The Effects of Caffeine on the Development of Fatigue in a Prolonged Driving-Related Task

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ABSTRACT

A study was conducted to investigate the effects of caffeine (200 mg) on the performance of subjects on a prolonged three-way divided attention task which was designed to induce fatigue. Progressive development of fatigue occurred with time on-task and a dose of caffeine, equivalent to 2-3 cups of coffee, alleviated fatigue.

INTRODUCTION

In recent years, the vigorous application of counter-measures against drink-driving has resulted in a significant reduction in alcohol-related road crashes. In turn, this reduction has directed greater emphasis towards the second largest causal factor in road fatalities, fatigue (Haworth, 1990). The introduction of public awareness campaigns which aim to educate the public about driver fatigue and its subtle manifestations may also reduce road fatalities. These campaigns urge drivers to take frequent rest breaks and to drink coffee or other caffeine-containing beverages. Although there is little doubt that frequent rest breaks will delay the onset of fatigue (Lisper et al., 1986), scientific evidence supporting an additional role for caffeine is, at best, equivocal.

Previous studies have shown that caffeine, in doses similar to those delivered by normal amounts of caffeinated beverages, improved task performance (Kerr et al., 1991, Hasenfratz & Battig, 1992; Smith et al., 1994). It is interesting to note, however, that although many studies have examined the effects of fatigue on driving and of caffeine on psychomotor performance, little attention has been paid to the interaction of caffeine and fatigue on driving-related skills. The primary aim of this study was to determine whether a modest dose of caffeine (200 mg) was capable of delaying the onset and/or of ameliorating fatigue in a prolonged simulated driving situation.

METHODS

Subjects

Ten male and 10 female subjects were recruited for the study. Each group consisted of 5 young (< 23 y) and 5 older subjects (> 30 y). All subjects were moderate consumers of caffeine (mean = 175 mg/day), non-smokers and were not on any medication, other than oral contraceptives. Ethical approval for the study was obtained from the Ethics Review Committee of the Central Sydney Area Health Service.
Procedure

The subjects were tested on four occasions (3.00 pm), at least a week apart. They were asked not to consume any food for 4 h before testing and were thus essentially in the fasting condition. They were also asked to abstain from caffeine-containing products and alcoholic beverages on the day of testing. On arrival at the laboratory, subjects signed a consent form and completed questionnaires which detailed caffeine consumption, general health and previous medical history. The first two occasions enabled the subjects to become familiar with the tests but they also received caffeine (200 mg) or a placebo and, after 30 min, their cardiac inter-beat-interval (IBI) was monitored for 1 h in an unstressed and non-fatigued situation. Blood pressure and oral temperature were also measured before and after these 1 h sessions.

The third and fourth occasions were the fatigue test sessions. Here, systolic and diastolic blood pressure, oral temperature, heart rate and performance on a psychomotor test battery (digit symbol coding, divided attention, critical flicker fusion) and responses to questions (visual analogue scales) probing mood effects, were recorded before and after the test session. During the fatigue sessions, subjects were required to carry out a 3-way divided attention task (tracking, target detection, “emergency” reaction) for an uninterrupted period of 4 h. After 2 h, placebo or caffeine (200 mg) capsules (2) were given to the subjects and taken with water (60 ml). The final segment (120 min) of the task was then completed. The heart IBI was monitored continuously over the whole 4-hour period. A full description of the tests and cardiac monitoring/analysis can be found in Mascord et al. (in press).

Analysis of Results

All variables were analysed using a repeated measures analysis of variance. The within subject factors were treatment (placebo, caffeine), time (hours 1, 2, 3, 4 or pre-post fatigue session) and pre-post treatment (hours 1,2 -v- 3,4). The between subject factors were gender (male, female) and age (young, older).

RESULTS

Measurements During the Fatigue Trial

A reduction in tracking control over time occurred when subjects were given placebo, but after caffeine, their performance improved during the fourth hour of the fatigue trial (F 1,16 = 10.45; p < 0.01). No significant effects of age, gender, treatment or time were found for peripheral detection or the time to respond to the “emergency” light components of the task. After placebo, response times to the “emergency” light increased but there was a decrease in the final hour after caffeine.

Physiological Measurements During the Fatigue Trial

A highly significant (F 1,16 = 28.82; p < 0.001) reduction in heart rate over time was found. Caffeine had no effect on heart rate during the last two hours of the fatigue trial. Heart rate variability increased significantly (F 1,16 = 5.89; p < 0.05) after the placebo but decreased
after caffeine. Older subjects had significantly (F_{1,16} = 4.46; p < 0.05) lower heart rate variability than the younger subjects.

**Spectral Analysis of the Heart Rate**

The log power values of the temperature component (0.02 - 0.04 Hz) of the power spectra significantly (F_{1,16} = 5.04; p < 0.05) increased during the first 2h of the fatigue trial but, after administration of either the placebo and caffeine treatments, there was a reduction in the value of this component. The log power values were found to decrease in older subjects after both placebo and caffeine treatments but a decrease only occurred in younger subjects after caffeine (F_{1,16} = 8.42; p < 0.01). The log power values for both male and female subjects decreased over the last 2 h of the fatigue trial, but during the first 2 h, the log power values decreased in males and increased in females. This difference was significant (F_{1,16} = 8.07; p < 0.05).

An increase in the log power values of the blood pressure component (0.08 - 0.15 Hz) was found over the first 2 h of the fatigue trial. An increase in signal power for this frequency band is held to provide a reliable indicator of fatigue. The log power values remained elevated during the final 2 h of the trial when subjects received placebo, but fell after caffeine (F_{1,16} = 4.49; p < 0.05). The mean log power values of the blood pressure component were found to decrease in older subjects after both placebo and caffeine. In younger subjects, a decrease was noted after caffeine, but after placebo, there was a substantial increase (F_{1,16} = 6.28; p < 0.05). This could suggest that younger subjects are more susceptible to fatigue. The log power values for both male and female subjects increased over the first 2 h of the trial, confirming that fatigue had occurred, but during the final 2 h, the log power values increased for males but not for females (F_{1,16} = 6.98; p < 0.05).

The log power values for the respiration component (0.25 - 0.35 Hz) of the power spectra were found to increase significantly (F_{1,16} = 6.27; p < 0.05) during the fatigue trial. They remained elevated during the final hour in placebo- but not caffeine-treated subjects. Younger subjects exhibited a significantly (F_{1,16} = 6.10; p < 0.05) greater increase in spectral power for the respiration component over time than older subjects.

**Physiological Measurements Before and After the Fatigue Trial**

A highly significant reduction in mean heart rate (F_{1,16} = 19.63; p < 0.001) was found for all subjects after the fatigue trial. A significant age by treatment by time interaction was found for both systolic (F_{1,16} = 5.28; p < 0.05) and diastolic blood pressure (F_{1,16} = 6.70; p < 0.05). In younger subjects given placebo, systolic and diastolic blood pressure were both lower after the fatigue trial but were increased after caffeine. In the older subjects, systolic and diastolic blood pressure were increased at the end of the trial, irrespective of treatment. A highly significant reduction in mean oral temperature (F_{1,16} = 32.03; p < 0.001) occurred in all subjects after the fatigue trial.
Psychomotor Measurements Before and After the Fatigue Trial

A highly significant ($F_{1,16} = 17.21; p < 0.001$) reduction in tracking control on the divided attention task was noted after the fatigue trial. A significant age by time interaction ($F_{1,16} = 4.69; p < 0.05$) revealed that the older subjects had poorer tracking control than the younger subjects. Overall, the tracking performance of the females was significantly worse than that of the males ($F_{1,16} = 4.73; p < 0.05$). No significant treatment effect was found for tracking control. However, reaction time on the peripheral component of the divided attention task was found to increase significantly ($F_{1,16} = 14.08; p < 0.01$) after placebo and to decrease after caffeine. An increase in reaction time on the digit symbol coding task was found at the end of the fatigue trial although the difference just failed to reach significance ($F_{1,16} = 3.36; p = 0.082$). Older subjects were found to be significantly ($F_{1,16} = 13.12; p < 0.01$) slower than younger subjects on this task, but this was not related to drug treatment. There was a significant reduction in critical flicker fusion frequency ($F_{1,16} = 13.70; p < 0.01$) at the end of the trial. A significant age by treatment by time interaction ($F_{1,16} = 5.01; p < 0.05$) revealed that older subjects had a greater reduction in critical flicker fusion frequency after placebo (1.98 Hz) than after caffeine (1.28 Hz), whereas the reverse was true in younger subjects (1.71 Hz after caffeine; 0.73 Hz after placebo).

Effects on Mood

Although significant reductions in subjective feelings of alertness, coordination, concentration and willingness to drive a motor vehicle were found at the end of the fatigue session, no significant separation between caffeine and placebo treatments was identified.

DISCUSSION

This study was aimed primarily at exploring the nature of the interaction between fatigue and caffeine on driving-related skills. When the heart rates of the subjects were monitored for 1 h in a non-fatigued, non-stressed situation after receiving caffeine (200 mg) or a placebo, no treatment (caffeine, placebo) or gender effects were seen for heart rate variability, the heart rate power spectra components or systolic and diastolic blood pressure. An increase in oral temperature was found at the end of the trial, irrespective of treatment.

Harris & Mackie (1972) were able to establish a relationship between hours driven and the development of fatigue, as measured by heart rate monitoring. In this study, there was a significant decrease in heart rate over the 4 h testing period. It is interesting to note that the administration of caffeine after 2 h did not cause an increase in heart rate at any time during the remainder of the fatigue trial. It is commonly believed that caffeine is a stimulant which increases heart rate. In fact, caffeine has complex, varied and often antagonistic effects on the cardiovascular system, depending on the dose and the caffeine tolerance of the subject (Myers & Reeves, 1991).

When heart rate variability was examined using frequency domain spectral analysis there were a number of findings which support the postulate that caffeine can alleviate fatigue. Both the temperature and the blood pressure components of the power spectra were shown
to have a significant treatment (caffeine, placebo) effect in younger subjects. This effect was probably due to their lower daily caffeine intake (84-v-266 mg) and a lesser degree of tolerance (Robertson et al., 1978). A significant increase in both the temperature (0.02 - 0.04) and blood pressure (0.08 - 0.15) components of the power spectrum were found in all subjects during the first two hours of the fatigue test, indicating the development of fatigue. During the final two hours of the trial, the older subjects exhibited a decrease in the power spectra after the administration of both placebo and caffeine. This is interesting, especially for the blood pressure component, which is thought to be the most valid indicator of driver fatigue (Mascord & Heath, 1992).

The 3-way divided attention task used in the this study has been shown to be able to detect fatigue-induced decrements in performance (Mascord et al., in press). In this study there was a progressive reduction in the tracking control of all groups during the first 2 h on-task, before they received placebo or caffeine. This reduction in tracking control continued during the following 2 h for subjects given placebo, but when subjects received caffeine, their performance improved during the third and final hour of the fatigue session.

Although no significant treatment differences were found on the other two components of the divided attention task, a non-significant reduction in reaction time was found in the final hour after caffeine administration, when compared with placebo. This finding is consistent with the concept of an overall anti-fatigue effect for caffeine.

An increase in systolic and diastolic blood pressure occurred in older subjects after both placebo and caffeine. The younger subjects showed a decrease in systolic and diastolic blood pressure after the placebo but there was a significant increase in both parameters after the caffeine. This may also reflect the lower caffeine intake of the younger subjects. Oral temperature also decreased significantly after the fatigue session, irrespective of the treatment administered. This may have resulted from prolonged immobility (Sherwood, 1989).

The two-way divided attention task used before and after the fatigue session was essentially similar to the three-way divided attention task used during the fatigue except that there was no “emergency” brake light. Although caffeine had no effect on tracking control, the reaction time on the peripheral detection component was found to increase significantly after placebo and to decrease after caffeine. Overall performance in the task was thus improved after caffeine. These results indicate that a modest dose of caffeine is able to counteract the objectively measured development of fatigue in performance on a driving-related task.

REFERENCES


