Psychopharmacology (1991) 104:536–540
003331589100158E

Psychopharmacology

Effects of nicotine gum on repeated administration of the Stroop test

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Received November 1, 1990 / Final version January 25, 1991

Abstract. Using a double-blind procedure, 24 non-smoking subjects chewed either 2 mg nicorette® gum or a placebo for 20 min, before completing a Stroop test on three occasions. Colour-word reading and simple colour naming times were consistent across repeats, and were unaffected by nicotine. However, the time taken to name the colour of incongruous colour word stimuli declined across trials. This increase in speed across repeats was significantly greater in those subjects who had received nicotine. These data are consistent with previous reports of a decreased Stroop effect following nicotine administration, but are not compatible with a simple model which assumes that nicotine alters the way in which information is filtered by selective attentional mechanisms. The present results can be explained by postulating that nicotine influences either the rate at which colour naming become more automatic, or changes the way in which resources are allocated to non-automatic processes.

Key words: Nicotine – Attention – Stroop test – Automatic processes – Resource allocation

Smokers often report that one of the reasons they smoke is because it helps their thinking and aids concentration (Warburton and Wesnes 1984). In an influential series of papers, Warburton and Wesnes (Wesnes and Warburton 1978, 1983; Warburton and Wesnes 1984) have argued that nicotine does indeed enhance performance in a variety of simple cognitive tasks. Early evidence for this notion was obtained in experiments with smokers and is thus ambiguous, because nicotine may merely have been restoring performance in subjects who were initially deficient. However, this evidence has been bolstered by comparable data obtained when nicotine-naive subjects consume nicotine in pill or gum form. Such experiments have demonstrated that nicotine increases speed and accuracy in vigilance and rapid information processing tasks (Wesnes and Warburton 1978, 1983), reduces the threshold for critical flicker and two flash fusion (Warwick and Eysenck 1968), and reduces colour naming times in the Stroop test (Wesnes and Warburton 1978, 1983). Warburton and Wesnes (1984) have argued that these results indicate a beneficial effect of nicotine upon selective attention, probably taking place through its impact on central cholinergic pathways in the reticular activating system.

One of the difficulties in assessing Warburton's claims is that most of the evidence is compatible with a general stimulant effect of nicotine on arousal, but does not conclusively demonstrate a specific influence of nicotine on selective attention. For example, the evidence concerning vigilance and information processing performance consists of demonstrations that nicotine arrests the decline in performance which normally occurs across time in these tasks (Wesnes and Warburton 1978, 1983). It is thus possible that nicotine is acting as a stimulant (see, for example, Wolkowitz et al. 1985b), enabling subjects to maintain concentration in what is an otherwise monotonous task. This may well constitute a benefit to cognitive functioning, but it should be distinguished from the claim that nicotine produces selective enhancements in the subject's ability to attend to particular categories of information.

Wesnes and Warburton's (1978) evidence for the influence of nicotine in the Stroop task is important, because it seems to provide the least ambiguous test of nicotine's influence on selective attention. In the Stroop test (Stroop 1935) subjects are asked to name the colour of ink in which colour-words are printed (for example the word "red" in green ink). Subjects are much slower in this task if the ink colour and the word are incongruous, than if the word is either not colour-related or is meaningless (for example "XXXX"). The difference between the time

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taken to name the colour of meaningless stimuli (task "C") and the incongruent colour-words (task "CW") is called the Stroop effect. Wesnes and Warburton (1978) found that the size of the Stroop effect was reduced following consumption of either a 1 or 2 mg nicotine pill. They interpreted these data to indicate that subjects were better able to ignore the irrelevant semantic information, and concentrate on the colour information in the task following nicotine consumption, as anticipated by the notion that nicotine has an impact upon selective attention in other cognitive tasks.

Although the precise mechanisms responsible for the Stroop effect remains a source of debate (Morton and Chambers 1973; Kahneman and Chajczyk 1983; Dunbar and MacLeod 1984; MacLeod and Dunbar 1988) an absolute change in the size of the Stroop effect does seem to indicate a rather precise influence of nicotine on selective attention. As such, Wesnes and Warburton's data constitute strong evidence in favour of the attentional hypothesis. However, a close reading of a subsequent description of their experiment (Wesnes and Warburton 1983) indicates a possible difficulty for this interpretation. Wesnes and Warburton (1983) indicate that the difference between the nicotine and placebo conditions was not significant on the first block of test trials, but that this difference only became significant on a second block of 200 test stimuli. These data are thus similar to those reported for vigilance and information processing in that the effect of nicotine emerged across repeated testing occasions. The Stroop test is, like vigilance performance, subject to fatigue, and is stressful to the subject (Tulen et al. 1989). It is therefore possible to postulate that the improvement in performance following nicotine could be a result of its stimulant properties maintaining performance on all components of the Stroop test at an optimal level for longer than would be the case following a placebo.

There is very little other information available concerning the effect of nicotine on the Stroop test. Suter et al. (1983) found smoking to have no effect in a Stroop test. Interestingly, their procedure involved presentation of only 45 stimuli, in well spaced blocks of 15 trials. This entire procedure was repeated on three occasions, each a week apart, which would have limited fatigue and reduced the effect which a stimulant might have on performance. Wesnes and Revell (1984) examined the influence of nicotine on the Stroop effect, following a rapid information processing task. Although they found no direct influence of nicotine on the Stroop effect, over 2 h elapsed between nicotine consumption and Stroop testing in this experiment, which would have limited the degree to which nicotine could have been expected to produce an effect. The present experiment was therefore designed to provide further evidence concerning the influence of nicotine across repeated administrations of the Stroop test.

Materials and methods

Subjects. Of the 24 subjects in this experiment, 17 were first year psychology students at the Australian National University (6 males; 11 females) who participated on a voluntary basis and received 1% credit towards their course result. The remaining seven subjects were volunteers from a nearby research institution (six males; one female). The mean age of the subjects was 25.1 years, with a range of 18–49 years. Subjects gave informed consent prior to participating in the experiment, which excluded any person who was using prescription drugs or who had any of the contraindicated conditions for nicotine use such as pregnancy, breast feeding or a history of cardiovascular disease. The consent form indicated that they might receive caffeine, nicotine or a placebo. All subjects were currently non-smokers, and none had ever been a regular user of cigarettes. They were required not to eat, or to drink tea, coffee or other caffeine containing products, for 2 h prior to testing.

Apparatus. The Stroop test materials (C.H. Stoelting Co) comprised three sheets of white A4 paper, one for each separate condition of the test. The overall layout of the 100 randomly ordered stimuli on each sheet was identical, with five columns of 20 stimuli. Sheet 1 had columns of colour words written in black ink (condition W); sheet 2 had columns of XXXX's written in different coloured inks (condition C); and sheet 3 had columns of colour words written in different colour inks, where the colour word and the ink it was written in were never the same (condition CW). Three colours/colour words were used: "red", "green" and "blue".

Procedure. Subjects were assigned double blind to the placebo or nicotine condition. After completing the informed consent, each subject was given a piece of gum to chew. The gum was either 2 mg nicorette® gum, or a placebo provided by the Glaxo Pharmaceutical Company, Melbourne. The Glaxo prescribing instructions were followed, and subjects were required to chew the gum for 10 s every 30 s for 20 min to allow for maximum blood sera levels of nicotine to be attained through the buccal mucosa (see Pickworth et al. 1986). During the chewing period, subjects sat quietly reading magazines until testing commenced.

The Stroop test employed consisted of three components. In the word test (W), subjects were asked to read the words written on the sheets, beginning at the top left hand corner of the page and proceeding down the columns. In the colour naming (C) and incongruent colour/word naming test (CW), they were asked to name the colour, again starting at the top left hand corner and proceeding down the columns. Subjects were instructed in each condition to give their verbal responses to the task as quickly and as accurately as possible. Each task was preceded by the experimenter saying "let's go" and each test terminated with the end of the list. In a pilot experiment using this procedure no subject made more than two uncorrected errors in a single repeat of the three components of the Stroop test. Since corrected errors contribute to the time taken in the task, a speed/accuracy trade-off is unlikely to have been possible. Errors were therefore not recorded in this experiment, and subjects were not interrupted when errors were made.

Following consumption of the gum the subjects completed three repeats of the three components of the Stroop. The order of presentation of the nine tests (three repeats by three components) was partially counterbalanced across subjects by selecting six possible orders at random, and repeating them twice within each group. The two groups were thus matched for any order effects, and the order of tests within each repeat would have been random for any subject. The three components of each repeat of the Stroop test were completed in approximately 5 min. The subjects were allowed to rest for 30 s after each repeat of the three components was completed.

Statistical analysis. Separate two-way (groups × repeats) trend analyses were conducted on each of the three components of the Stroop test. The multivariate model (O'Brien and Kaiser 1985) was adopted in each of these analyses because repeated measures designs such as this commonly violate the assumptions of sphericity and compound symmetry made in a conventional repeated measures ANOVA. A decision-wise error rate procedure was adopted, with

all decisions being made at $\alpha = 0.05$, in order to maintain compatibility with Wesnes and Warburton's (1978) analysis.

Results

The mean times taken by the two groups to perform the three components, W, C, and CW, over the three trials are depicted in Fig. 1. It is clear from this figure that a Stroop effect was obtained in both groups on every trial, with the difference between condition C and CW ranging between 28 and 39%. Figure 1 also shows that performance in condition W and C was stable across repeats. There was no evidence for any change in the time taken for these conditions [largest $F(1,22) = 2.3$, $P > 0.05$] across trials. There was also no evidence for any difference between the nicotine and control group in condition W [$F(1,22) = 0.1$, $P > 0.05$] or C [$F(1,22) = 0.3$, $P > 0.05$]. However Fig. 1 reveals two significant effects taking place in the CW condition. Firstly, there is a decline in naming times in both groups across trials, which has a significant linear [$F(1,22) = 59.2$, $P < 0.001$] and quadratic [$F(1,22) = 14.7$, $P < 0.01$] component. Secondly, and more importantly, there was a significant interaction between the treatment conditions and trials [$F(2,44) = 4.5$, $P = 0.017$]. This interaction was due to the linear rate of decline being greater in the group which had received nicotine than in the control [$F(1,22) = 7.3$, $P = 0.013$]. The faster decline in CW times following nicotine consumption resulted in the mean time taken for the nicotine group being below that for the control on the third testing occasion. This difference was not significant according to a simple t-test [$t(22) = 1.2$, $P > 0.05$], but this failure is most reasonably attributed to the use of a between groups design in the present experiment, rather than the within-subjects procedure employed by Wesnes and Warburton. Indeed, if the difference between C and CW (CW–C) is taken as a measure of the Stroop effect, the size of effect obtained here on the final trial (a difference of 4.8 s between the nicotine and placebo groups, over 100 stimuli) is slightly larger than that obtained by Wesnes and Warburton (1978) (approximately 6 s over 200 stimuli).

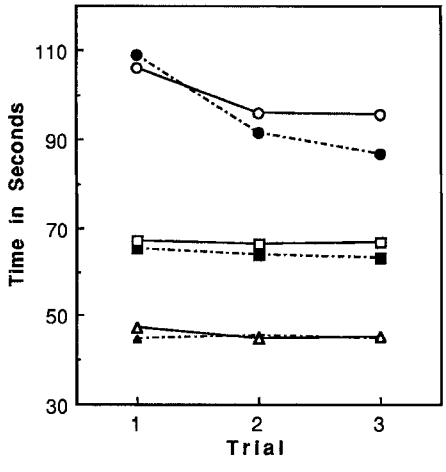

Fig. 1. Time taken to complete the three components of the Stroop test on the three testing occasions. *Triangles:* task W. *Squares:* task C. *Circles:* task CW. *Unfilled symbols:* placebo group. *Filled symbols:* nicotine group

Discussion

The results of the present experiment provide a confirmation of the data obtained by Wesnes and Warburton (1978, 1983). They reported that nicotine reduced the time taken to name the colour of incongruous colour-words, but that this result was significant only on the second block of 200 test stimuli. In the present experiment nicotine resulted in a sharper drop in the time taken in the CW task across three blocks of 100 stimuli, although there was no evidence for any influence of nicotine on the first test trial. There was no evidence for any difference between subjects which had received nicotine and those that received a placebo on either of the other two components of the Stroop test, nor was there any evidence for a change in performance across repeats of these tests. It seems clear, then, that nicotine has a selective effect on the colour naming times for incongruous colour-word pairs, which emerges across repeated administrations of this task.

Despite the fact that nicotine's influence depends upon repeated administration of the Stroop test, the results of this experiment are not compatible with an explanation based upon its capacity to reduce fatigue. Indeed, there was little evidence for the decline in performance across repeats which might have indicated that fatigue was an important factor in the task. It is of course possible that fatigue was present, but that a second process, responsible for the decline in times on the CW task, was also present, and that the resultant performance was the net result of these two opposing pressures. If this were true, it would still be possible to maintain a simple arousal account for the effect of nicotine. However, there was also no change in performance of the other components of the Stroop test, which might have been anticipated if fatigue was a potent factor in this situation. More convincing evidence might be obtained by replicating these data in a situation in which the potential for fatigue is reduced.

However, an arousal explanation for nicotine's effect in this experiment cannot be entirely excluded. It is possible that nicotine has acted as a stimulant, resulting in a general increase in speed across all tasks, with the failure to see evidence for such an influence in the W and C tasks being ascribed to a floor effect. This argument is difficult to eliminate, given the present experimental design. One means of addressing the problem could be to assess word reading and colour naming in a situation where the floor effect is reduced, for example by presenting stimuli closer to sensory thresholds, or by making the colour discriminations more difficult. Alternatively, this argument would be countered if a drug could be found which produced faster colour naming times in both the CW and C condition. It is of interest to note in this context that caffeine, a stimulant, was found to increase the size of a numerical version of the Stroop effect (Foreman et al.

1989). This effect could have been partly due to a reduction in the time taken to respond to the non-Stroop stimuli, as well as an increase in the time taken on the Stroop stimuli, as caffeine has been shown to improve performance in simple reaction time tasks (cf Foreman et al. 1989). As Foreman et al. point out, an examination of the influence of caffeine on the conventional Stroop test could be of some interest.

Wesnes and Warburton (1978) interpreted their evidence to indicate that nicotine improves selective attention, thus allowing their subjects to ignore the irrelevant semantic information provided by reading the coloured word in the CW task. Their model of selective attention is an early-stage filter, which seems incompatible with the results obtained here, as well as with psychophysiological evidence (see, for example, Duncan-Johnson and Kopell 1981). If nicotine modulates selective attention in the way suggested by Wesnes and Warburton, it could reasonably be expected to do so on the first testing occasion. The experiment described here indicates clearly that nicotine has an effect only after the testing procedure has been repeated. The only way that this could be explained by a simple filter model would be if the peak dose of nicotine was not reached until the third testing occasion. However, Ashton and Stepney (1982) indicate that blood levels of nicotine start to decline immediately following termination of chewing, making this possibility unlikely.

One popular explanation of the Stroop effect is known as the "horse-race" theory (Dunbar and MacLeod 1984). According to this account, interference in the CW task comes about because the word meaning is processed more rapidly than the colour naming task. This results in false information being available at a limited capacity response buffer before the information from the colour naming task, and this response competition slows down performance. According to the horse-race model, anything that slows down semantic access in the word-reading process will reduce the size of the Stroop effect. The simplest way in which word-reading can be suppressed is through deliberate strategies employed by the subject to reduce their capacity to detect the words. Squinting, deaccommodation and rhythmic arrangements of the stimuli are strategies that have been noted by others (Jensen and Rohwer 1964; Logan and Zbrodoff 1979), and subjects in the present experiment confirmed that they had tried to develop ways of doing the task so it was less confusing. However, it is difficult to see how nicotine might have interacted with these strategies to further enhance their effect. Alternatively, detection of the colour-words may be unaltered across trials, but their capacity to trigger lexical access may be reduced. The influence of nicotine could then be explained by reference to its deleterious effects on memory (Dunne et al. 1986). However, since there was no change in word reading times across trials, nor any effect of nicotine on this task, this explanation seems implausible.

Alternatively, "modified automaticity" accounts of the Stroop effect stress the degree to which word reading and colour naming gain control of automatic processes, rather than the speed with which the tasks are carried out (Posner and Snyder 1975). These models suggest that a continuum exists distinguishing automatic processes from those which demand considerable cognitive effort or resources. The reading of isolated words is considered to be an example of automatic processing, and is presumed to be rapid, independent of processing strategies, and therefore not reliant on cognitive resources. Effortful or controlled processing, such as colour naming, requires active use of strategies and cognitive resources, thus limiting the range of operations that can be performed at the same time (Wolkowitz et al. 1985a). This difference is, of course, one of degree since colour naming can become more automatic (MacLeod and Dunbar 1988), and word reading makes at least some demands upon cognitive resources (Kahneman and Treisman 1984). In this account, interference on the CW condition of the Stroop test occurs because the relatively more automatic process of word reading is difficult to suspend in favour of the controlled response of colour naming.

According to this modified automaticity theory, a reduction of the Stroop effect would occur if either colour naming became more automatic, or if there was a change in the resources allocated to the effortful process of colour naming. It seems unlikely that the change in performance on the CW condition can be explained by the colour naming process becoming more automatic, since MacLeod and Dunbar (1988) found that over 20 h of practice on the colour naming task was required for such an effect to become apparent. It therefore seems more likely that effortful processing has been selectively affected in the CW condition. The demonstration that subjects offered incentives to perform the CW task quickly are able to do so (MacKinnon et al. 1985) indicates that it is possible to reduce the impact of word reading under appropriate circumstances, although the mechanism by which this might take place remains mysterious.

In summary, the evidence presented here provides support for nicotine's influence on cognitive performance. It seems most likely that this effect is attentional, but the fact that it emerges across trials seems to suggest an influence on resource allocation, rather than sensory filtering. More compelling evidence concerning nicotine's influence on selective attention could perhaps be obtained in other experimental paradigms, such as dichotic listening or visual search, where attentional theories have traditionally been developed (Kahneman and Treisman 1984).

Acknowledgements. The authors would like to thank Michael Cook for his assistance and support, Nigel Bond for his helpful comments on this paper, and Glaxo Australia for supplying the placebo.

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