypical levels of motivation, or may differ in other important ways from the broader population of smokers; hence their experience may not generalize to all smokers. In studies which lack a randomly assigned 'continuing-to-smoke' control group, the interpretation of findings may be limited by practice or familiarity effects.

The present study explored changes in withdrawal symptoms, mood, reward motivation and response inhibition over 3 months of continuous smoking abstinence, comparing smokers allocated randomly between 'quit' and 'continue-to-smoke' conditions.

METHODS

Participants

Smokers were recruited through advertisements in local newspapers, radio stations, colleges, libraries and pharmacies in the South East London area. All were aged between 18 and 65 years and smoked 10 or more cigarettes a day and within the first hour of waking. Exclusion criteria included current diagnosis of psychiatric or neurological condition, regular use of prescription or class A recreational drugs and pregnancy. All participants gave written informed consent and the study was approved by Goldsmiths Ethics Committee.

Design and procedure

This was part of a larger study [5,8]. One hundred and forty-five smokers (57% female; 78% Caucasian) were assessed on two occasions after overnight (12 hours) abstinence [confirmed by breath carbon monoxide (CO) levels <11 parts per million (ppm)], once after receiving a 4-mg NiQuitin lozenge and once after receiving a placebo lozenge (order counterbalanced; double-blind procedure).

Immediately after the second session participants were allocated randomly in a 3 : 1 ratio between 'quit' and 'continue-to-smoke' conditions. Those in the quit group were provided with written information and advice but were prohibited from using nicotine replacement therapy (NRT) or other medications. Assessments were repeated at 7 days, 1 month and 3 months, and any quitters who reported more than one lapse since the last session or who had a salivary cotinine level of more than 20 ng/ml were classified as relapsers. Participants allocated to the 'continue-to-smoke' condition were required to smoke a cigarette just before each follow-up testing session to ensure that they were tested in a satiated state.

All participants were offered incremental financial incentives for participating in each successive assessment, subject to their compliance with the requirement to remain abstinent or continue smoking. Participants did not receive any payment until their final assessment. The maximum payment was £150 for those who attended all five sessions.

Assessment measures

Demographic information included age, gender and years of education.

Baseline smoking-related measures

- 1 Cigarettes smoked per day (self-report).
- 2 Salivary cotinine: participants provided a saliva sample at a pre-test screening session and at each

follow-up. A cut-off of 20 ng/ml was used for verification of non-smoking status [27].

- 3 The Fagerström Test of Nicotine Dependence (FTND) [28]: a six-item self-report scale to assess nicotine dependence. Scores range from 0 (low dependence) to 10 (high dependence).

Clinical variables measured at baseline and each follow-up

- 1 The Hospital Anxiety and Depression Scale (HADS) [29] assesses self-rated anxiety and depression over the preceding 7 days. Total scores range from 0 to 21 for both states.
- 2 Desire to smoke: participants rated their response to the question 'how strong is your desire to smoke right now?', from 1 = not at all strong to 7 = extremely strong.
- 3 Mood and Physical Symptoms Scale (MPSS) [30]: participants rated the severity of seven withdrawal-related symptoms on a 0–4 scale 'at this moment in time'. The maximum score of 28 indicates severe symptoms.

Experimental measures assessed during acute abstinence and at each follow-up

The full assessment battery is detailed in Dawkins *et al.* [5]. Here we focus on only those indices found in the full sample to be impaired during acute abstinence (i.e. in the placebo relative to the nicotine lozenge condition). Specifically:

Reward motivation

- 1 The Card Arranging Reward Responsivity Objective Test (CARROT) [3]: participants are required to sort cards according to a simple rule under conditions of financial reward (R) and no reward (NR) presented over three experimental trials in the order NR1, R, NR2. The 'reward responsivity index' (RRI), impaired during abstinence [5], is the average card sorting rate (cards per second) under NR subtracted from the average card sorting rate under R.
- 2 Anhedonia: the Snaith–Hamilton pleasure scale (SHAPS) [31] is a 14-item self-report scale measuring hedonic tone. Total score ranges from 0 (not anhedonic) to 42 (highly anhedonic).
- 3 Attentional bias to reward cues (modified Stroop) [6]: participants colour-name the ink in which each of 88 words (either neutral or pleasure-related; order counterbalanced) are printed. The neutral words serve as a comparison against which to evaluate the interference from the pleasure-related words. Abstinence reduces bias towards pleasure-related relative to neutral words as reflected in number of errors [5]. The 'pleasure bias' index is errors to pleasure-related words minus errors to neutral words; previously we have found the effect of

acute abstinence to affect this error index and not the overall speed of colour-naming (see Dawkins *et al.*, [5]).

Response inhibition

- 1 Oculomotor anti-saccade accuracy [32,33]: participants are required to suppress a reflexive glance towards a peripherally appearing stimulus and instead generate an eye movement (anti-saccade) in the opposite direction. The index impaired during acute abstinence [7], and therefore analysed here, is percentage correct.
- 2 Motor errors in the Continuous Performance Task (CPT) [34]: five-digit numbers are presented visually at a constant rate of two per second for 5 minutes. Experimental stimuli (sequences with no obvious structure, e.g. 97528) are separated one from the next by three 'filler' stimuli of the fixed sequence 12345. Participants are required to press a button when two consecutive experimental stimuli are identical, and not to press the button in response to filler stimuli. Acute abstinence was associated with a higher number of commission errors to filler stimuli ('CPT motor errors') [7].

Statistical analysis

Each variable was subjected to repeated-measures analysis of variance (ANOVA) with the between-subjects factor of GROUP (abstainers versus continuing smokers) and the within-subjects factor of OCCASION (acute abstinence as assessed in the baseline placebo lozenge condition; 7 days; 1 month; 3 months). Thus, while both groups were in the same 12-hour abstinent state at baseline, in subsequent assessments the continuing smokers were nicotine-satiated, having smoked immediately prior to the assessment session while the quit group were completely nicotine-free. As we were interested specifically in comparing the two groups' patterns of change from one occasion to the next, *a priori* contrasts compared scores at adjacent time-points (i.e. baseline versus one week; 1 week versus 1 month; 1 month versus 3 months). Where relevant, *post-hoc t*-tests were also used to compare groups at specific time-points to supplement these contrasts.

Given the high rate of relapse in the quit group (see below), which begins to undermine the initial effects of randomization, we have conducted additional 2×4 ANOVAs for each variable based on a better-matched subgroup of successful abstainers and continuing smokers. Because pre-baseline salivary cotinine levels were shown to be the single most important clinical predictor of abstinent status in this sample (withdrawal symptoms, mood or dependence as assessed by the FTND were not significant predictors) [35], we have used this variable as a basis for matching. Thus, a cut-off of 330 ng/ml was employed which resulted in the loss of three successful abstainers

who were outliers at the high end, and 11 continuing smokers. These additional subanalyses based on 29 quitters and 20 smokers matched for salivary cotinine level [quitters mean: 189.5; smokers mean: 179.5; $t < 1$, not significant (NS)] are also reported in brief to supplement the main findings.

RESULTS

Background and demographic information

Of the 145 participants who completed the baseline assessments [5], 107 were randomized to quit; of these, 33 (31%) maintained cotinine-verified abstinence at all follow-ups. Of the 38 participants allocated to continue smoking, 31 (82%) attended all follow-ups. All analyses are based on these two subgroups. Some data were missing for some variables, due usually to calibration or technical problems. Thus, sample sizes vary between analyses, from 26 to 33 abstainers and 25 to 31 continuing smokers.

Baseline (acute abstinence) scores for the 33 successful abstainers versus the 31 continuing smokers were compared for all clinical and experimental variables via independent-samples t -tests (and χ^2 for sex ratio). The groups did not differ in sex ratio, age, years of education, number of cigarettes smoked per day, dependence (FTND), pre-baseline salivary cotinine levels or any of the experimental variables (see Table 1).

Clinical variables

Withdrawal symptoms

Mean scores are shown in Fig. 1.

There was a significant decline in symptom severity from baseline (acute abstinence) to 1 week ($F_{1,61} = 8.0$, $P < 0.01$), this being more pronounced in the continuing smokers (GROUP \times OCCASION: $F_{1,61} = 4.4$, $P < 0.05$). From 1 week to 1 month, a significant GROUP \times OCCASION interaction ($F_{1,61} = 4.4$, $P < 0.05$) reflects a continued improvement in the abstainers versus a slight worsening in the continuing smokers. Symptoms remained stable from 1 to 3 months (no main effect of OCCASION nor an interaction with GROUP: $F_{1,61} < 1$, NS in both cases). The groups did not differ significantly in the severity of their symptoms at any individual follow-up ($t_{62} < 1.5$, NS in all cases). The pattern of findings was unchanged when we repeated the analysis using the better matched subsample.

Desire to smoke

Subjective desire to smoke is shown in Fig. 2.

The decline in scores from baseline to 1 week was significant ($F_{1,62} = 12.5$, $P = 0.001$) and similar in both

Table 1 Means and standard deviation (SD) for smoking-related, clinical and experimental variables assessed at baseline (acute abstinence) for abstainers and continuing-smokers.

Variable	Mean (SD)	t/χ^2	P
Age			
Abstainers	34.36 (12.56)	-0.06	0.96
Smokers	34.54 (14.07)		
Gender (male : female)			
Abstainers	15 : 18	0.55	0.81
Smokers	15 : 16		
Years in education (post-16)			
Abstainers	4.86 (4.04)	1.70	0.10
Smokers	3.35 (2.95)		
No. of cigarettes/day			
Abstainers	17.84 (5.88)	-0.42	0.68
Smokers	18.48 (6.27)		
Baseline cotinine			
Abstainers	216.45 (120.94)	-1.61	0.11
Smokers	272.76 (155.77)		
FTND			
Abstainers	4.58 (1.66)	-1.65	0.11
Smokers	5.29 (1.81)		
HADS anxiety			
Abstainers	7.12 (3.62)	0.46	0.65
Smokers	6.71 (3.49)		
HADS depression			
Abstainers	4.79 (3.30)	0.79	0.43
Smokers	4.16 (3.03)		
Desire to smoke			
Abstainers	3.73 (1.64)	-1.37	0.18
Smokers	4.29 (1.63)		
MPSS			
Abstainers	6.56 (4.33)	-1.31	0.19
Smokers	8.00 (4.36)		
CARROT reward responsivity			
Abstainers	-0.00 (0.08)	0.90	0.37
Smokers	-0.016 (0.06)		
SHAPS anhedonia			
Abstainers	10.74 (5.65)	-0.27	0.79
Smokers	11.16 (6.75)		
Stroop interference index			
Abstainers	-0.15 (1.42)	-0.70	0.49
Smokers	0.10 (1.42)		
Anti-saccade accuracy (%)			
Abstainers	67.88 (22.82)	0.76	0.45
Smokers	64.05 (15.87)		
CPT motor errors			
Abstainers	4.20 (3.63)	-1.53	0.13
Smokers	6.11 (5.66)		

FTND: Fagerström Nicotine Dependence scale; HADS: Hospital Anxiety and Depression Scale; MPSS: Mood and Physical Symptoms Scale; CARROT: Card Arranging Reward Responsivity Objective Test; SHAPS: Snaith-Hamilton pleasure scale; CPT: Continuous Performance Task.

groups (no OCCASION \times GROUP interaction: $F_{1,62} < 1$, NS). A further significant decline from 1 week to 1 month ($F_{1,62} = 19.7$, $P < 0.001$) was qualified by a significant GROUP \times OCCASION interaction ($F_{1,62} = 4.1$, $P < 0.05$),

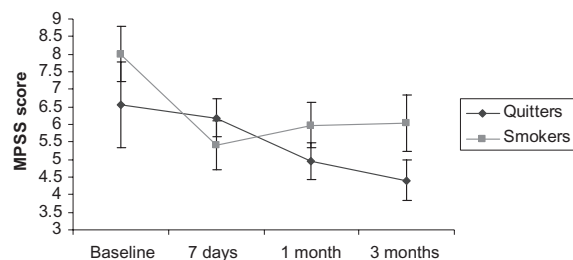


Figure 1 Withdrawal symptoms scores on the Mood and Physical Symptoms Scale (MPSS) on each assessment occasion for quitters and continuing smokers. Error bars are ± 1 standard error

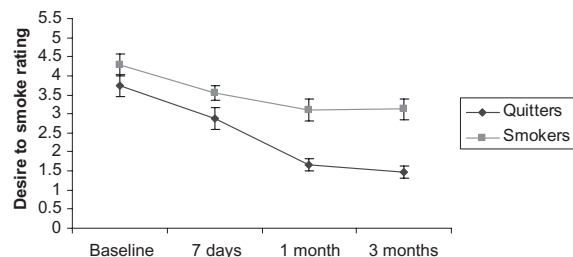


Figure 2 Ratings of desire to smoke on each assessment occasion for quitters and continuing smokers. Error bars are ± 1 standard error

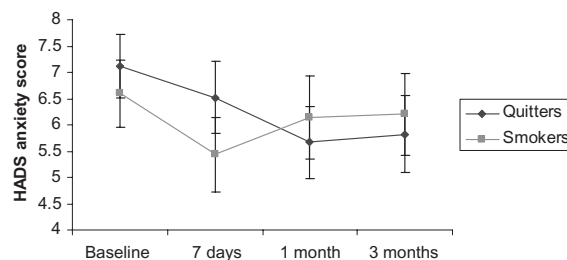


Figure 3 Hospital Anxiety and Depression Scale (HADS) anxiety scores on each assessment occasion for quitters and continuing smokers. Error bars are ± 1 standard error

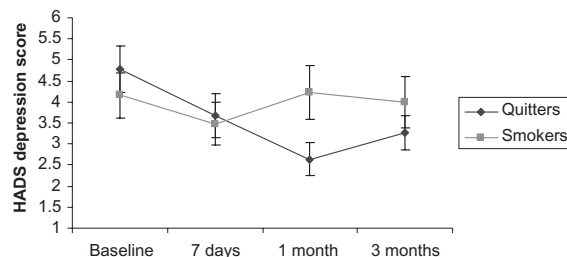


Figure 4 Hospital Anxiety and Depression Scale (HADS) depression scores on each assessment occasion for quitters and continuing smokers. Error bars are ± 1 standard error

with abstainers' scores reducing more. There was no overall further reduction from 1 to 3 months, nor any interaction with GROUP ($F_{1,62} < 1$, NS in both cases).

Abstainers' scores were lower than those of the continuing smokers at all follow-up points; this difference was just short of significance at 1 week ($t_{62} = -1.95$, $P < 0.06$) but highly significant at both 1 and 3 months ($t_{62} = 4.2$ and 5.2 , $P < 0.001$). The pattern of findings was unchanged when we repeated the analysis using the better-matched subsample.

HADS anxiety

Anxiety scores are shown in Fig. 3.

ANOVA confirmed a significant reduction from baseline to 1 week (OCCASION: $F_{1,61} = 5.7$, $P = 0.02$) with no GROUP \times OCCASION interaction ($F_{1,61} < 1$, NS). There was, however, a significant GROUP \times OCCASION interaction from 1 week to 1 month ($F_{1,61} = 4.9$, $P < 0.05$), with abstainers showing a further reduction in anxiety but continuing smokers an increase. There was no significant change from 1 to 3 months (neither a main effect nor interaction: $F_{1,61} < 1$, NS).

Although the graph suggests that anxiety was higher in abstainers than continuing smokers at 1 week and vice versa at 1 month, the groups did not differ significantly at any follow-up point ($t_{62} < 1$, NS in all cases).

These findings were replicated essentially in the better-matched sample, although the GROUP \times OCCASION interaction from 1 week to 1 month now fell short of significance ($F_{1,46} = 2.78$, NS).

HADS depression

These scores are shown in Fig. 4.

Mood improved significantly from baseline to 1 week ($F_{1,62} = 7.7$, $P < 0.01$), and this did not interact with GROUP ($F_{1,62} < 1$, NS).

A significant GROUP \times OCCASION interaction from 1 week to 1 month ($F_{1,62} = 6.5$, $P = 0.01$) reflects an improvement in the abstainers but, if anything, a worsening in the continuing smokers. At this point, abstainers were significantly less depressed than continuing smokers ($t_{62} = 2.1$, $P < 0.05$). From 1 to 3 months there was neither a main effect of OCCASION nor a GROUP \times OCCASION interaction ($F_{1,62} < 1$, NS in both cases), although slight changes meant that they no longer differed significantly at this point ($t_{62} < 1$, NS).

Analyses using the better-matched sample of abstainers and continuing smokers again replicated these findings, although the main effect of OCCASION from baseline to 1 week now fell short of significance ($F_{1,47} = 2.17$, NS).

Reward motivation

SHAPS anhedonia

Anhedonia scores are shown in Fig. 5.

There was a significant improvement in hedonic tone (i.e. a reduction in SHAPS anhedonia scores) from baseline to 1 week ($F_{1,59} = 4.9, P < 0.05$), not qualified by an interaction with GROUP ($F_{1,59} < 1, NS$). There was no subsequent change (all main effects and interactions: $F_{1,59} < 1, NS$). At no time-point did the two groups differ significantly from each other ($t_{59} < 1, NS$ in all cases).

Analysis of the smaller, better-matched sample revealed a similar pattern of results, although the significant improvement from baseline to 1 week was now lost ($F_{1,44} = 1.7, NS$).

CARROT reward responsivity

Reward responsivity increased significantly from baseline to 1 week ($F_{1,59} = 3.87, P = 0.05$), with no GROUP \times OCCASION interaction ($F_{1,59} < 1, NS$). There were no further changes across consecutive points ($F_{1,59} < 1, NS$ for both main effects and interactions), and at no follow-up did the two groups differ from each other ($t_{59} < 1, NS$ in all cases; see Fig. 6).

The same pattern of findings emerged in the better-matched sample but again, the improvement from baseline to 1 week now fell short of significance ($F_{1,45} = 1.0, NS$).

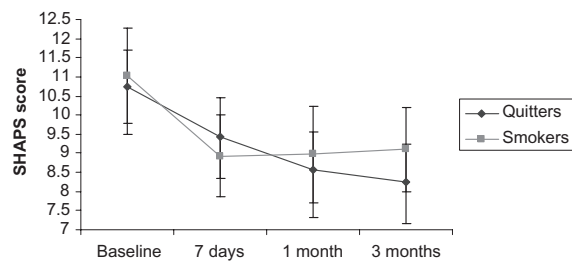


Figure 5 Snaith–Hamilton pleasure scale (SHAPS) anhedonia scores on each assessment occasion for quitters and continuing smokers (high score = greater anhedonia). Error bars are ± 1 standard error

Attentional bias towards appetitive words (Stroop)

There was neither a significant main effect of OCCASION nor an OCCASION \times GROUP interaction for the contrasts between any two consecutive occasions ($F_{1,61} < 1, NS$ in all cases; Table 2). The pattern of findings was unchanged when we repeated the analysis using the better-matched subsample.

Response inhibition

Oculomotor (anti-saccade) task

Accuracy fluctuated markedly from one occasion to the next (see Fig. 7). An improvement from acute abstinence to 1 week was significant ($F_{1,50} = 10.9, P < 0.01$) and greater in the continuing smokers (OCCASION \times GROUP: $F_{1,50} = 6.1, P < 0.02$). A subsequent decline in accuracy between 1 week and 1 month was also significant ($F_{1,50} = 4.1, P < 0.05$) and did not interact with GROUP ($F_{1,50} < 1, NS$). There was a near-significant improvement from 1 to 3 months ($F_{1,50} = 3.4, P = 0.07$), again not interacting with GROUP ($F_{1,50} < 1, NS$). At no individual follow-up did the groups differ significantly from each other ($t_{50} < 1, NS$ in each case). Given the complexity of this pattern, scores at baseline were contrasted directly with those at 3 months, revealing a significant GROUP \times OCCASION interaction ($F_{1,55} = 6.1, P < 0.05$), in which continuing smokers had improved highly

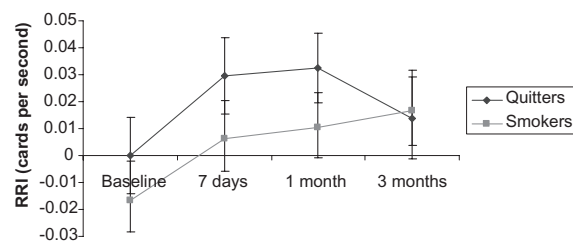


Figure 6 Reward responsivity index (RRI) scores on the Card Arranging Reward Responsivity Objective Test (CARROT) on each assessment occasion for quitters and continuing smokers. Error bars are ± 1 standard error

Table 2 Means and standard deviation for the ‘interference index’ (pleasure—neutral errors) on the Stroop task and motor errors on the Continuous Performance Task (CPT).

Variable	Baseline (acute abstinence)	7 days	1 month	3 months
Stroop interference index				
Quitters	-0.15 (1.42)	0.03 (1.29)	0.15 (1.54)	0.00 (1.37)
Smokers	0.10 (1.42)	-0.30 (1.58)	-0.07 (1.14)	0.13 (1.31)
CPT motor errors				
Quitters	4.20 (3.63)	5.22 (6.12)	5.07 (5.25)	5.85 (6.27)
Smokers	6.11 (5.66)	5.84 (5.05)	5.72 (5.47)	6.28 (6.37)

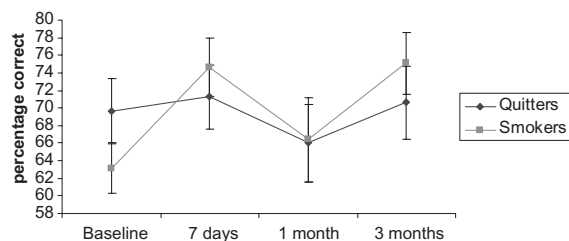


Figure 7 Anti-saccade percentage correct on each assessment occasion for quitters and continuing smokers. Error bars are ± 1 standard error

significantly ($t_{27} = 4.0$, $P < 0.0001$) while abstainers had not ($t_{28} < 1$, NS).

Analyses of the smaller, better-matched groups again revealed a significant improvement from acute abstinence to 1 week ($F_{1,36} = 4.0$, $P < 0.05$), while all other significant main effects and interactions now fell short of significance ($F_{1,36} < 2.5$, NS in all cases). However, the critical interaction from baseline to 3 months remained significant ($F_{1,36} = 4.11$, $P < 0.05$).

CPT motor errors

There were no main effects of OCCASION nor any GROUP \times OCCASION interactions in the full ($F_{1,50} < 1$, NS in all cases; mean scores given in Table 2) or the better-matched subsamples.

DISCUSSION

Consistent with previous reports [17–19], self-reported withdrawal symptoms, anxiety and depression improved steadily over 1 month, while in continuing smokers they remained relatively stable across 3 months. Anxiety and depression scores were well within the ‘normal’ (non-clinical) range for both groups, even during acute abstinence (baseline).

Abstainers’ marked decline in desire to smoke contrasted with the stability shown by continuing smokers’ across the three follow-ups. This profile is consistent with Gilbert *et al.*’s findings that craving dropped steadily over the first month of quitting, differing statistically from the scores of continuing smokers by days 16–22 [36]. In the present study ratings of desire to smoke, mood and physical symptoms were made towards the end of the 1-hour testing session; thus, although continuing smokers had smoked immediately prior to the session, they may have begun to experience withdrawal by this point. As participants reported smoking an average of 18.5 cigarettes per day (just over one per waking hour), their ratings within the session are likely to correspond to their experience at many points during a normal day.

Both abstainers’ and continuing smokers’ SHAPS anhedonia scores were lower at the 1-week follow-up than during acute abstinence, and then remained stable to 3 months. The two groups did not differ at any point, and their mean scores fell within the normal range on all occasions. Pomerleau *et al.* [37] found self-reported anhedonia in ex-smokers (abstinent for 6 months or more) to be comparable with that in current smokers; both groups were more anhedonic than never-smokers. Thus, although the present data suggest that any initial abstinence-related decline in hedonic tone recovers rapidly to the levels smokers achieve by smoking, in the absence of a matched group of non-smokers it is unclear to what extent it truly normalizes.

Turning to reward motivation, while acute abstinence was characterized by lower baseline reward responsivity on the CARROT; this improved equally in the two groups by 1 week. As performance in the continuing smokers was presumably enhanced by their recent nicotine use (consistent with our previous experimental findings [3–5]), the parallel improvement by the abstainers is therefore consistent with natural recovery. However, practice/familiarity effects may also have contributed to the observed improvements in both groups.

With regard to attentional bias to pleasure-related words, there was little change in either abstainers or continuing smokers. In fact, there was no evidence that acute abstinence reduced attentional bias to pleasure versus neutral words in the subgroup of successful quitters described here, contrasting with our findings in the larger sample of 145 smokers [5]. This may reflect the lower statistical power yielded by this smaller sample, or alternatively a relative lack of motivational blunting during acute abstinence in smokers who are able to maintain prolonged abstinence. However, it is notable that this same subgroup exhibited diminished reward responsivity on the CARROT during acute abstinence.

Finally, abstainers showed no improvement on two indices of response inhibition (anti-saccade accuracy and motor errors on the CPT). Although neither group showed a change in CPT errors over time, continuing smokers showed improved accuracy on the anti-saccade task once they had resumed smoking, reflecting our previous finding [8]. Thus, deficits in one index of inhibitory control—oculomotor response inhibition—do not appear to recover across 3 months of abstinence. These findings parallel Neuhaus *et al.*’s observation of abnormally low activation of frontal regions in long-term abstainers [16], and are consistent with the existence of long-term deficits in response inhibition. These may reflect underlying neural dysfunctions which predate regular smoking or which are acquired during the course of regular smoking which fail to recover within the first few months of cessation. In either event, it could

be an indicator of susceptibility to relapse, either because it correlates with a difficulty in inhibiting habitual smoking behaviour or because smokers smoke, in part, to increase control over other their impulsive tendencies. Interventions to aid smoking cessation might therefore focus usefully on strategies for enhancing inhibitory control over the longer-term as well as in the initial stages of abstinence.

This study is not without its limitations. First, although an impressive one-third of smokers who were allocated to the quit group managed to abstain for 3 months, this resulted nevertheless in a fairly modest sample size of only 33 abstainers. Secondly, that two-thirds of those allocated to the quit group relapsed subsequently introduces the possibility that the self-selected abstainers showed reduced severity of impairment during acute abstinence. Nevertheless, we have shown in this sample that withdrawal symptoms, mood and dependence (on the FTND) did not predict relapse significantly while pre-quit salivary cotinine level did [35]. That our supplementary subanalysis of successful abstainers and continuing smokers matched for cotinine levels confirmed the results of the full sample affords us greater confidence in these findings. Thirdly, it is possible that this group of successful abstainers had better emotional regulation ability for genetic or other reasons, or experienced fewer environmental stressors during abstinence, both of which were not assessed here.

Overall, the findings suggest tentatively that appetitive processes and related affective states do improve over 3 months of abstinence in those smokers who are able to remain nicotine-free, while response inhibition may not. Nevertheless, the sample size and findings remain modest, and should be treated with caution until they can be replicated in a larger and better-matched sample.

Declarations of interest

Robert West undertakes consultancy and research for, and receives travel funds and hospitality from, manufacturers of smoking cessation medications and has a share of a patent for a novel nicotine delivery device.

Acknowledgements

This research was funded by the National Institute of Drug Abuse (NIDA); grant code 3527427).

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