Psychopharmacology (1989) 99:393–396

Psychopharmacology

Smoking and human information processing

Rachel X.A. Petrie and Ian J. Deary
Department of Psychology, University of Edinburgh, 7, George Square, Edinburgh EH8 9JZ, UK

Abstract. There is much evidence which indicates that smoking improves various aspects of human information processing (Wesnes 1987). The aim of the present study was to elucidate the stages of human information processing which are improved after cigarette smoking. Twelve regular smokers were tested on three cognitive tasks using a repeated measures design. Tasks used were: rapid visual information processing (RVIP), digit symbol substitution (DSST), and inspection time (IT). Performance parameters derived from these were intended to index different stages of the information processing sequence. Only those measures which involved a motor component were improved after smoking: response time on the RVIP task ($P<0.025$) and DSST performance ($P<0.1$). These findings suggest that central cholinergic pathways are involved in the late, response-related stages of the processing sequence.

Key words: Cigarette smoking – Nicotine – Cholinergic pathways – Information processing – Reaction time – Inspection time

Clinical and experimental evidence supports the view that central cholinergic pathways are involved in memory formation and in the efficient processing of information (Kopelman 1987; Broks et al. 1988). However, since most studies use cognitive tests which require the participation of many mental processes, it is not clear precisely which of these are supported by cholinergic neurones. For instance, even a simple reaction time task involves stimulus encoding, decision making and response execution, and an impairment of any of these processes will result in a longer reaction time. It is preferable, therefore, to examine manipulations of cholinergic activity using more analytical tests of cognitive functioning (Sanders 1983; Broadbent 1984) where individual processing stages may be either inferred or indexed directly. The present study attempts to define those processing stages which are improved by the cholinergic agonist, nicotine. However, it should be made clear that the definition of information processing stages is problematic and, at best, approximate (see, for example, Chiang and Atkinson 1976; Jensen 1987).

Nicotine, often taken in the form of cigarette smoking, either improves performance in, or reduces the effects of fatigue in, vigilance tests, (Mangan and Golding 1978), reaction time tests (Frankenhaeuser et al. 1971; Myrsten et al. 1972) and in letter cancellation tests (Williams 1980). A series of studies by Wesnes, Warburton and colleagues (see Wesnes 1987, for a detailed account) investigated the information processing enhancing effects of nicotine in more detail, using signal detection theory to derive their parameters. Wesnes, Warburton and Matz (1983) showed that nicotine prevented the decline of stimulus sensitivity in the Mackworth Clock Test, while having no effect on response bias. They concluded that "ascending reticular cholinergic pathways, by controlling electrocortical arousal, determine the efficiency of stimulus selection aspects of information processing."

In subsequent experiments they used a test of rapid visual information processing (RVIP) (Wesnes and Warburton 1983). This involves responding to target sequences of three consecutive odd or even numbers in a series of digits being presented at a fast rate on a computer screen. Smoking increased speed of response and the number of targets correctly identified. For the first time an actual improvement in performance was shown with nicotine, as opposed to a reduction in the impairment which occurs over time in the placebo condition (Wesnes and Warburton 1984a). High nicotine cigarettes improved performance most. Further work showed that nicotine improved both the detection of targets on the RVIP task, and the response time (Wesnes and Warburton 1984a, b).

Three indices are recorded in the RVIP task: the number of target "hits", the number of "false alarms" and the response times. Performance success on each of these measures depends on the efficiency of several complex mental operations and their inter-relations. The task may be described as involving: the encoding of rapidly presented stimuli; comparing recent stimuli to a "rule" held in working memory (i.e., "look for three consecutive odd or even numbers"); making a decision about whether a target triplet has been detected; and effecting a response.

It is of interest to discover whether performance changes on the RVIP task are accompanied by changes in psychophysical parameters of perceptual efficiency. The present study employs the RVIP task, a psychophysical measure of stimulus encoding speed (inspection time) and a psychometric test (digit symbol substitution – which involves encoding, decision-making and response speed) to discover whether stimulus encoding or response-related stages of information processing are affected by nicotine.

Offprint requests to: I.J. Deary

Materials and method

Subjects

Twelve regular smokers (six males, six females) took part in the study. Their mean age was 20 years, 4 months (SD 1 year, 3 months; range 18–23 years).

Tests

All subjects performed these in the same order.

Rapid visual information processing (RVIP). In this test a series of digits is displayed at a rate of 100 per min on a computer monitor. The subject is required to press a response bar as quickly as possible on detecting three consecutive odd or even numbers. Eight target triplets appear in each minute of this 10-min task. Three variables are derived from this test: the number of correctly detected triplets (hits); the number of responses made when a triplet was not present (false alarms); and the average response time (RT). The RVIP test was run on a BBC Master microcomputer.

Digit symbol substitution test (DSST). This is a subtest of the Wechsler Adult Intelligence Scale (WAIS; Wechsler 1955). It is used widely in psychopharmacology (see Hindmarch and Stonier 1987). The task involves substituting abstract letter-like characters for numbers, according to a given code. The measure taken is the number of correct substitutions in 90 s. This test was administered exactly as described in the WAIS manual.

Inspection time (IT). This is a psychophysical measure of perceptual intake speed (Vickers et al. 1972; Vickers and Smith 1986) which estimates the rate of transfer of information from sensory stores to short term memory (Nettelbeck 1987; Zhang et al. 1989). The stimuli for the test are presented on a light emitting diode (LED) display and consist of two parallel, vertical lines. One stimulus line is 4.8 cm, the other is 2.4 cm and they are 2.4 cm apart. The stimulus lines are backward masked immediately after exposure using two parallel 6 cm lines which obliterate them. Subjects sit at a distance of 150 cm and their task is to indicate, by means of thumb presses held in each hand, which of the stimulus lines (left or right) was longer. Responses are made at leisure, since only the correctness of the response was recorded, not the response time. Stimulus exposure times are varied using the PEST adaptive staircase algorithm (Taylor and Creelman 1967) which searches for the exposure duration at which the subject is 85% correct in responding. This is called the inspection time (IT). Starting stimulus duration is 200 ms, and the first step and stopping step sizes are 75 ms and 1 ms, respectively. A minimum of five trials is presented at each duration. Rather than completing a set number of trials, subjects are stopped on the task using a reliability criterion. Therefore, the duration of the IT task is variable (about 15–20 min), the average number of trials per session being about 100. The IT test was run on a BBC Master microcomputer which drove the LED stimulus presentation device.

Design and procedure

A within subjects design was used. Subjects did not smoke or consume caffeine or alcohol from 11 p.m. on the evenings prior to testing. All testing sessions took place in the morning to eliminate possible time-of-day effects.

The order of the conditions (smoking and non-smoking) was counterbalanced. A particular brand of cigarettes was used throughout the experiment. These have a relatively high nicotine content and were the usual brand for the majority of the subjects. Brain nicotine half-life is short (about 10–15 min) and the plasma concentration peak coincides with finishing a cigarette. The entire session lasted about 20–25 min after smoking. Therefore, in order to ensure that nicotine levels were maintained throughout the session subjects smoked one cigarette immediately before beginning the RVIP task and a second before the IT task.

Results

Table 1 shows the means and standard deviations for the five dependent variables in both conditions. Two-way ANOVA for repeated measures was used to analyse the data for the effects of smoking and of order (smoking – non-smoking and non-smoking – smoking). The ANOVA results are presented in Table 2. There was an improvement in RVIP response time after smoking ($P=0.028$). There was a trend toward an improvement in DSST performance after smoking ($P=0.091$). Smoking had no effect on the other dependent variables and there were no significant order effects on any of the dependent variables. There were significant treatment (smoking or non-smoking) – order interactions for Hits on the RVIP task ($P<0.001$) and for RVIP reaction times ($P=0.028$), and there was a trend toward this interaction for IT duration ($P=0.06$). These interactions appear to be due to practice effects.

Wesnes (1987) has shown that the analysis of 10-min blocks of RVIP performance may be too crude and that more subtle changes in performance may take place within each 10-min period. Therefore, minute-by-minute analysis of RVIP task performance was carried out. The graphs (Figs. 1 and 2) show that both of the accuracy parameters (hits and false alarms) show little performance change over time or between smoking and non-smoking conditions. However, the response times (Fig. 3) show that the smoking condition improved responses mainly in the first 5 min of the task. In order to analyse this in more detail, smoking and non-smoking response times were calculated for each 5-min period of the RVIP task in each subject. In the first, but not in the second 5 min of the RVIP task there was a significant difference between the two drug conditions, with the smoking condition being faster ($t=2.88$, $df=11$, $P<0.02$, two-tailed).

Discussion

In the present experiment there were no significant changes after smoking in any of the parameters which indexed en-

Table 1. Means (SD) for the five performance parameters ($n=12$)

	Non-smoking	Smoking
DSST	70.1 (13.5)	74.4 (13.2)
IT(ms)	36.8 (11.2)	41.8 (14.6)
RVIP hits	4.92 (1.64)	5.15 (1.34)
RVIP false alarms	0.69 (0.78)	0.70 (0.88)
RVIP RT(ms)	510.3 (93.3)	485.5 (97.2)

Table 2. Results of two-way ANOVA (related) on performance parameters using smoking and order as factors ($n = 12$)

	Smoking			Order			Interaction		
	F	*df*	*P*	*F*	*df*	*P*	*F*	*df*	*P*
DSST	3.49	1,10	0.091	0.03	1,10	ns	0.68	1,10	ns
IT(ms)	1.77	1,10	ns	1.81	1,10	ns	4.47	1,10	0.06
RVIP hits	0.71	1,10	ns	0.17	1,10	ns	27.78	1,10	<0.001
RVIP false alarms	0.19	1,10	ns	1.09	1,10	ns	3.23	1,10	ns
RT(ms)	6.59	1,10	0.028	0.06	1,10	ns	6.61	1,10	0.028

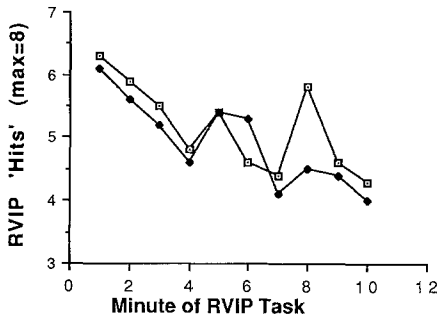

Fig. 1. Successful detection of target triplets in each minute of the RVIP task. *Open symbols:* smoking. *Shaded symbols:* non-smoking

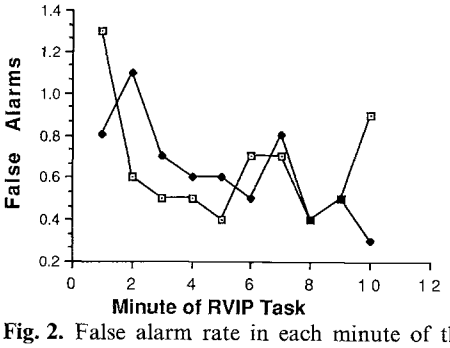

Fig. 2. False alarm rate in each minute of the RVIP task. *Open symbols:* smoking. *Shaded symbols:* non-smoking

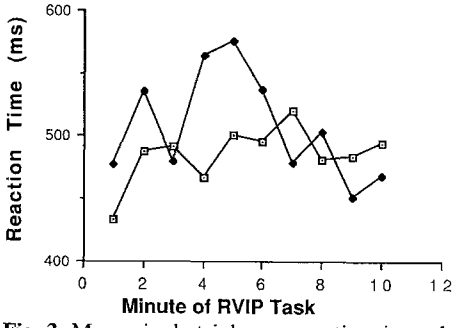

Fig. 3. Mean single trial response time in each minute of the RVIP task. *Open symbols:* smoking. *Closed symbols:* non-smoking

coding or decision making and which did not have a response component: IT, RVIP hits and RVIP false alarms. Only those performance parameters involving a response component were affected by smoking in this study, i.e. RVIP response time and DSST performance. In fact, there are very few previous studies which have demonstrated improvements in DSST performance (Wittenborn 1987). These results implicate brain cholinergic mechanisms in the later, response-related parts of the information processing sequence. However, we are not in a position to say whether cholinergic pathways are involved in response choice or initiation: more detailed reaction time parameters will be required. Since there was no effect of smoking on IT duration, we conclude that the RT and DSST improvements were not a result of improved encoding speed, although this assumes that IT provides a good model for the encoding process in other tasks.

Two findings in the present study require further discussion: the lack of an effect of smoking on RVIP hits and the fact that RT was improved during only the first 5 min of the RVIP task. The reasons may be statistical or due to the design of the present experiment, or a combination of both. It is not uncommon for studies to make Type II errors when the number of subjects is relatively small. Therefore, the finding that RVIP hits is not affected by smoking in this study may be added to the results of other studies to achieve a consensus. However, this is possible only when studies have similar designs. In the present study subjects were given little practice on the tasks (beyond a thorough explanation and short familiarisation) prior to testing. Instead of eliminating the effects of practice we controlled for them by using a counterbalanced design. On the one hand this may be seen as design fault, but on the other hand it mimics the real life situation where subjects meet novel performance tasks. Wesnes (1987) has argued that the effects of nicotine on the RVIP task should be investigated by using different task situations. In the present study it appears that smoking improves reaction time on the task when it is relatively novel.

After analysing performance on the RVIP task for each minute we discovered that smoking improved RT during only the first 5 min. This may be due to the rapid drop in body nicotine levels which take place after smoking. However, this is not in keeping with the finding that DSST performance tended to improve even after RVIP was completed or the fact that others have demonstrated prolonged advantages for smokers over non-smokers in the RVIP task.

Our finding that smoking improves RT compared with non-smoking in a novel complex task still leaves unanswered the question as to whether the improvement is absolute or whether it is an alleviation of a decrement which exists in deprived smokers. As Wesnes (1987) suggests with respect to many other details of RVIP task performance, the resolution of this possibility must await the results of further experiments.

Our findings are in agreement with a recent investigation into the relationships among smoking, intelligence and reaction time (Frearson et al. 1988). They demonstrated

that smoking significantly improves both choice reaction time and reaction time in their new "odd-man-out" paradigm. Faster reaction time and improved performance on tasks involving a motor component have been found in several other studies after smoking (Heimstra et al. 1967; Frankenhaeuser et al. 1971; Myrsten et al. 1972; and Williams 1980).

The problem of how nicotine produces these behavioural changes should be considered. The possibility that better psychomotor performance observed after smoking is caused not by cholinergic enhancement but by the increased motivation due solely to the act of smoking is excluded indirectly in the experiments carried out by Wesnes and Warburton, where nicotine significantly altered performance decrements when compared to placebo (either dextrose tablet or nicotine-free cigarette). The arousal modulation model states that people use nicotine to control their general level of arousal in order to perform optimally in a variety of situations (Mangan and Golding 1978). In support of this idea, Warburton (1981) has hypothesised that cholinergic activity alters electrocortical arousal and consequently produces changes in stimulus processing efficiency. Warburton's hypothesis is rather imprecise. In his terms arousal, attention, processing efficiency and speed of information intake seem almost synonymous. Although there is no generally accepted operational definition, far less a definitive test, of these terms, the approach taken in the present study gives a start to those wishing to tease out the contribution that cholinergic processes make to human information processing.

Acknowledgement. The authors wish to thank Professor D.M. Warburton for providing the computer programs for the Rapid Visual Information Processing Task.

References

Broadbent DE (1984) Performance and its measurement. Br J Clin Pharm [Suppl] 1:5–11

Broks P, Preston GC, Traub M, Poppleton P, Ward C, Stahl SM (1988) Modelling dementia: effects of scopolamine on memory and attention. Neuropsychologia 26:685–700

Chiang A, Atkinson RC (1976) Individual differences and interrelationships among a set of cognitive skills. Memory and Cognition 4:661–672

Frankenhaeuser M, Myrsten AL, Post B, Johansson G (1971) Behavioural and physiological effects of cigarette smoking in a monotonous situation. Psychopharmacologia 22:1–7

Frearson W, Barrett P, Eysenck HJ (1988) Intelligence, reaction time and the effects of smoking. Person Individ Diff 9:497–518

Heimstra NW, Bancroft NR, DeKock AR (1967) Effects of smoking upon sustained performance in a simulated driving task. Ann NY Acad Sci 142:295–307

Hindmarch I, Stonier PD (eds) (1987) Human psychopharmacology: measures and methods, vol 1. Wiley, Chichester

Jensen AR (1987) Process differences and individual differences in some cognitive tasks. Intelligence 11:107–136

Kopelman MD (1987) How far could the cholinergic depletion account for the memory deficits of Alzheimer-type dementia or the alcoholic Korsakoff syndrome? In: Stahl SM, Iversen SD, Goodman EC (eds) Cognitive neurochemistry. Oxford University Press, Oxford, pp 303–326

Mangan GL, Golding J (1978) An "enhancement" model of smoking maintenance. In: Thornton RE (ed) Smoking behaviour: physiological and psychological influences. Churchill Livingston, Edinburgh, pp 87–114

Myrsten A, Post B, Frankenhaeuser M, Johansson G (1972) Changes in behavioural and physiological activation induced by cigarette smoking in habitual smokers. Psychopharmacologia: 27:305–312

Nettelbeck T (1987) Inspection time and intelligence. In: Vernon PA (ed) Speed of information processing and intelligence. Ablex, New Jersey, pp 295–346

Sanders AF (1983) Towards a model of stress and human performance. Acta Psychol 53:61–97

Taylor MM, Creelman CD (1967) PEST: efficient estimates on probability functions. J Acoust Soc Am 4:782–787

Vickers D, Smith PL (1986) The rationale for the inspection time index. Person Individ Diff 7:609–624

Vickers D, Nettelbeck T, Willson RJ (1972) Perceptual indices of performance: the measurement of "inspection time" and "noise" in the visual system. Perception 1:263–295

Warburton DM (1981) The neurochemistry of behaviour. Br Med Bull 37:121–125

Wechsler D (1955) Manual for the Wechsler Adult Intelligence Scale (WAIS). Psychological Corporation, New York

Wesnes K (1987) Nicotine increases mental efficiency: but how? In: Martin RW, Van Loon GR, Iwamoto ET, Davis L (eds) Tobacco smoking and nicotine: a neurobiological approach. Plenum Press, New York, pp 63–80

Wesnes K, Warburton DM (1983) The effect of smoking on rapid visual information processing performance. Neuropsychobiology 9:223–229

Wesnes K, Warburton DM (1984a) Effects of cigarettes of varying yield on rapid visual information processing performance. Psychopharmacology 82:338–342

Wesnes K, Warburton DM (1984b) Effects of scopolamine and nicotine on human rapid information processing performance. Psychopharmacology 82:147–150

Wesnes K, Warburton DM, Matz B (1983) The effects of nicotine on stimulus sensitivity and response bias in a visual vigilance task. Neuropsychobiology 9:41–44

Williams DG (1980) Effects of cigarette smoking on immediate memory and performance in different kinds of smokers. Br J Psychol 71:83–90

Wittenborn JR (1987) Psychomotor tests in psychopharmacology. In: Hindmarch I, Stonier PD (eds) Human psychopharmacology: measures and methods, vol 1. Wiley, Chichester

Zhang Y, Caryl PG, Deary IJ (1989) Evoked potential correlates of inspection time. Person Individ Diff 10:379–384

Received October 6, 1988 / Final version May 30, 1989