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Article (Unspecified)

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Abstract

Rationale Nicotine is known to improve performance on tests involving sustained attention and recent research suggests that nicotine may also improve performance on tests involving the strategic allocation of attention and working memory.
Objectives We used traditional measures and eye tracking techniques to examine the effects of nicotine on visual search tasks.
Methods In experiment 1 smokers and non-smokers performed pop-out and serial search tasks. Experiment 2 used a within subject design and a more demanding search task for multiple targets. In both studies, 2-hour abstinent smokers were asked to smoke one of their own cigarettes between baseline and post-tests.
Results In experiment 1, Pop-out search times were faster after nicotine, without a loss in accuracy. Similar effects were observed for serial searches, but these were significant only at a trend level. In experiment 2, nicotine facilitated a strategic change in eye-movements resulting in a higher proportion of fixations on target letters. If the cigarette was smoked on the first trial (when the task was novel), nicotine additionally reduced the total number of fixations and refixations on all letters in the display.
Conclusions Nicotine improves visual search performance by speeding up search time and enabling a better focus of attention on task relevant items. This appears to reflect more efficient inhibition of eye-movements towards task irrelevant stimuli, and better active maintenance of task goals. When the task is novel, and therefore more difficult, nicotine lessens the need to refixate previously seen letters, suggesting an improvement in working memory.

Keywords

Nicotine, visual search, attention, working memory, executive functions

Introduction

A large body of research has demonstrated that nicotine reliably facilitates performance on tasks involving low-level perceptual and motor processes. For example, nicotine administration leads to faster rates of finger-tapping (West and Jarvis 1986), decreased reaction times (Bates et al 1994;Witte et al 1997, Greisar et al 2002) and improved performance on visual discrimination tasks such as the inspection time (IT) paradigm (Thomson et al 2002;Stough 1995). Nicotine has also been shown to prevent the performance decrement usually seen over time in simple tests of sustained attention such as the Mackworth Clock (Wesnes et al 1983), and to prevent fatigue-related decline in performance overnight (Parkin et al 1998).

The effects of nicotine on higher level cognitive processes are less well established. . The Rapid Visual Information Processing (RVIP) task involves monitoring a series of digits and responding to 'targets' defined as 3 consecutive odd or even digits. It requires sustained attention but also has a moderate working memory load. Nicotine has been found to decrease reaction times and improve correct detections on this task (Foulds 1996, Warburton and Mancuso 1998, Baldinger et al 1995, Revell 1988). These findings are unlikely to reflect the reversal of a withdrawal-induced deficit in performance in nicotine-dependant smokers as they have also been observed in non-abstinent smokers (Warburton and Arnall 1994) and non-smokers (Wesnes & Revell, 1984). Nicotine also improves performance on the Continuous Performance Task that requires monitoring visually presented digits and responding with a button click only to a rarely occurring target. Nicotine improves reaction times without increasing errors in non-abstinent smokers (Pritchard et al 1992) and reduces both errors of omission and reaction time variability in non-smokers (Levin et al 1998) and adults with mild to moderate Alzheimer's Disease (White and Levin 1999).

There is now increasing evidence that nicotine can improve performance on tasks that tap high level executive functions such as error detection and correction, planning, updating working memory and active response inhibition. Kumari et al (2003) gave injections of nicotine or placebo to non-smokers whilst they performed the n-back task. In this task, participants monitor a stream of visually presented numbers and respond to the target digit either as it appears or when it appears twice with 1, 2 or 3 digits presented between occurrences. After nicotine, accuracy of responses was better in all conditions, but response latency decreased only in the 3-back condition. The authors point out that faster responses are more desirable as load increases on this task, to allow digits currently held in working memory to be unloaded, and new ones reloaded. Ernst et al (2001) also reported improved accuracy and decreased reaction time in a 2-back task after nicotine administration to ex-smokers. Random letter generation is another task that requires rapid monitoring and updating of information in working memory, and is improved after nicotine administration, although only in the more difficult, 1 item-per-second condition (Mancuso et al 1999). Nicotine also improves response inhibition as measured by the antisaccade task. This task requires participants to inhibit a reflexive saccade towards a sudden onset target, and initiate a saccade in the opposite direction. Nicotine reduces the number of antisaccade errors (Depatie et al 2002, Powell et al 2002). Finally, nicotine has been found to improve the ability to inhibit responses to irrelevant stimuli in the Stroop (Della Casa et al 1999) and the retrieval-induced forgetting (Edginton and Rusted 2003) paradigms. These findings suggest that nicotine may also improve performance on tasks that require the strategic allocation of attention and active maintenance of task goals within working memory.

The interaction between working memory and attentional selection can be effectively studied in the laboratory using visual search tasks. In everyday life our visual system is continually faced with the task of identifying a single item of relevance among the vast amount of information available. Visual search tasks provide a laboratory analogue of this situation. In a typical search task, participants are required to indicate the presence or absence of a specific target item within an array containing multiple distractor items. A distinction can be made between parallel and serial searches. If the target has a unique, attention grabbing property (e.g. colour) then it is generally found very quickly regardless of the number of distracter stimuli in the display, suggesting that the entire display is processed in parallel. Such searches are often described as pop-out as the presence of the target is immediately obvious. In more demanding search tasks the target shares many properties or features with the distracters (Triesman and Gelade 1980). Here, time to locate the target increases in a linear fashion with the number of distracters. This has been taken as evidence for a serial, or item-by-item search of the display that continues until the target is found. While a distinction between serial & parallel searches as separate, distinct mechanisms has been disputed (Wolfe 2003), it is generally agreed that pop-out searches are relatively automatic and do not require use of limited attentional resources whereas more demanding item-by-item searches require the rapid planning of an ordered sequence of saccades - an effortful process requiring use of limited attentional resources (Woodman and Luck 2003).

Different types of search tasks can be used that put varying demands on working memory from simply scanning the display until a single target is found to requiring use of a planned and coherent search strategy to find multiple targets. Therefore visual search could potentially be used to separate nicotine's effects on lower-level stimulus processing and higher-level or executive functions. Trimmel and Wittberger (2004) used a conjunction search (search for a target of specific colour and shape) with moving targets and distracters and tested non-smokers, non-deprived smokers and 12-hour abstinent smokers. They reported no effect of transdermal nicotine on accuracy, but nicotine increased reaction times in the hardest search condition in all three groups, the opposite of what would be expected. As their dosage of nicotine did decrease reaction times, again in all three groups, on many other tasks in their test battery the authors suggest that negative finding on visual search may be a function of the heightened alertness reported by smokers which led processes normally carried out unconsciously to be allocated more conscious, attentional resources.

A complex visual search will require memory for previously visited locations and the use of a well-planned and coherent strategy. Successful visual search also requires rapid planning of saccades to locations in the visual field, an effortful process requiring use of limited processing resources. Data from Araujo et al (2001) suggests that we have a inbuilt preference to minimize the effort involved in planning saccades and will attempt to scan as much of the display as we can as quickly as possible rather than using cognitive resources to make eye movements only towards places where the target is likely to be. Butter (2004) demonstrated that performing searches with multiple distracters that share many features with the target led to faster identification of the targets in probe trials that followed. From this data, Butter (2004) suggested that one role of executive functions in visual search is to increase the activity of representations of the target in working memory. This augmentation of target representations appears to be a direct consequence of searching for the target and it does not occur on searches with few distracters, or when the target and distracters have very different features. Therefore, it seems that only more demanding search tasks will have a sufficient enough cognitive load to require such use of executive functions.

The experiments that follow were designed to allow comparison of nicotine effects on a simple, 'pop-out' search requiring parallel processing to progressively more complex searches that put considerable demands on executive functions. Traditional visual search studies have relied purely on accuracy and latency measures to assess performance, however advances in eye-tracking technology allow more detailed analyses of task performance to be made. These include the precise quantification of the number of fixations and refixations made on target and non-target items. In experiment 1 we used a 'pop-out' search and a serial search and would expect nicotine to speed up response times in the parallel search task and may also improve accuracy as well in the more demanding serial search. Experiment 2 used a more demanding search for multiple targets and was designed to give some insight into how nicotine could improve visual search performance when working memory demands are high and strategic processing would be advantageous.

Materials and Methods

Experiment 1

Volunteers

Twenty non-smokers (2 male, mean age 21.5 years) and 19 smokers (5 male, aged 22.47 years) recruited from a subject pool at the University of Sussex completed the experiment. All smokers smoked between 10 and 20 cigarettes a day, habitually smoked their first cigarette before lunchtime and were on average 224 minutes abstinent at the start of the experiment (range 120-780: two smokers were overnight abstinent). They scored (mean, s.d) 3.74 (1.28) on the Fagerström (1978) test of nicotine dependence and had been smoking for an average of 6.55 (s.d. 2.99) years. All participants gave their written, informed consent, were fully debriefed at the end of the session and paid for their time. The School of Biological Sciences Ethics Committee approved all experiments reported in this paper.

Materials

Novel search matrices were created using a 7 x 7 grid in MS PowerPoint. 'E' and 'G' were selected as targets and 'O', 'Z', 'C', 'D', 'B', 'F', 'Q', 'M', 'N', 'U', 'S' and 'W' as distracter letters. Each search matrix filled the 21 inch monitor. Two search tasks were created - a pop-out task in which participants searched for a pink target letter amongst white distractor letters and a serial search in which the target letter was also white. Each task used 16 matrices with each of 12, 24 or 48 distracter letters resulting in 48 trials in total. The target was present in 50% of trials. . See fig.1 The order of presentation of matrices within a search task was random.

Insert fig. 1

Procedure

All participants performed three blocks of visual search tasks within a single experimental session. All sessions started after 1pm to ensure smokers were not overnight abstinent. Upon arrival, smokers completed a smoking behaviours questionnaire (Fagerström 1978) and an end-tidal CO reading of <15ppm was taken as a measure of compliance with the request not to smoke for two hours before arriving at the laboratory Participants were first shown some examples of the search matrices for both visual search tasks and instructions were read to them before the first full trial. Each block lasted for 10-15 minutes and involved one pop-out search task, followed by one serial search task. Throughout each block, eye-movements were recorded using an Eyelink II. After the baseline block a short break was taken when smokers were permitted to smoke one of their own, or preferred brand cigarettes ad libitum. Non-smokers rested during the break. Participants then completed the second (POST1) block, and then had another short break where again, smokers smoked one of their own cigarettes. A third (POST2) block was then competed and participants were fully debriefed.

Analysis

This created an experimental design with 3 within subjects variables: block, target presence and set size and one between subjects variable, group. Performance measures taken were reaction time (RT), number of fixations made (NF), fixation duration (FD) and saccade amplitude (SA). Scores reported below are the means taken from each 48-matrix search task. Baseline data were entered into a 2 (group) x 2 (target presence) x 3 (set size) ANOVA to identify any pre-existing differences between smokers and non-smokers. Difference from baseline scores were calculated to explore nicotine effects and these were entered into a 2 (block: post1-baseline vs. post2-baseline) x 2 (target: absent/present) x 3 (Setsize: 12,24,48) x 2 (group: smoker/non-smoker).

Experiment 2

Participants

Twenty smokers (4 male, mean age 22.8 (s.d. 4.58) years) drawn from the same subject pool and meeting the same criteria as experiment 1 completed this experiment. Participants had been smoking for an average of 7.70 (s.d. 4.23) years and scored 3.85 (s.d. 1.69) on the Fagerström (1978) test of nicotine dependence. Participants were paid for their time or given course credits.

Materials

For the visual search task 24 original search matrices were created in a 7 x 9 grid in MS PowerPoint, with one letter in each square. 30 targets (upright T's) were randomly assigned to positions in the grid, the other 43 spaces were filled with L's in four rotations, upright, and rotated by 90, 180 and 270 degrees. The letters were not aligned centrally within the squares creating an array of letters that appeared 'random' See fig. 4. Each search matrix filled the 21 inch monitor. This manipulation was designed to discourage a systematic left to right scanning strategy by participants and to make the task as difficult as possible.

Insert fig. 4

Task

For each matrix, participants were required to search for every 'T' in the display, and to click a button on the response pad with their right finger whilst they were looking at each T. Instructions were to click each T once and only once, and that nothing would appear on the screen to notify them of a click, so it was up to them to remember which ones had been clicked. Participants were required to terminate each task by clicking a button with the left thumb on the response pad, so they had as long as they needed to find every T, but were instructed to work as quickly and accurately as possible. Eye-movements were recorded throughout using both pupil and corneal tracking allowing analysis of fixations and refixations made on each individual letter.

Procedure

All participants visited the laboratory twice. Upon arrival for the first session, after giving informed consent, a smoking behaviours questionnaire was completed (Fagerström, 1978). Homogeneity of the sample was maintained by recruiting smokers who smoked between 10 and 20 cigarettes per day, ensuring a moderate dependency measure, and an easy tolerance of the two-hour deprivation request. Absolute time since last cigarette was not standardised, in favour of maintaining a more naturalistic schedule for the smokers. In practice, most smokers smoked two to four hours before the session, the apparently large variance (2 - 13 hours abstinence) reflecting the choice of two smokers not to smoke on the morning of the session). An end-tidal CO reading of >15ppm was taken on arrival as a measure of compliance with the request not to smoke for two hours before arriving at the laboratory and all sessions started after 1pm to ensure smokers were not overnight abstinent. Within each session participants performed a practice block of 8 trials before completing a baseline experimental block of 18 search matrices. After a five minute break and a second measure of end-tidal CO was taken, participants completed a second experimental block of 18 search matrices. 9-point calibrations were taken before the practice and experimental blocks, and between every 2-4 search matrices presented. During one of the two testing sessions participants were asked to smoke one of their own, preferred brand of cigarettes during the break. The order of smoking/abstaining was counterbalanced with half participants smoking in the first session and half smoking on the second session.

Analysis

Nine performance measures were taken from the mean scores in each 18-trial block: completion time (taken from the last fixation made before termination of search), number of refixations on all letters in the display, percentage of T's clicked, number of reclicks on T's, number of T's clicked on 2nd fixation but not first (an indication of strategy used, or pick-up of targets fixated whilst scanning the display), number of T's clicked on 1st fixation but not subsequent fixations (measure of working memory for previously clicked targets), percent of fixations on 'T's and total number of fixations made.

Data from the two baseline sessions was entered into a 2 (Session: 1 vs. 2) x 2 (Order: smoked in session 1 vs. smoked in session 2) ANOVA to look for practice and order effects from one session to the next and to check that performance at baseline was the same amongst those who smoked in session 1 and 2. Difference-from-baseline scores were used to explore effects of nicotine with data entered into a 2 (Nicotine: smoking session vs. abstain session) x 2 (Order: smoked in session 1 vs. smoked in session 2) ANOVA.

Results

Experiment 1

Baseline Data

There were no differences between smokers and non-smokers at baseline for any of the performance measures taken on all search tasks apart from for saccade amplitude on the POP search. See table 1.

Insert table 1.

Smokers appear to have smaller saccades at baseline although this effect was significant on the pop-out search only and this appears to be a group difference that had no bearing on subsequent analyses. There is a trend towards non-smokers making fewer fixations than smokers at baseline on the serial search, but this trend is not seen in the reaction time data.

Difference from baseline scores

Pop-out search

For all participants reaction times and number of fixations decreased over the three blocks (RT: $F_{(1,37)}$=14.21, p=0.001, NF: $F_{(1,37)}$=9.53, p=0.004). All participants became faster and made fewer fixations for target absent matrices (RT: $F_{(1,37)}$=6.19, p=0.018, NF: $F_{(1,37)}$=11.88, p=0.001). There was a significant interaction between these factors, reflecting larger practice effects for target absent than target present matrices (RT: $F_{(1,37)}$=7.81, p=0.008, NF: $F_{(1,37)}$= 11.65, p=0.002). See table 2.

Insert table 2.

A main effect of group revealed a greater overall decrease in number of fixations made by smokers ($F_{(1,37)}$= 4.35, p=0.044) and a trend towards a corresponding decrease in reaction times for this group ($F_{(1,37)}$=3.12, p=0.086), suggesting greater improvement after nicotine relative to practice alone. Smokers also had faster reaction times ($F_{(1,37)}$= 0.509, p=0.030) and made fewer fixations ($F_{(1,37)}$= 4.28, p=0.046) for target absent matrices. See figs. 2 & 3.

Insert fig. 2

Insert fig. 3

No other main effects or interactions were significant in this data set.

Serial Search

As with the pop-out search all participants demonstrated decreased reaction times and number of fixations over the three blocks (RT: $F_{(1,37)}$= 34.69, p<0.0001, NF $F_{(1,37)}$= 18.25, p<0.0001) and a greater decrease in reaction time and number of fixations for target absent than target present matrices (RT: $F_{(1,37)}$= 25.80, p<0.0001, NF: $F_{(1,37)}$= 26.49, p<0.0001). This time there was also a greater decrease in reaction times and number of fixations as setsize increased (RT: $F_{(2,74)}$= 9.89, p<0.0001, NF: $F_{(2,74)}$= 7.72, p=0.001) representing greater practice effects for the searches that contain more distracter letters. See table 3.

Insert table 3.

The data showed a trend for smokers to speed up more and make fewer fixations than non-smokers, but these main effects failed to reach significance (RT: $F_{(1,37)}$= 3.31, p=0.077, NF: $F_{(1,37)}$= 3.70, p=0.062). There were no other interactions (p>0.1) involving group for any other performance measure.

Error Data

Number of errors made was very low, and analysis of the baseline data revealed no significant differences between smokers and non-smokers ($p>0.1$). Difference-from-baseline scores revealed no differences between smokers and non-smokers for the pop-out search. For the serial search, there was a greater reduction in all errors ($F_{(1,37)}= 7.047$, $p=0.012$) and target present errors ($F_{(1,37)}= 7.697$, $p=0.009$) amongst non-smokers.

Experiment 2

Baseline data

Practice effects of an improvement in performance from one baseline test to the next were seen for all participants for almost all measures. There were no differences between those who smoked in session 1 and those who smoked in session 2. See table 4.

Insert table 4.

Difference from baseline scores

For all measures there was no main effect of order ($p>0.1$). After smoking, all participants made a higher percentage of fixations on T's ($F_{(1,18)}= 15.697$, $p=0.0001$) with change from baseline being (mean, s.d.) 1.28 (2.24) after smoking and –1.22 (2.38) after abstinence. The data also showed a trend towards a reduction in T's clicked on second, but not first fixation ($F_{(1,18)}= 4.024$, $p=0.060$), a measure of strategy used, or pick-up of T's fixated but not clicked straightaway and a reduction in refixations after nicotine ($F_{(1,18)}=0.3623$, $p=0.073$). There were no other main effects of nicotine ($p>0.1$).

However interactions between nicotine and order did emerge. Number of refixations made ($F_{(1,18)}= 11.611$, $p=0.003$) and total number of fixations ($F_{(1,18)}= 7.408$, $p=0.014$) decreased after nicotine (fig. 6), and there was also a trend towards a decrease in T's clicked on first, but not subsequent fixation, an indirect measure of working memory performance ($F_{(1,18)}= 3.981$, $p=0.061$). Volunteers who smoked in session 1 made fewer refixations ($t=-3.968$, $df=9$, $p=0.003$) and total fixations ($t=-2.41$, $df=9$, $p=0.039$).

Insert fig. 5a & b

Discussion

Experiment 1

The main finding of experiment 1 was that nicotine resulted in faster search times for pop-out targets. Nicotine also led to faster search times for the more difficult serial targets, but the effects were only significant at a trend level. Interestingly, the reduction in search times on the pop-out searches after nicotine were greatest in the target absent trials suggesting a more specific action of nicotine than simply speeding up all reaction times. This may reflect simply that target absent trials take longer on average, and are likely to benefit from the sustained attentional effort that nicotine promotes. These findings are in line with previous research demonstrating effects of nicotine on low level perceptual processes (Thomson et al 2002;Stough 1995) and also suggest that nicotine may impact on higher level processes such as those involved in the strategic allocation of attention. In order to explore these effects further, experiment 2 used a considerably more demanding search task combined with detailed analysis of eye-movements and a more robust, crossover, within-subjects design.

Experiment 2 Discussion

Administration of nicotine led to a higher percentage of fixations on target letters, suggesting a better focus on task-relevant items and a move towards a more strategic search pattern. Such a change in strategy would lessen the need to refixate previously seen letters and would improve pick-up of targets that had been previously fixated whilst scanning the display and both of these measures showed some indication of better performance after nicotine. When the task was most novel, that is, in session one, nicotine enabled equivalent task performance in terms of number of targets clicked with reduced number of fixations and refixations. This indicates an improvement in memory for previously clicked targets and a speeding up of the search process when the task is novel and therefore performance is not optimal. It is possible that ceiling effects prevented any further improvement with nicotine on these measures amongst those who smoked in the second session. Improvements on more strategic aspects of this task, such as planning of saccades are seen regardless of the amount of practice. Saccade planning is thought to be an effortful process requiring use of executive functions (Araujo et al, 2001) that we usually try to avoid (by looking at as much of the display as possible in a single fixation). This data clearly shows that nicotine is leading to more efficient, task-relevant eye movements suggesting that it is indeed improving this more demanding aspect of visual search. Two clear findings from this experiment, then, are that eye-movement tracking can give insight into visual search performance that would not be picked up by response accuracy and latency measures and that nicotine is improving performance above and beyond faster stimulus processing or motor responses.

General Discussion

Together the two experiments reported here have shown that visual search is a useful paradigm with which to explore effects of nicotine on both high and low level cognitive processes.

In experiment 1 pop-out visual search became faster following nicotine, suggesting an effect on low-level stimulus processing similar to that reported by Thomson et al (2002) and Stough (1995) using an IT paradigm. These faster search times were not seen to the same extent in the serial searches in experiment 1, or in experiment 2, implying that one action of nicotine may be to speed up visual search when the target can be quickly discriminated from distracters. This interpretation is consistent with the data reported by Trimmel and Wittberger (2004) whose tasks required a conjunction search for a single target, and showed no effect of nicotine, and data reported by Le Houzec et al (1994) showing faster information processing after nicotine on a choice reaction time task where the subject has decide which of four stimuli to respond to, rather than simply responding to one, unchanging stimulus.

Experiment 2 used a search task with multiple targets that had a much higher working memory load; optimal performance required memory for previously visited locations rather than a simple scanning strategy. Administration of nicotine facilitated efficient, strategic planning of eye movements and, when the task was novel, led to a reduction in the number of fixations and refixations made. Such data provide further evidence that nicotine enhances strategic aspects of the search task rather than simply speeding up information processing.

The fact that some aspects of nicotine's performance enhancing effects on visual search were only seen when the task is novel, and therefore more cognitively demanding is consistent with data demonstrating that other tests of executive function, such as the Wisconsin Card Sorting task, or Towers of Hanoi have a low test-retest reliability, and are therefore usually only considered to be reliable indicators of central executive ability the first time they are administered (Rabbit 1997). This may be because once such tasks have been practiced they no longer require as much cognitive effort or because there is something about the novelty of a task when it is first administered that taps an underlying ability that is not required on repeated administrations of the task.

While our data do not directly address the mechanism of action of nicotine, our findings are consistent with the hypothesis that nicotine may be acting to improve working memory processes, which incorporate multiple components of attention and attentional control (Miyake et al, 2000). Nicotine has previously been shown to improve prepotent response inhibition (Della Casa et al 1998; Larrison Briand and Sereno, 2004). In our study, the strategic change that resulted in more fixations on target letters could reflect more effective inhibition of overt eye-movements towards task irrelevant items, or enhanced monitoring of the ongoing task. Computational models of working memory, however, make the point that changes in the ability to inhibit irrelevant information are a direct consequence of changes in ability to maintain relevant information (e.g. Kimberg & Farrah, 1994). Although research has only recently begun to address the role of working memory in visual search, its role in other oculomotor paradigms is comparatively well established. For example several authors have linked increased antisaccade errors to dysfunctional working memory processes (Roberts et al, 1994, Hutton et al 2002;2004). Similarly intrusive anticipatory saccades that can occur during smooth pursuit eye movements have been argued to reflect a failure of inhibitory control mechanisms [Avila et al 2003]. Studies in patients with schizophrenia, who demonstrate both increased antisaccade errors and impaired smooth pursuit have found that nicotine can significantly ameliorate both of these deficits [Olincy et al, 2003; Larrison Briand and Sereno, 2004). Avila et al (2003) have reported that nicotine reduces the number of leading (or anticipatory) saccades during smooth pursuit tasks both in people with schizophrenia and in healthy controls. There is also evidence that nicotine maintains visuospatial working memory performance in people with schizophrenia (George et al 2002).

In conclusion, the data presented here use the novel analysis of eye movement data to provide evidence for a specific action of nicotine on visual search, indicating that it drives a more efficient search strategy. We have suggested working memory as the framework for interpretation of these data. Further work that continues to differentiate the conditions under which nicotine alters cognitive performance must address the accuracy and detail of the cognitive models that seek to describe the complexity of executive function in human information processing.

Acknowledgments

This work was completed as part of N Rycrofts D.Phil thesis, funded by a bursary from the BBSRC. Thanks to Pennie Ingram for management of the database of volunteers.

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Figure legends

Fig. 1 Example of stimuli used in Experiment 1.

Fig. 2. Mean change from baseline collapsed across both post-tests for reaction time in the pop-out search.

Fig. 3. Mean change from baseline collapsed across both post-tests for number of fixations in the pop-out search.

Fig. 4. Example of stimuli used in Experiment 2.

Fig 5a. Mean change from baseline for number of refixations on all letters

Fig 5b. Mean change from baseline for total number of fixations made

Figures

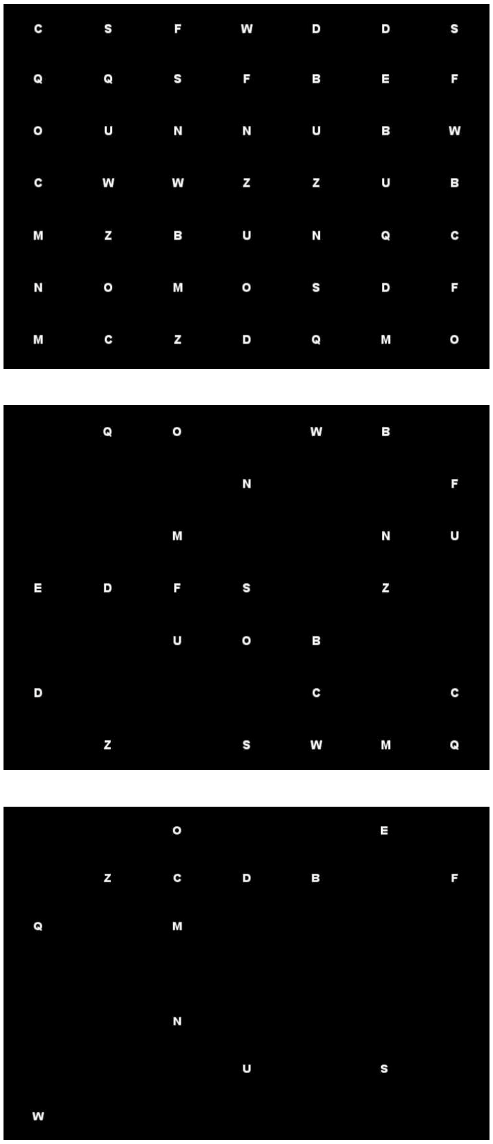
C S F W D D S
Q Q S F B E F
O U N N U B W
C W W Z Z U B
M Z B U N Q C
N O M O S D F
M C Z D Q M O
Q O W B
N F
M N U
E D F S Z
U O B
D C C
Z S W M Q
O E
Z C D B F
Q M
N
U S
W

Fig 1.

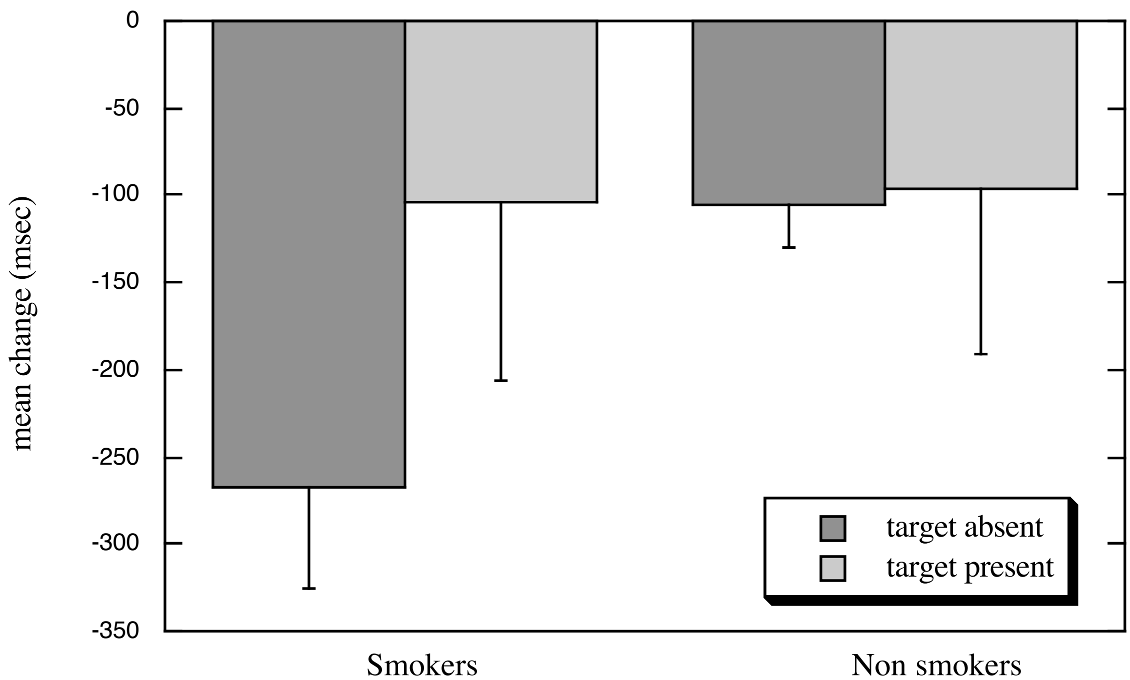
0
-50
-100
-150
-200
-250
-300
-350
mean change (msec)
target absent
target present
Smokers
Non smokers

Fig 2.

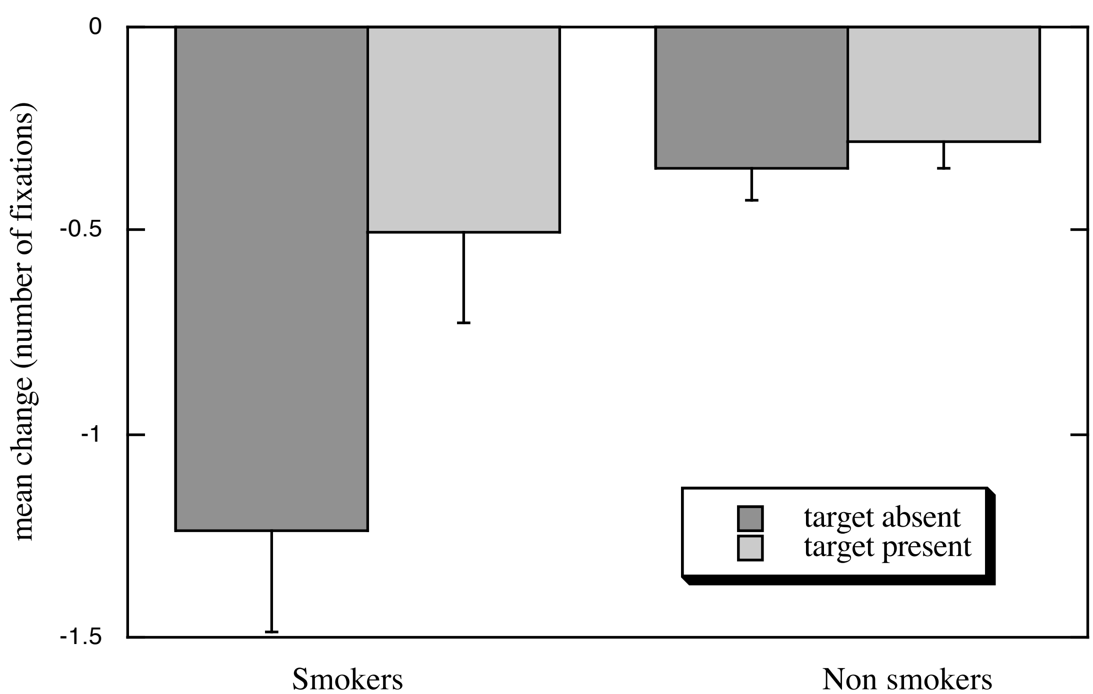
0
-0.5
-1
-1.5
mean change (number of fixations)
target absent
target present
Smokers
Non smokers

Fig. 3

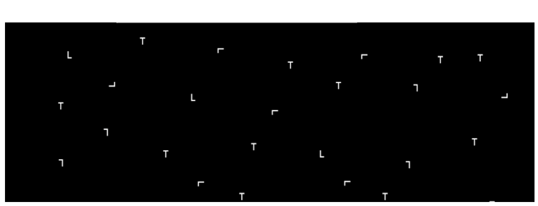

Fig. 4

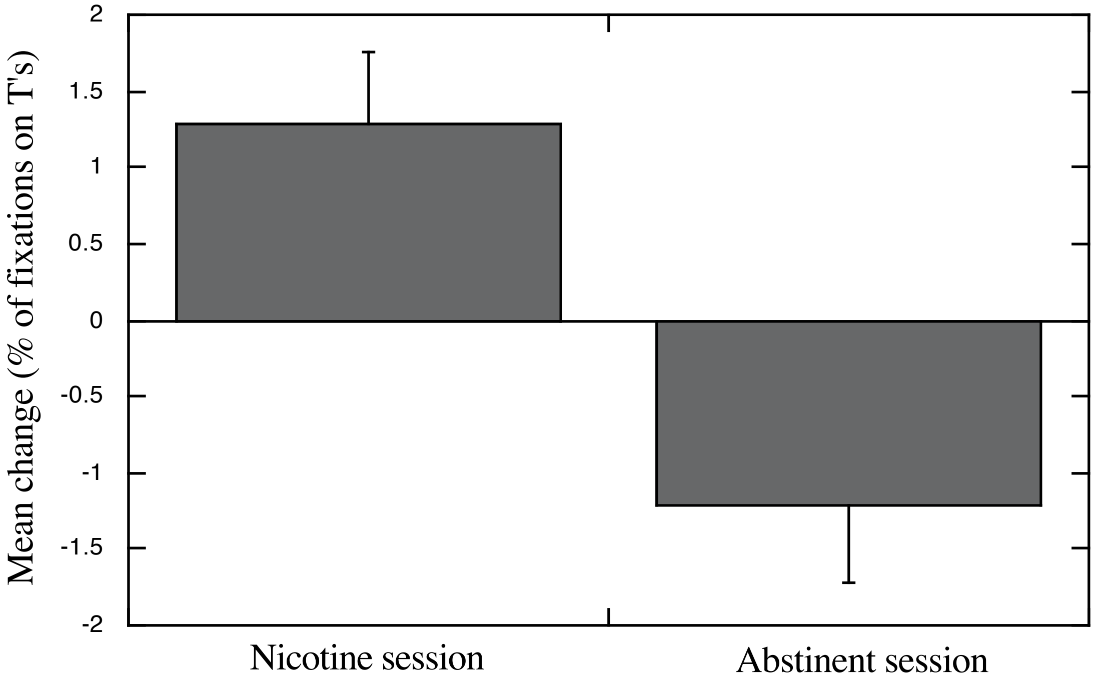
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Mean change (% of fixations on T's)
Nicotine session
Abstinent session

Fig. 5

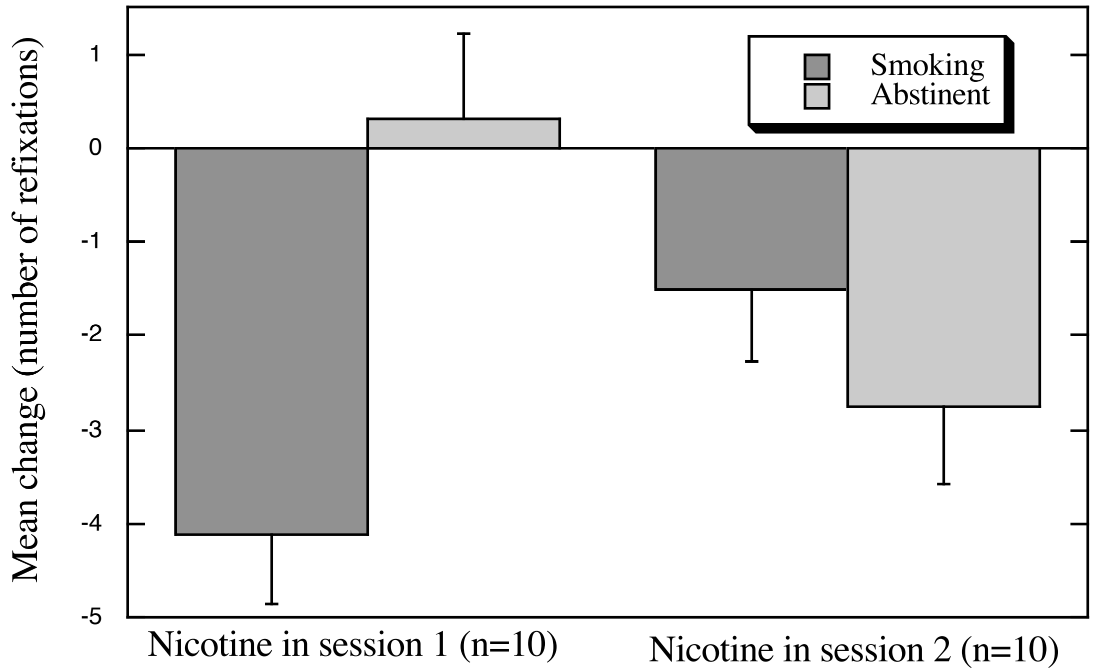
Mean change (number of refixations)
1
0
-1
-2
-3
-4
-5
Smoking
Abstinent
Nicotine in session 1 (n=10)
Nicotine in session 2 (n=10)

Fig. 6a

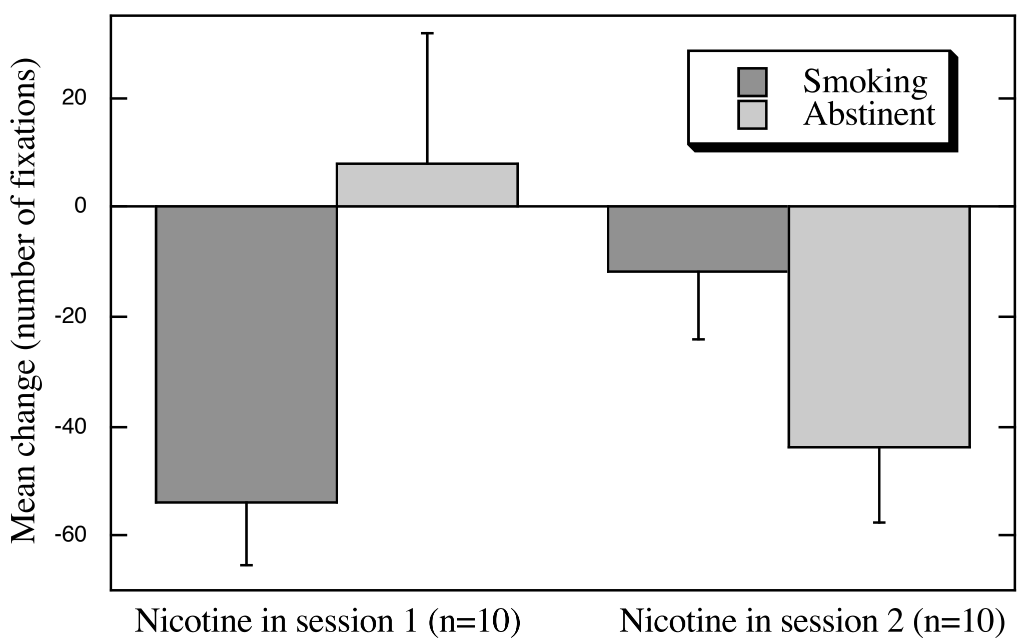
Mean change (number of fixations)
20
0
-20
-40
-60
Smoking
Abstinent
Nicotine in session 1 (n=10)
Nicotine in session 2 (n=10)

Fig. 6b

List of Tables

	Smokers				non-smokers			
	RT(msec)	NF	FD(msec)	SA	RT(msec)	NF	FD(msec)	SA
Pop-out	1196	4.67	252	8.47*	1107	4.19	236	9.59*
	(297)	(1.18)	(40.69)	(0.97)	(215)	(0.80)	(47.28)	(1.31)
Serial	3658	16.57+	197	6.26+	3273	14.31+	187	6.91+
	(968)	(4.65)	(30.74)	(1.06)	(728)	(2.91)	(23.09)	(1.18)

Table 1. Mean (s.d.) scores for baseline data from smokers (n=19) and non-smokers (n=20) collapsed across setsize and target absent/target present manipulations. RT = reaction time, NF = number of fixations, FD = fixation duration, SA = saccade amplitude.
*p <0.05
+ 0.1>p>0.05

	Reaction Time			Number of Fixations		
	All	Target Absent	Target Present	All	Target Absent	Target present
Post1 - baseline	-100.48 (174.96)	-116.50 (290.79)	-84.47 (87.13)	-0.43 (0.69)	-0.57 (1.23)	-0.28 (0.34)
Post2 - baseline	-183.44 (169.28)	-249.80 (281.47)	-117.09 (95.34)	-0.75 (0.70)	-1.15 (1.23)	-0.34 (0.38)

Table 2. Mean (s.d.) change from baseline in reaction times and number of fixations on the pop-out search for all participants (n=39).

		Reaction Time	Number of Fixations
Post1-baseline		-266.94 (311.01)	-1.54 (1.77)
Post2 - baseline		-516.37 (445.41)	-2.36 (2.06)
Target Absent		-544.93 (479.76)	-2.66 (2.29)
Target Present		-238.38 (317.99)	-1.25 (1.70)
	12	-205.29 (216.51)	-1.05 (1.04)
Setsize	24	-420.81 (410.45)	-1.99 (1.91)
	48	-548.86 (641.49)	-2.82 (3.63)

Table 3. Mean (S.D.) change from baseline in reaction times and number of fixations on the serial search for all participants (n=39).

	Completion Time (msec)	No. of refixations	% of T's clicked	No. of reclicks on T's	T's clicked on 2nd fixation	T's clicked on 1st & not other fixations	% of fixations on T's	Total no. of fixations made
Baseline 1	37.17* (6.53)	13.09* (5.29)	83.8* (0.0062)	1.26* (0.90)	1.11 (0.99)	2.52* (1.43)	58.84+ (4.65)	553.1+ (96.86)
Baseline 2	34.63* (5.78)	8.88* (3.89)	89.6* (0.0056)	0.97* (0.75)	0.99 (0.61)	1.54* (0.79)	60.28+ (4.49)	493.3+ (86.20)

Table 4. Mean (s.d.) scores for baseline test 1 and baseline test 2 for all participants(n=20).

*p <0.05

+ 0.1>p>0.05