Psychol. Belg.
1989, XXIX-1, 51-62.

EFFECTS OF CAFFEINE ON TASK DIFFICULTY

Wing Hong LOKE
Department of Social Work and Psychology
National University of Singapore

The effects of caffeine on levels of task difficulty were examined with a digit-symbol substitution task. In a double-blind study, 37 undergraduates were randomly assigned to one of four doses: 0, 200, 400, or 600 mg of oral administration of caffeine. Subjects attempted the task 10 and 90 min post-drug. Performance increased over time and declined across increasing levels of task difficulty. In general, neither caffeine nor task difficulty showed a systematic influence on the task. The exception was at the first test time where the 600 mg dose decreased performance at a moderate level of task difficulty. As expected of the digit-symbol substitution task which had a speed component, males were more faster and yet maintained accuracy in the task compared to females; initially, at 10 min post-drug, males also showed fewer errors than females. Post-hoc analysis with history of caffeine use was done; subjects were grouped as lower or higher caffeine users. In general, higher caffeine users had higher performance than lower users, especially at the moderate levels of task difficulty. Overall, the male higher caffeine users showed the highest performance.

Recent studies have shown that the effects of caffeine vary depending on the demands of the task (in cancellation tasks by Anderson & Revelle [1982] and Loke, Hinrichs, & Ghoneim [1985], and in a memory task by Anderson, Revelle, & Lynch [1984]). For example, in a symbol cancellation task, caffeine increased performance at the easy level (one target) than the difficult levels (two and four targets; Loke et al., 1985). However, in a recent modified and complex version of cancellation (Loke, 1988a), caffeine facilitated performance on the more difficult cancellation (addition and multiplication versions) than the standard digit cancellation task.

The present study attempts to further examine the effects of caffeine on task difficulty; a range of caffeine doses and task difficulty are selected. The digit-symbol substitution task is chosen because individuals find it easy to use and the task allows for a wide range of levels of task difficulty to be tested. Furthermore, in a pure psychomotor (hand steadiness) task, Loke et al. (1985) showed that subjects who received 6 mg/kg of caffeine were less steady (greater number of contacts) as the level of difficulty increased. Therefore, the digit-symbol

This research was supported by the National University of Singapore Research Grant RP870028. The author thanks Cynthia Goh and Joy Tang for their careful and diligent assistance and Goh Boon Tay for his clerical assistance.

substitution task — which is reported to measure psychomotor skill (Erber, Botwinick, & Storandt, 1981; Glosser, Butters, & Kaplan, 1977; Murstein & Leipold, 1961) especially at low levels of difficulty — would be sensitive to the effects of caffeine. The digit-symbol substitution task is similar to one of the subtests of the Wechsler Adult Intelligence Scale (WAIS; Wechsler, 1955).

Also of interest is whether the current history of caffeine use of individuals could alter the levels of task difficulty. Past studies showed that (a) heavy coffee users reported less nervousness and more euphoriant effects after caffeine than light users or abstainers (Goldstein, Kaizer, & Whitby, 1969), (b) habitual coffee users increased flicker-fusion frequency whereas inexperienced users showed decreased frequency (Landgrebe, 1960), (c) high caffeine users made fewer hits and more false alarms on a protracted visual vigilance task than lower caffeine users after ingestion of caffeine (Loke & Meliska, 1984), and (d) high caffeine consumers had more muscle tension after abstinence than low consumers (White, Lincoln, Pearce, Reeb, & Vaida, 1980).

Method

Subjects

Subjects were 37 healthy paid undergraduates (18 females, 19 males; mean of 20.71, S.D. = ± 1.5 years) from the National University of Singapore. They were within 20 procent of their ideal body weight and were not taking any regular medication. Subjects were randomly assigned in a double-blind manner to one of the four dose conditions: 0, 200, 400, or 600 mg of caffeine (range of 0 to 6 cups of coffee). Each dose condition consisted of about an equal number of females and males; 8, 10, 11, and 8 subjects for 0, 200, 400, and 600 mg dose groups respectively. As expected, analysis showed that the random assignment of caffeine consumption levels across dose conditions resulted in no significant differences among the dose groups.

Treatments

All subjects ingested three identical opaque-colored capsules, containing caffeine or placebo, with a cup of water. Each subject was given 0, 200, 400, or 600 mg of caffeine. Combinations of 200 mg caffeine and lactose (0 mg of caffeine) capsules were used to administer the calculated doses.

Materials

The digit-symbol substitution task was printed in a test booklet comprising of 5 pages. At the top of each page, written instructions were given. Below the instructions, the digit-symbol pairs were shown and below the pairs were ten rows of boxes (see Figure 1).

Each page has 2, 4, 6, 8, or 10 unique digit-symbol pairs. The number of pairs represented the five levels of difficulty from the lowest difficulty (2 pairs) to the highest difficulty (10 pairs). Each booklet randomly contained one of the possible five combinations of order of task difficulty: (a) 2, 4, 6, 8, and 10, (b) 4, 6, 8, 10, and 2, (c) 6, 8, 10, 2, and 4, (d) 8, 10, 2, 4, and 6, and (e) 10, 2, 4, 6, and 8.

Each row consisted of 10 boxes and each box consisted of an upper and lower panel (see Figure 1). A digit was marked on the upper panel of each box. A page with two digit-symbol pairs has either a "1" or "2" marked on each of the upper panel; a page with 4 pairs has "1", "2", "3," or "4" marked on each of the upper panel, and so on. The particular digit was determined in a random manner. The lower panel was left empty for subjects to write down the appropriate symbol corresponding to the digit in the upper panel of the box.

Procedure

At an initial interview, subjects completed several questionnaires: medical history, personal characteristics (e.g., age, height, and sex), and current history of caffeine consumption (Loke et al., 1985). The medical report served to screen out subjects who were taking medication, who had a history of drug abuse, or whose medical history contraindicated use of stimulant drugs. No subject, however, was rejected by the report. Subjects were advised to have their normal night's sleep, to abstain from caffeinated beverages, alcohol, and any drugs for 24 h before testing, and to abstain from food 6 h prior to testing.

To control for diurnal variations in arousal (Revelle, Humphreys, Simon, & Gilliland, 1980), all experimental sessions were held at 9:00 a.m. To control for possible weekday/end effect (Loke, 1988b), the sessions were held on weekdays. Upon arrival, subjects received general instructions and signed informed consent forms. Then each subject ingested three capsules, amounting to 0, 200, 400, or 600 mg of caffeine, with a cup of water. At 10 min post-drug, subjects were given the digit-symbol substitution task and they were alloted one min per page. Subjects filled in the blank spaces (lower panels) with the symbol that is

Look at the double boxes on the first row (across from the title, "Digit Symbol"). Each has a number in the upper part and a special mark in the lower part. Each number has its own mark. There are also boxes which have numbers in the top part but the squares at the bottom are empty (the bottom 10 rows of double boxes). You are to put in each of the empty squares the mark that should go there (watch the experimenter first). When the experimenter asks you to start, fill in the empty boxes. Fill in as many squares as you can, one after the other, without skipping any. Keep working until the experimenter tells you to stop. Work as quickly as you can without making mistakes. When you finish one line, go to the next line. Do the squares in order; do not skip any.

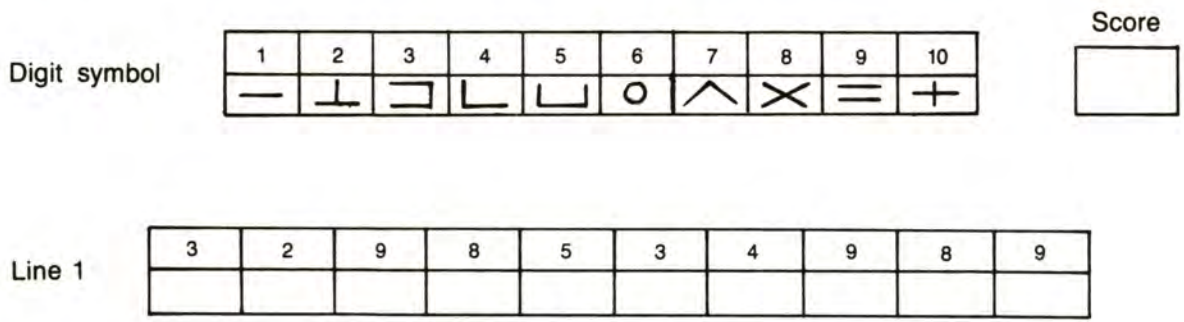

Figure 1. An example of the digit-symbol substitution task printed on a page. The actual page contained ten rows of boxes; the above example illustrates only one row of boxes.

paired to the number above the blank space as quickly as they can. Then, subjects did other memory tests unrelated to the present study. The task was repeated 90 min post-drug; the presentation order of the levels of difficulty was different from the 10 min post-drug test. On completion, subjects were debriefed and informed of the administered dose.

Data Analysis

Unequal-cell analyses of variance (ANOVA) were used. The between factors examined were dose (0, 200, 400, and 600 mg of caffeine), sex (male and female) and the within factors were relative test time (10 and 90 min post-drug) and level of difficulty (2, 4, 5, 8, and 10 unique digit-symbol pairs). In addition, separate analyses were performed for each of the relative test times. Separate analyses were performed to detect possible effects of the drug at a particular time.

Also, a between factor examined post-hoc was user (lower and higher caffeine users). Lower (19 subjects; mean of 197 mg caffeine/week, S.D. = ± 168, range of 0-455 mg caffeine/week) and higher users (18 subjects; mean of 1076 mg caffeine/week, S.D. = ± 384, range of 470-1795 mg caffeine/week) were determined by a median split of the caffeine consumption scores. As expected, the median split resulted in a significant difference between caffeine consumption levels of lower and higher users, $F(1, 35) = 83.06$. The averages of the present lower and higher users are similar to previous low/high designations in previous studies by the author and colleagues (178 and 1582 mg/week [Loke, 1988a], 308 and 1428 mg/week [Loke & Meliska, 1984], and 282 and 1533 mg/kg [Landrum, Meliska & Loke, 1988] for low and high users respectively). For comparisons, the per capita intake of caffeine in the United States averages 1400 mg/week for the general population (Rall, 1980) and 490 mg/week for the United States undergraduates (Loke, 1988b).

The dependant variables were number of lines (rows) completed, number of correct substitutions, and number of incorrect substitutions (errors). Line completion is an index of the speed at which subjects could complete the number of line substitutions. Correct substitutions and errors are measures of accuracy. The completion and accuracy rates were reported whenever necessary. The completion rate was calculated by taking the number of lines completed and multiplying by 100%. The accuracy rate was calculated by multiplying 100% to the overall value of the number of correct substitutions divided by the total number of correct substitutions and errors. Both rates were based on the percentage of performance per min (subjects were given a min to complete each page of digit-symbol substitutions).

All significant effects ($p < .05$) and relevant marginal effects ($.05 < p < .01$) were reported. Significant effects were further analyzed using the Duncan's new multiple-range tests.

Results

Overall, individuals increased in performance across time [means of 6.28 and 7.00 line completion, 63.24 and 70.17 correct substitutions, and 0.24 and 0.14 errors at 10 and 90 min post-drug; F (1, 29) = 54.01, 62.21, and 10.30 respectively]. As expected, performance declined across increasing levels of difficulty [means of 9.69, 6.86, 5.96, 5.51, and 5.16 line completions, 96.93, 69.12, 59.58, 55.80, and 52.10 correct substitutions, and 0.05, 0.19, 0.18, 0.27, and 0.26 errors for 2, 4, 6, 8, and 10 digit-symbol pairs; F (4, 16) = 486.33, 587.27, and 2.59 respectively]. The interaction between time and level of difficulty was also significant [F (4, 16) = 3.03 and 4.05 for line completions and correct substitutions respectively; see Table 1].

Table 1. — *Effects of caffeine across levels of difficulty on performance*

Post-drug time (min)	Level of difficulty				
	2	4	6	8	10
10	9.49[a] 94.95[b]	6.49 65.92	5.43 54.43	5.19 52.32	4.78 48.60
90	9.89 98.92	7.24 72.32	6.49 64.73	5.84 59.27	5.34 55.60

[a] Number of line completions.
[b] Number of correct substitutions.

Males completed more lines (mean of 6.85) than females [mean of 6.41; F (1, 29) = 5.25] and therefore, males had more corrects (mean of 68.82) than females [mean of 64.48; F (1, 29) = 4.72]. Two additional analyses for errors were significant. Males had fewer errors (mean of 0.13) than females (mean of 0.30) at 10 min post-drug; however, at 90 min post-drug, they had about equal number of errors (means of 0.14 and 0.13 for males and females respectively).

The effects of dose and dose by level of difficulty were not significant. Separate analyses at each particular time were examined, and revealed that the dose by level of difficulty at 10 min post-drug was significant for correct substitutions [F (12, 116) = 1.92]. Further analysis showed that 600 mg of caffeine decreased performance relative to placebo at the 4-digit-symbol pair level (see Figure 2).

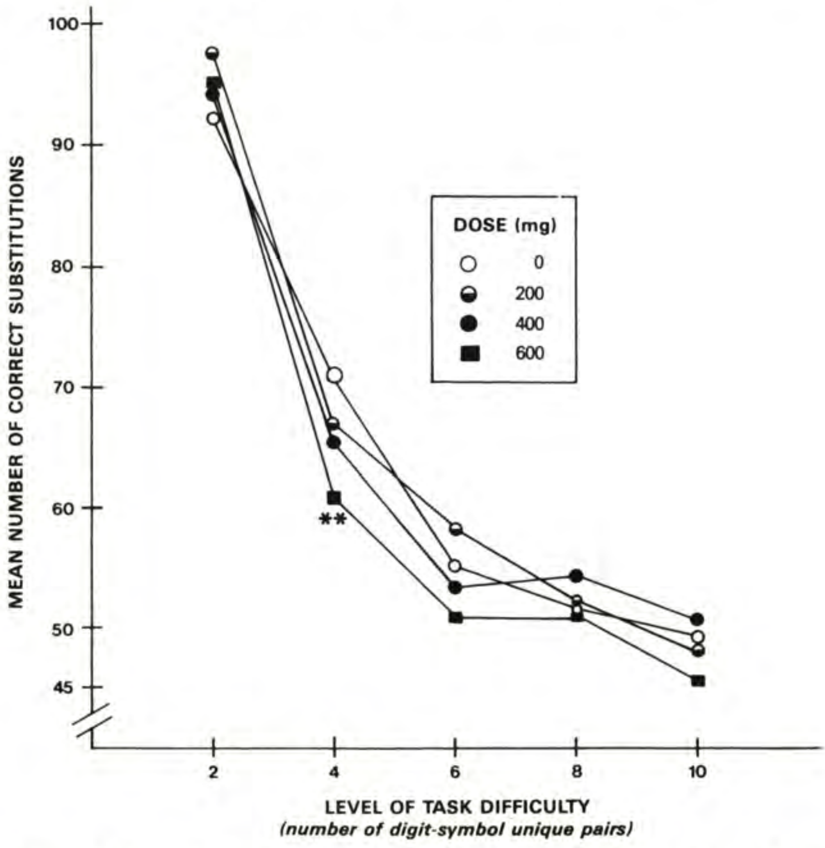

Figure 2. Mean number of correct substitutions at various levels of dose and task difficulty after 10 min of caffeine administration. The double asterisks indicate significant difference from placebo condition at $p < .01$.

The three-way interaction of dose by time by level of difficulty was also significant [F (12, 116) = 3.08]. Further analyses to compare differences between placebo and caffeine conditions were examined. At 10 min post-drug, 600 mg of caffeine increased errors (mean of 0.62) relative to placebo (mean of 0) at the 4-digit-symbol pair level; for the 10-digit-symbol pair level, placebo increased errors (mean of 0.88) relative to 200 and 600 mg of caffeine (means of 0.10 and 0 respectively). At 90 min postdrug, placebo increased errors (mean of 0.62) relative to 400 and 600 mg of caffeine (means of 0 and 0 respectively) at the 4-digit-symbol pair level.

The main and interactive effects of caffeine users with other relevant variables were also examined. In general, higher caffeine users completed more lines (mean of 6.84) and therefore had more correct substitutions (mean of 68.77) than lower users [means of 6.45 and 64.75 for line completions and correct substitutions; $F(1, 29) = 4.81$ and 4.43 respectively]. The interaction of user by level of difficulty was also

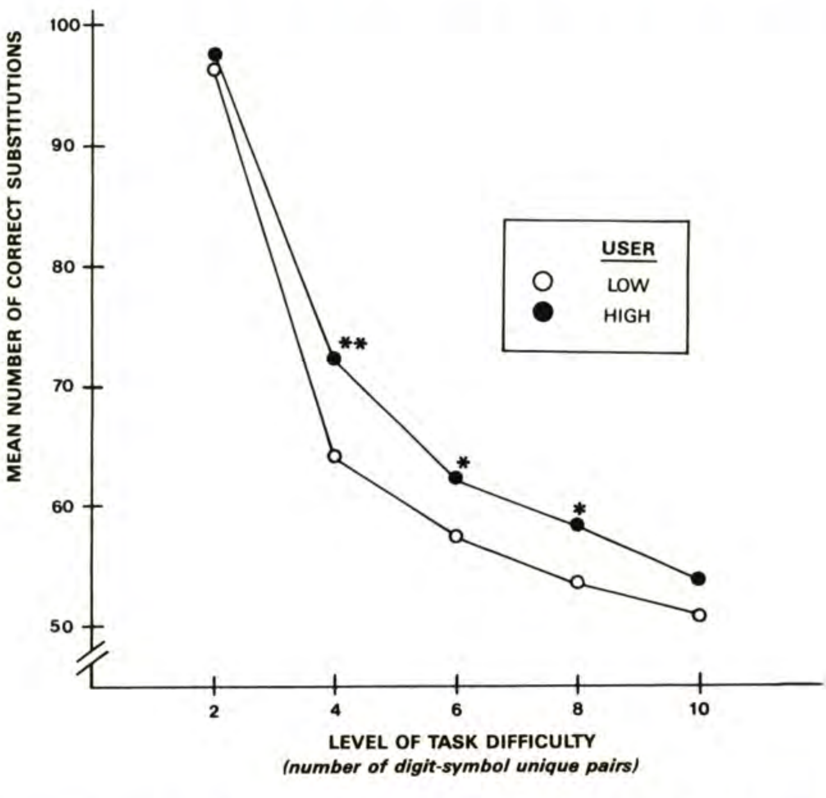

Figure 3. Mean number of correct substitutions for low and high caffeine users at various levels of task difficulty. Asterisks indicate significant differences from low user condition: $^{*}p < .05$ and $^{**}p < .01$.

significant for correct substitutions and marginally significant for number of lines completed [$F(4, 116) = 2.53$ and 2.31 for correct substitutions and line completions respectively]. Further analyses showed that higher users showed more correct substitutions than lower users at the moderate levels of difficulty (see Figure 3).

The sex by user interaction was significant [$F(1, 29) = 5.72$ and 4.48 for lines completed and correct substitutions respectively]. Further analyses showed that male higher users completed more lines and had more correct substitutions (means of 7.16 and 71.84 for lines and corrects respectively) than other users (female higher users had means of 6.33 and 63.93 for lines and corrects respectively; male lower users had means of 6.42 and 64.65, and female lower users had means of 6.46 and 64.83).

Discussion

As expected, subjects improved at the digit-symbol substitution task as they received more practice — from 63% completion rate on the first test to 70% on the second — while their accuracy was maintained in the second test. Males were quicker (an extra 0.44 lines per min) than females without the expense of accuracy. Also, increasing the levels of difficulty progressively decrease performance.

Overall, caffeine did not show any systematic influence on digit-symbol substitution task. The exception was at the first test time where the highest dose decreased performance at a moderate level of task difficulty (see Figure 2). Another variable of interest is the user effect; past studies have reported that the current history of caffeine use may modulate performance (Goldstein et al., 1969; Landgrebe, 1960; Loke & Meliska, 1984; White et al., 1980). In the present study, higher caffeine users had more correct substitutions than lower users, particularly at the moderate levels of task difficulty (see Figure 3), while the accuracy rate is maintained at a high level (99%). So, higher users work faster and also made more correct substitutions than lower users.

Two variables of interest emerge from the present study: history of caffeine consumption (user effect) and sex. Specifically, higher caffeine users showed increased performance relative to lower users. Perhaps higher caffeine users developed tolerance to the deleterious effects of caffeine whereas the lower caffeine users are more susceptible to the effects of caffeine. Several studies seem to support the above proposal. Coffee drinkers tend to acquire a tolerance to the actions of caffeine than nondrinkers (Colton, Gosselin, & Smith, 1967). Synder (1981) noted that regular consumers of caffeine have a greater density of caffeine (adenosine) receptors and therefore, the users experienced less of the drug's effects. Also, low users reported that coffee made them jittery, nervous, and wakeful at night; in contrast, coffee drinkers reported stimulant and euphoric effects from caffeine (Goldstein & Kaizer, 1969; Goldstein, et al., 1969).

Performance modulated by the user effect is further accentuated when user interacts with sex. Higher users who are males showed the highest performance (means of 7.16 lines and 71.84 corrects) compared to all the other combinations of sex and user. So, males completed more lines and were more accurate than females particularly if the males are also high caffeine users. The significant interaction is due to the reduced deleterious effect of caffeine experienced by the higher caffeine users than lower users and the higher performance on psychomotor task by males than females.

The above generality, however, is limited by the following considerations. First, division of subjects into lower/higher caffeine users was done post-hoc in order to allow for exploratory tests; however, the variables are not manipulated and therefore, the results show an association among caffeine usage and performance but not causality. Second, the effects of caffeine on performance depend on the nature of the task. The digit-symbol substitution task examines individuals' performance under time pressure. Motor speed (responses) is an important part of the task, particularly at ages below 35 (Savage, Britton, Bolton, & Hall, 1973). In general, digit-symbol is a test of psychomotor performance (motor persistence, sustained attention, response speed, and visuomotor coordination) that is relatively unaffected by learning or memory (Erber et al., 1981; Glosser et al., 1977; Murstein & Leipold, 1961). So, as in the present study caffeine is sensitive to tasks that have a motor or speed component (similar results were found in Loke et al., 1985). Of note, however, is that at the higher end of task difficulty (e.g., 10 unique digit-symbol pairs), digit-symbol may measure simple cognitive skill since individuals may need to encode the symbols verbally and rehearse/remember the digit-symbol pairs.

The present study suggests that the higher caffeine users developed tolerance to the deleterious effect. Also whether regular users of caffeine performed higher or lower than occasional users may depend on the specificity of the task. One clear finding, however, is that the difference between high and low caffeine users is significant. Moreover, the user effect is suggested to be a universal phenomenon as the present study using Singaporeans showed the effect as were the studies (Kuznicki & Turner, 1986; Loke & Meliska, 1980) done using Americans.

References

Anderson, K. J., & Revelle, W. (1982). Impulsivity, caffeine, and proofreading: A test of the Easterbrook hypothesis. *Journal of Experimental Psychology: Human Perception and Performance, 8*, 614-624.

Anderson, K. J., Revelle, W., & Lynch, M. J. C. (1984). *The effects of caffeine and impulsivity on memory scanning.* Unpublished manuscript.

Colton, T., Gosselin, R. E., & Smith, R. P. (1967). The tolerance of coffee drinkers to caffeine. *Clinical Pharmacology and Therapeutics, 9*, 31-39.

Erber, J. T., Botwinick, J., & Storandt, M. (1981). The impact of memory on age differences in digit symbol performance. *Journal of Gerontology, 36*, 586-590.

Glosser, G., Butters, N., & Kaplan, E. (1977). Visuoperceptual processes in brain damaged patients on the digit symbol substitution test. *International Journal of Neuroscience, 7*, 59-66.

Goldstein, A., & Kaizer, S. (1969). Psychotropic effects of caffeine in man. III. A questionnaire survey of coffee drinkers and its effects in a group of housewives. *Clinical Pharmacology and Therapeutics, 10*, 477-488.

Goldstein, A., Kaizer, S., & Whitby, O. (1969). Psychotropic effects of caffeine in man. IV. Quantitative and qualitative differences associated with habituation of coffee. *Clinical Pharmacology and Therapeutics, 10*, 489-497.

Kuznicki, J. T., & Turner, L. S. (1986). The effects of caffeine on caffeine users and non-users. *Physiology and Behavior, 37*, 397-408.

Landgrebe, B. (1960). Vergleichende Untersuchungen mit dem Flimmertest nach coffeinhaltigem und coffeinfreiem Kaffee [Comparative investigation with the flimmer test using caffeinated and decaffeinated coffee]. *Die Medizinische Welt, 2*, 1486-1490.

Landrum, R. E., Meliska, C. J., & Loke, W. H. (1988). Effects of caffeine and task experience on task performance. *Psychologia, 31*, 91-97.

Loke, W. H. (1988a). Effects of caffeine on mood and memory. *Physiology and Behavior, 44*, 367-372.

Loke, W. H. (1988b). Caffeine and undergraduates. *Psychology: A Journal of Human Behavior, 25*, 8-11.

Loke, W. H., Hinrichs, J. V., & Ghoneim, M. M. (1985). Caffeine and diazepam: Separate and combined effects on mood, memory, and psychomotor performance. *Psychopharmacology, 84*, 54-57.

Loke, W. H., & Meliska, C. J. (1984). Effects of caffeine use and ingestion on a protracted visual vigilance task. *Psychopharmacology*, 84, 54-57.

Murstein, B. I., & Leipold, W. D. (1961). The role of learning of motor abilities in the Wechsler-Bellevue digit symbol test. *Educational Psychological Measurement, 21*, 103-112.

Rall, T. W. (1980). Central nervous system stimulants — the xanthines. In L. S. Goodman & A. Gilman (Eds.), *The pharmacological basic of therapeutics* (6th ed.). New York: Macmillan.

Revelle, W., Humphreys, M.S., Simon, L., & Gilliland, K. (1980). The interactive effect of personality, time of day, and caffeine: A test of the arousal model. *Journal of Experimental Psychology: General, 109*, 1-31.

Savage, R.D., Britton, P.G., Bolton, N., & Hall, E.H. (1973). *Intellectual functioning in the aged.* New York: Harper and Row.

Synder, S.H. (1981). Adenosine receptors and the actions of methylxanthines. *Trends Neuroscience, 4*, 242-244.

Wechlser, D. (1955). *Manual for the Wechsler Adult Intelligence Scale*. New York: The Psychological Corporation.

White, B.C., Lincoln, C.A., Pearce, N.W., Reeb, R., & Vaida, C. (1980). Anxiety and muscle tension as consequences of caffeine withdrawal. *Science, 209*, 1547-1548.

10 Kent Ridge Crescent
Singapore 0511

Received December 1988