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THE INTERACTIVE EFFECTS OF CAFFEINE AND ESTROGEN ON MEMORY FOR WORD LISTS

by
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Bachelor of Arts, Kansas State University, 1971
Master of Arts, University of North Dakota, 1986

A Dissertation

Submitted to the Graduate Faculty

of the

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in partial fulfillment of the requirements

for the degree of

Doctor of Philosophy

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This dissertation submitted by Mary Ellen Arnold in partial fulfillment of the requirements for the Degree of Doctor of Philosophy from the University of North Dakota has been read by the Faculty Advisory Committee under whom the work has been done, and is hereby approved.

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This dissertation meets the standards for appearance and conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

24 March 1989
Dean of the Graduate School

Permission

Title THE INTERACTIVE EFFECTS OF CAFFEINE AND ESTROGEN ON MEMORY FOR WORD LISTS

Department Psychology

Degree Doctor of Philosophy

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Signature Meg Ellen Arnold

Date March 3, 1989

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ABSTRACT

Previous research has yielded conflicting results regarding the effects of caffeine on word list recall. Erikson et al. (1985) found that caffeine impaired recall among females when words were presented at a slow rate. Arnold et al. (1988) observed a facilitory effect of caffeine on the recall, after practice, of females tested during Days 1-5 of the menstrual cycle. Research on cognitive task performance among females suggests that performance varies according to the phase of menstrual cycle. Medical research demonstrates a relationship between estrogen and caffeine metabolism. In this study, it was hypothesized that females' recall of word lists would vary with level of caffeine administered and phase of the menstrual cycle. It was further hypothesized that the performances of oral contraceptive users and non-oral contraceptive users would differ.

Two hundred and eight females were administered 0, 2, or 4 milligrams of caffeine per kilogram of body weight. Approximately half of the subjects used oral contraceptives. Subjects were tested during either Days 1-5 or Days 9-13 of the menstrual cycle. Subjects heard 13 lists of 12 words and wrote their recall immediately after hearing each list.

The proportion of words recalled from the primacy, middle, and recency portion of each list was computed. A 3(Caffeine) x 2(Pill) x 2(Phase of Cycle) x 3(Practice) x 4(Presentation Rate) x 3(Serial Position) ANOVA was performed. A dose x serial position interaction

indicated that caffeine facilitated recall for words in the primacy position.

A dose x pill x phase x rate x serial position interaction was observed. Among subjects tested during Days 1-5, caffeine facilitated recall only among oral contraceptive users for words in the primacy position at the two slowest rates. Among subjects tested during Days 9-13, caffeine facilitated recall for words in the primacy position at the three slowest rates among non-oral contraceptive users and for words in the middle position at the fastest rate among oral contraceptive users.

Results suggest that among females, the effect of caffeine on word list recall are modulated according to the level of estrogen in their system.

INTRODUCTION

The effect of caffeine on human memory functioning has become a focus of research only within the recent past. Much of this research has been conducted within a theoretical framework developed by Humphreys and Revelle (1984) which incorporates the variables of personality, arousal, time of day, and motivation into a model to account for differences in performance on memory tasks. At the same time, medical research on the physiological effects of caffeine has demonstrated a relationship between caffeine and estrogen, although the exact nature of this relationship requires further clarification. Finally, research concerning the effect of endogenous hormones on cognitive functioning has demonstrated a relationship between phase of menstrual cycle and performance on cognitive tasks.

This dissertation has combined elements from each of these areas of research to examine the potential interactive effects of phase of menstrual cycle and caffeine on human memory performance. Specifically, this project examined the effect of caffeine on human memory performance and examined whether different phases of the menstrual cycle modulated the size or direction of this effect. The contribution of each of the above mentioned areas of research will be examined, beginning with the effect of caffeine upon memory.

Arousal and Memory Research

The Yerkes-Dodson Law (1908) concerns the influence of arousal on performance. This law states that there is an inverted U function relating performance and cortical arousal, such that optimal performance occurs at medium levels of activation or arousal. Both low and high levels of cortical arousal will lead to less than optimal levels of performance. Therefore, individuals should perform at their best when their level of cortical arousal or activation is at an optimal level, i.e., they are neither underaroused nor overaroused.

The effects of caffeine on behavior have been studied within a framework of a theory of personality proposed by Eysenck (1967) which postulates that the personality dimension of introversion/extraversion is based upon physiological differences between individuals, specifically an individual's level of cortical activation or arousal. Arousal level is controlled in the brain by the reticular activating system. Eysenck proposed that introverts have a higher base level of arousal than extraverts. According to Eysenck's theory, the behavior of extraverts results from their attempts to raise their level of arousal to an optimal level. The introvert's level of cortical arousal is higher and, thus, already near the optimal level. The behavior of introverts is explained as an attempt to avoid overstimulation by maintaining their optimal level of arousal.

The examination of the effect of caffeine on memory performance has its roots in an experiment conducted by Revelle, Amaral, and Turiff (1976) to examine the effects of arousal on cognitive performance. The experimental task consisted of a 60-item verbal test (similar to the Graduate Record Examination), which consisted of

analogies, antonyms, and sentence completions. In this experiment, subjects were administered three comparable forms of this test under three increasingly stressful conditions on three consecutive evenings. In one session, subjects were allowed as much time as they needed to complete the items. A second condition, the time press condition, required subjects to complete another comparable test in 10 minutes. In a third condition which combined time press plus caffeine, subjects were administered 200 milligrams of caffeine and, after an absorption period, were given 10 minutes to complete a third 60-item test. Subjects were classified as introverts or extraverts based upon their score on the Eysenck Personality Inventory, a self-report instrument designed to measure the introversion/extraversion dimension of personality as well as sociability and impulsivity. Results of the study indicated that the performance accuracy of extraverts improved across increasingly stressful or arousal producing conditions, while the performance accuracy of introverts declined. Caffeine appeared to aid the performance of extraverts and hinder the performance of introverts. In terms of Eysenck's theory, caffeine raised extraverts' level of cortical arousal to a level which enabled them to perform the task more accurately than without caffeine. Furthermore, caffeine impaired the performance of introverts because, theoretically, it led to overstimulation of their cortical system.

A more precise method of manipulating the level of cortical arousal was employed in a subsequent replication of this experiment by Gilliland (1980). All subjects completed the same verbal ability test employed by Revelle, Amaral, and Turiff (1976) under a 10-minute time press condition. Next subjects were administered caffeine according to

their body weight. Subjects received either a placebo, 2 milligrams of caffeine per kilogram of body weight, or 4 milligrams of caffeine per kilogram of body weight. Following administration of the drug, subjects waited for 30 minutes for the caffeine to be absorbed into their systems and then completed a comparable form of the test under a 10-minute time press condition. For introverts, the 2 milligram per kilogram level of caffeine improved performance relative to the placebo, and the 4 milligram per kilogram level of caffeine decreased performance so that it was equivalent to introverts' performance under the placebo. For extraverts, caffeine improved performance across increasing dose levels.

Subsequent investigation (Revelle, Humphreys, Simon, & Gilliland, 1980) has led to several modifications of the basic hypothesis that increased arousal impairs the performance of introverts and aids the performance of extraverts. Analysis of subscales of the Eysenck Personality Inventory revealed that the impulsivity subscale was a better predictor of the effect of caffeine than the introversion/extraversion score. That is, the personality by caffeine interaction described above was more reliably and robustly observed by Revelle et al. (1980) when the impulsivity subscale score was used to define trait arousal as compared to the introversion/extraversion score. Revelle et al. (1980) also found that the time of day in which subjects were tested critically influenced the direction of the personality by caffeine interaction. For low impulsive subjects, i.e., introverts, caffeine hindered performance in the morning but facilitated performance in the evening. The reverse occurred for high impulsive subjects, or extraverts; caffeine facilitated their performance during

the early part of the day but impaired their performance in the evening. Based upon this, a revision of Eysenck's theory was suggested. Rather than an overall difference between introverts and extraverts in level of arousal, the revised theory proposed that introverts and extraverts have the same overall level of arousal, but that there are stable differences in the phases of diurnal rhythm of introverts and extraverts which affect the relationship between personality and performance.

This revision of Eysenck's theory is consistent with the Yerkes-Dodson Law (1908) which states that low and high levels of arousal will lead to less than optimal performance. According to this law, the 2 milligram per kilogram dose of caffeine may facilitate the performance of low impulsive subjects (i.e. introverts) who may be operating at slightly less than optimal levels of arousal in the morning. However, their performance declines under the 4 milligram per kilogram dose of caffeine because it overstimulates them, pushing them to high levels of arousal. During evening hours, when low impulsive subjects (introverts) are underaroused, caffeine raises their level of cortical arousal to medium levels, thus producing optimal performance.

The Yerkes-Dodson Law (1908) can also account for the performance of high impulsive extraverts. During the morning hours, the high impulsives are operating at levels of cortical arousal which are so low that a high (4 milligrams per kilogram) dose of caffeine is needed to raise their level of cortical arousal to an optimal level. In the evening, when high impulsives experience greater cortical activation, further stimulation by the drug caffeine leads to overarousal which results in performance decrement.

Based partially on the aforementioned research, Humphreys and Revelle (1984) developed a conceptual model to account for the effects of personality, situational moderators, and motivational states upon information processing and cognitive performance. According to this model, the personality trait of impulsivity interacts with time of day to determine the subject's level of arousal, such that low impulsives experience peak levels of arousal early in the day and high impulsives experience peak levels of arousal later in the evening. This level of arousal can be manipulated by stimulant drugs such as caffeine.

The model further states that information processing consists of two components, sustained information transfer and short-term memory. Sustained information transfer is reflected in performance on such tasks as reaction time, vigilance, simple arithmetic, and letter cancellation. These tasks require the subject to process a stimulus, associate a response to the stimulus, and execute the response. These tasks are characterized by little need to retain information in short-term memory, little or no distraction, and rapid pacing or temporal uncertainty. Short-term memory tasks include such tasks as memory for prose and recall of word lists. Short-term memory tasks require subjects to maintain the incoming information in an available state by rehearsal or other processes. Sustained information tasks and short-term memory tasks may be viewed as two ends of a theoretical continuum. In practice, some elements of each are involved in most tasks; however, experimental tasks are often selected which consist chiefly of one or the other of these information processing components. The model assumes that information processing capacity is limited and

that resources will be allocated according to the demands of the task and the availability of the resources.

Humphreys and Revelle (1984) have postulated a negative association between arousal and short-term memory performance such that a high level of arousal leads to a decrement in performance on tasks which place heavy demands on short-term memory, such as memory for prose or recall of words. However, a positive association exists between arousal and sustained information transfer such that a high level of arousal leads to improved performance on sustained information transfer or vigilance tasks such as reaction time, letter search, and simple arithmetic.

Anderson and Revelle (1982) manipulated caffeine and impulsivity using a proofreading task to test the hypothesis that the effects of increased arousal depend upon the processing demands of the task. According to the Easterbrook hypothesis (1959), the effects of arousal on performance are mediated by the effects of arousal on range of cue utilization. That is, the higher the level of arousal, the narrower the range of cues utilized to perform the task, with irrelevant cues being eliminated first. Anderson and Revelle (1982) tested 60 subjects, classified as either high or low impulsive, who were administered either 4 milligrams of caffeine per kilogram of body weight or a placebo dissolved in a glass of orange flavored breakfast drink. After a 30-minute absorption period, they proofread three passages. In the first passage, subjects were instructed to correct all errors they detected, regardless of type, with no reference made regarding the two experimental types of errors in the passage. In a second passage, subjects were asked to find interword errors, which

were contextual errors such as faulty grammar or incorrect word usage. In a third passage, subjects were asked to identify intraword or noncontextual errors such as misspellings or typographical errors. Detecting interword errors may be viewed as a task with a larger short-term memory component than detecting intraword errors, since the former would require more manipulation of words and phrases in a sentence in order to determine if the word was a contextual error. Caffeine resulted in lower interword error detection for low impulsive subjects relative to the placebo condition, while caffeine improved the interword error detection rate of high impulsives. These results are congruent with the Humphreys and Revelle (1984) model and support the suggestion that caffeine impairs performance on tasks with a short-term memory component.

In a subsequent experiment, Anderson and Revelle (1983) utilized a visual search task with varying processing demands to examine whether or not the effects of caffeine change as a function of the task demands on short-term memory. The task required subjects to pick out target letters from strings of 20 letters. The target size, i.e., the number of different letters to be picked out of the string, was manipulated. A target size of two letters represented a low short-term memory load and a target size of six represented a high short-term memory load. Eighty-four subjects classified as either high or low impulsives were administered ether 4 milligrams of caffeine per kilogram of body weight or a placebo dissolved in an orange flavored beverage drink. After a 20-minute absorption period, subjects scanned four pages of letters under a 3-minute time press condition. Both target sizes were employed for each subject. Caffeine slightly improved (to a non-significant

degree) performance while searching for the two letter target, a low memory load task, and hindered performance while searching for the six letter target, the high memory load task. These results support the Humphreys and Revelle (1984) model which states that high levels of arousal will impair performance on tasks which have a high short-term memory load.

Further support for the Humphreys and Revelle (1984) model is found in the research of Bowyer, Humphreys, and Revelle (1983) who investigated the effect of arousal on recognition memory. In this study, subjects were administered either 4 milligrams of caffeine per kilogram of body weight or a placebo. After a 45-minute absorption period, they were shown four lists (two 24-item and two 80-item) of four letter words. Immediately following each list, they were given a forced choice recognition test on the last 20 words of each list. The performance of the highly aroused subjects (low impulsives receiving the 4 milligrams per kilogram dose) showed a much smaller decline in performance from the first to fourth list. The repeated performance of this recognition test over four lengthy lists contains elements of a vigilance task and requires more sustained attention and less manipulation of information in short-term memory. The Humphreys and Revelle (1984) model predicts that heightened arousal will be accompanied by improved performance on a sustained information transfer task such as this. The performance of the least aroused subjects (high impulsives receiving the placebo dose) declined progressively from the first to fourth list. Thus, Bowyer et al. (1983) interpreted these results to support the Humphreys and Revelle (1984) model.

A shortcoming of the caffeine research conducted up to this point was that the tasks employed such as GRE test performance (Revelle, Amaral, & Turiff, 1976), proofreading (Anderson & Revelle, 1982), or a visual search task (Anderson & Revelle, 1983) lacked a sound theoretical basis. This made it difficult to ascertain which specific components of information processing were being influenced by caffeine.

Information processing theorists have used the serial position effect to illustrate the dissociation between long-term and short-term memory (Craik, 1970; Murdoch, 1962). When asked to recall items from a list of words in any order, subjects remember more items from the beginning and end of the list than from the middle, thus forming a U-shaped curve of words remembered. The greater retention of items from the first part of the list has been attributed to the fact that these items have been rehearsed and, thus, moved into long-term memory. This phenomenon is known as the primacy effect. The better recall of items from the end portion of the list is attributed to these items still being in short-term memory. This is called the recency effect.

Brodie and Prytulak (1975) demonstrated that the changes in free recall attributed to serial position, rate of presentation, and delay of recall can be accounted for by two phenomena: rehearsal time and item retention interval (the amount of time between last rehearsal and recall). In a series of experiments, the amount of rehearsal time and the rate of presentation were manipulated. In the first experiment, subjects were presented with lists of 18 words presented at three rates: one word every 1.25, 2.50, or 5.00 seconds. Subjects were permitted to spontaneously rehearse lists of words. Their subsequent recall either immediately followed the presentation of the last word or

was delayed for 15 seconds, during which time subjects counted backwards by three's to prevent additional rehearsal. Results indicated that increased rehearsal time due to slower presentation rate was responsible for improved recall in the primacy and middle portions of lists presented at slow rates. Improved recall of terminal items was due to the fact that the items were rehearsed later, i.e., the item retention interval was smaller.

In a second experiment, the amount of rehearsal time spent on the primacy, middle, and recency portions of the word lists was manipulated by asking subjects to concentrate on the primacy, middle, or terminal portion of the list as it was presented. Again, lists of 18 words were presented at three rates, and recall was either immediate or delayed. Results indicated that the amount of time spent on rehearsal was highly correlated with recall, even when the rehearsal pattern was not the subject's usual one. This finding provided additional support for the theory that changes in rehearsal are responsible for changes in recall performance.

Craik (1970) provided further evidence for the presence of two memory stores by employing a final free recall task. Subjects were presented with 10 lists of 15 words each and, immediately following each list, were asked for their recall of words from the list. After all of the lists had been presented, subjects were asked for a final recall of the entire series of lists. Analysis of results indicated the presence of a negative recency effect; that is, subjects' final recall was poorest for items from the recency portion of the list, items which had been retained for the shortest period of time prior to the immediate recall. Recall was best for items from the primacy portion

of the list, presumably because these items had been retained long enough to enter long-term memory.

Just as it has been shown that the amount of time spent on rehearsal can influence the number of items remembered, so it can be demonstrated that the efficiency of processing information in working memory will influence the amount of information remembered. Perfetti and Lesgold (1979) have described the "bottleneck in comprehension" which may occur as a result of too much information impinging at one time upon working memory. They maintain that while the capacity of working memory cannot be increased, it can be more efficiently utilized to increase comprehension. The bottleneck in working memory capacity can be influenced by three components which may exist independently or interact to interfere with comprehension. The first component of the potential bottleneck has to do with the speed and automation of decoding. If an individual is able to translate the visual representation from print to phonologically referenced words with ease, less working memory capacity will be required for this task. Skill at decoding single words and reading comprehension have been found to be highly related in children (Perfetti & Hogaboam, 1975). The second component of the potential bottleneck is the speed of accessing information about decoded words from long-term memory. Rapidly accessing word meanings minimizes the processing capacity necessary for this task and allows more capacity for comprehension processes. Hunt, Frost, and Lunneborg (1973), found that individuals with high verbal ability, i.e., large vocabularies, were able to rapidly handle data more easily than individuals with low verbal ability. The third component of the potential bottleneck involves strategies used in

processing. A skilled reader possesses efficient strategies which facilitate comprehension by taking advantage of the rules of language structure. According to the bottleneck hypothesis, increasing the speed with which incoming stimuli are decoded will lead to improved performance because it will leave an increased amount of time for manipulation of information in working memory.

These principles of information processing theory were applied in an experiment by Erikson et al. (1985) which examined the effect of caffeine on the free recall of supraspan word lists. Forty-seven males and 60 females were classified as either high or low impulsive on the basis of subjects' scores on the Eysenck Personality Inventory. Subjects were administered 2 milligrams of caffeine per kilogram of body weight, 4 milligrams per kilogram, or a placebo, dissolved in a glass of orange flavored breakfast drink. After a 30-minute absorption period, subjects were presented with 9 lists of 12 words each. Half of the lists were presented at a fast rate (1 word per second) and half at a slow rate (1 word every 3 seconds). Immediately after hearing each list, subjects orally recalled the words they remembered.

Results indicated that females who received caffeine showed impaired recall for words at the slow rate of presentation. For males, there was no significant effect of caffeine on recall performance. It was suggested that "caffeine may be affecting the efficiency with which the information was encoded or manipulated in working memory" (Erikson et al., 1985, p. 10).

The Erikson et al. (1985) study used two rates of presentation and found that caffeine impaired recall at the slower rate. This result was attributed to caffeine's impairment of performance on tasks that place

high demands on working memory under the assumption that a slow rate of presentation represents a more demanding task than a fast rate of presentation.

The Erikson et al. (1985) study appears to be the first to have investigated the variable of sex as a possible factor in the effect of caffeine on memory performance. The sex difference obtained was attributed to three possible reasons: (a) the use of a male sample size that was insufficient to test the hypothesis, i.e., only 47 males and 60 females were tested; (b) the fact that females in the study reported consuming significantly greater amounts of caffeine than males; or (c) a hypothesized sex difference in the rate of metabolism of caffeine wherein caffeine might be absorbed into the system and broken down differently for females than for males.

A final result of the Erikson et al. (1985) experiment was that it failed to replicate earlier findings with regard to the personality variable of impulsivity. Impulsivity did not interact with caffeine on any of the variables investigated.

A replication and extension of the Erikson et al. (1985) study by Arnold, Petros, Beckwith, Coons, and Gorman (1987) sought to clarify and strengthen aspects of the earlier experiment. Since Erikson et al. (1985) found that caffeine impaired performance only at the slow rate, the replication included four rates of presentation rather than two in order to more clearly elucidate the effect of rate on the influence of caffeine on memory performance. In addition to the two rates employed by Erikson (1 word per second and 1 word per 3 seconds), a faster rate (1 word per .5 second) and a slower rate (1 word per seconds) were added.

In order to clarify the subtle effect of caffeine, care was taken to control for other possible variables which might influence memory performance. For example, subjects were required to abstain from other substances which might interact with caffeine such as medications (24-hour abstention required) and alcohol (48-hour abstention required).

Erikson et al. (1985) had observed sex differences in the effect of caffeine such that caffeine impaired recall for females but not for males. In order to more carefully investigate the effect of caffeine on females, potential female subjects were screened by Arnold et al. (1987) for oral contraceptive use and only females not taking oral contraceptives served as subjects. In order to minimize differences among females caused by endogenous hormonal fluctuation associated with the menstrual cycle (Asso, 1983), each female subject in the experiment was tested only during one of the first 5 days of her menstrual cycle.

Finally, Arnold et al. (1987) employed a sample size appropriate to the design in order to increase the probability of detecting the subtle effect of caffeine. Eighty-two males and 75 females served as subjects. Subjects were divided by level of impulsivity (high and low), caffeine dose (0, 2, or 4 milligrams of caffeine per kilogram of body weight), and sex into 12 groups.

Caffeine or placebo was orally administered to subjects in 6 ounces of orange flavored breakfast drink using the same dose levels and following the same procedure used by Erikson et al. (1985). After a 30-minute absorption period, subjects listened to one practice and 12 experimental lists of 12 words, comparable to those used by Erikson et al. (1985). Lists were presented at each of the four rates of

presentation. Each successive four lists constituted one level of practice; thus, there were three levels of practice. Immediately after hearing each list, subjects wrote their recall. After completing the presentation and recall of all lists, subjects wrote a final free recall of words from all of the lists.

Results of this study indicated that caffeine facilitated recall for females under the 2 and 4 milligram per kilogram doses at the third level of practice, but impaired recall for males at the second and third levels of practice under the 2 milligram per kilogram dose only. In addition, a marginal interaction of caffeine, sex, and rate occurred such that caffeine impaired recall of males under the 2 milligram per kilogram dose for words at the slow rate of presentation and improved recall for males under the 4 milligram per kilogram dose for words at the fast rate of presentation. In summary, caffeine was found to facilitate recall in females and to impair recall in males.

The larger sample size can account for the discrepancy between the results of Arnold et al. (1987) for males and those of Erikson et al. (1985). First, an examination of the Erikson et al. (1985) means for males at the slow rate of presentation indicates that recall declined with caffeine, but not enough to reach statistical significance. The use of a more appropriate sample size for the design permitted a more powerful test, enabling this subtle decline to reach statistical significance.

The stricter controls employed by the Arnold et al. (1987) study may explain the discrepant findings for females. The use of a more homogeneous sample eliminated a variety of factors which potentially could have influenced performance in the Erikson et al. (1985) study.

One factor which was specific to females was the exclusion of subjects using oral contraceptives from the Arnold et al. (1987) experiment. Research (Abernethy & Todd, 1985) has demonstrated that caffeine takes longer to be absorbed by the system and remains in the system (i.e., has a longer half-life) for a significantly longer time among oral contraceptive users than among non-users. Furthermore, it is possible that controlling for endogenous hormonal variation explains the discrepancy in performance between this sample of females and the sample employed by Erikson et al. (1985), since differences in cognitive performance across the menstrual cycle have been demonstrated in some past research (Broverman et al., 1981; Graham, 1980). All female subjects in the Arnold et al. study (1987) were tested during one of the first 5 days of their menstrual cycle.

Reproductive Cycle Research

The hormonal variation which occurs across the menstrual cycle appears to be varied and complex. At least four hormones are involved with the female reproductive cycle. These include estrogen, progesterone, follicle stimulating hormone and luteinizing hormone. The estrogens are a class of female steroid hormones. Within this class, estradiol-17B is the most plentiful estrogen and the one which has been used as a measure of overall estrogen levels. Steroids or sex hormones are derived from cholesterol. They are produced in the adrenal gland and ovaries (testes in males) (Federman, 1981). Steroid levels are regulated by positive and negative feedback mechanisms. Positive feedback is a process whereby the effect produced by an action, e.g., the release of a hormone, enhances or maintains an

action. In negative feedback, the opposite occurs. The effect causes a reduction or termination of the action (Carlson, 1986). Gonadotropin releasing hormone (GnRH) is secreted by the hypothalamus and stimulates the rel se of follicle stimulating hormone (FSH) and luteinizing hormone (LH), called gonadotropins, at the site of the anterior pituitary gland. These gonadotropins, in turn, are carried by the blood to the site of the ovaries (or testes) where estrogen and progesterone are produced. The levels of these hormones vary greatly across the menstrual cycle and are regulated by the gonadotropins.

The hormonal fluctuations of the menstrual cycle are precisely orchestrated to bring about the production and release of a mature ovum each cycle. For the purpose of study, the menstrual cycle has been arbitrarily divided up into five phases: the menstrual phase which lasts from Days 1-5; the follicular phase lasting from Days 6-12; the ovulatory phase from Days 13-15; the luteal phase from Days 16-23; and the premenstrual phase from Days 24-28. While the average cycle length is 28 days, a great deal of variation in cycle length exists among women. This variation occurs in the pre-ovulatory portion of the cycle while the length of the ovulatory and post ovulatory phases tends to remain stable across women, with approximately 14 days between ovulation and the onset of menstrual bleeding (Asso, 1983). Variation is greater among younger women than older women. This may be due, in part, to the fact that younger women experience a greater number of anovulatory cycles than women between the ages of 20 and 35. In a study of 87 college women with a mean age of 19.2 1.3 years conducted by Broverman et al. (1981), it was found that 24% of the sample

experienced an anovulatory cycle during the course of a 1-month long experiment.

During the paramenstrum, i.e., the combined premenstrual and menstrual phases, estrogen is at the lowest level it will reach across the entire cycle. Also during this time, follicle stimulating hormone (FSH) reaches one of the two peaks in blood level it will achieve during the cycle. These two hormones have a negative feedback relationship such that high levels of estradiol are accompanied by low levels of FSH (see Figure 1). The premenstrual drop in estrogen is accompanied by a surge in FSH. The FSH initiates maturation of a follicle in one of the ovaries. As this maturation progresses, the ovary produces increased amounts of estrogen. Therefore, a gradual rise in estradiol level occurs during the follicular phase along with a drop in the level of FSH.

Toward the end of the follicular phase, estrogen reaches its highest level. As it begins to decline, a dramatic increase in the levels of FSH and LH occurs. This is called the midcycle gonadotropin surge. This surge has been attributed to a positive feedback relationship between luteinizing hormone releasing hormone (LH-RH), also known as gonadotropin releasing hormone, and estrogen which produce the midcycle surge (American Medical Association, 1986). Although much remains unknown about this midcycle surge, it has been demonstrated that in order for this surge to occur estrogen must reach a critical level and remain there for a minimum period of time, at least several hours (Shaw, 1978). The role of FSH in this midcycle surge is not understood, yet it is known that ovulation does not occur if the LH peak occurs without a concomitant FSH surge. The level of progesterone

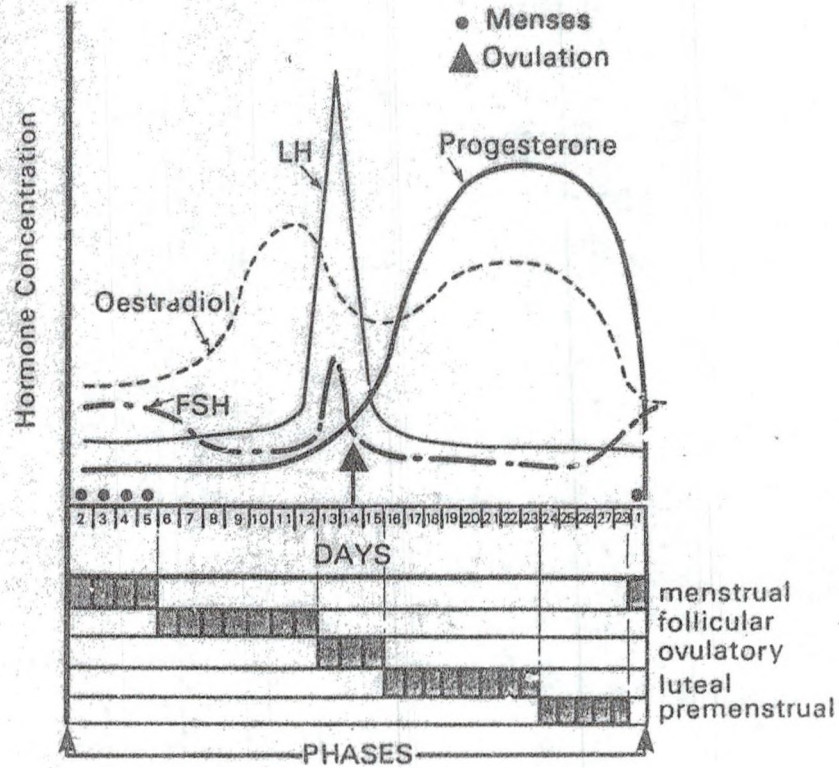

Figure 1. Relative levels of oestradiol, progesterone, FSH, and LH throughout the menstrual cycle (Asso, 1983; adapted from Shaw, 1978).

secreted by the ovaries also begins to rise prior to the midcycle gonadotropin surge and it has been proposed that progesterone has both a positive and subsequent negative feedback relationship with the gonadotropins, possibly by facilitating gonadotropin release at the pituitary or hypothalamic level.

Twenty-four hours after the peak in LH, the mature follicle bursts and releases a mature ovum from the ovary. Changes in the epithelial lining of the vagina and quality of mucus secretions which have begun under the influence of estrogen during the preovulatory phase culminate at this time to enhance the probability of fertilization and implantation. During the ovulatory phase, estrogen continues to decline from the peak it achieved during the final portion of the preovulatory phase.

The luteal phase is characterized by the collapse of the follicle from which the mature ovum was released and its transformation into the corpus luteum. Under the influence of LH, the corpus luteum secretes progesterone and estrogen. The 14-day luteal phase is divided into two parts. During the first 7 days, the rise in progesterone serves to prepare the endometrium for the possible reception of a fertilized ovum. If this does not occur, a 7-day regression period occurs. The end of the growth period and the beginning of the regression is thought to result from the interaction of estrogen with prostaglandins from the endometrium (Cutler & Garcia, 1980).

Finally, during the premenstrual phase, estrogen levels and progesterone levels decline sharply resulting in changes in the endometrium which cause it to shed its lining and, thus, produce the menstrual flow. The low level of estrogen again activates the negative

feedback mechanism of FSH and the level of this gonadotropin begins to rise, initiating the maturation of another ovarian follicle.

This endogenous cyclical hormonal variation in women is modified by oral contraceptive use. The most commonly used oral contraceptives include mixtures of a synthetic estrogen and a progestin (American Medical Association, 1986). Other oral contraceptives, called minipills, contain progestin only. Oral contraceptives are available in low or regular doses containing less than 50 micrograms or 50 micrograms of estrogen, respectively. In phasic regimens, the level of estrogen remains stable but the level of progestin varies according to the day of the cycle. Phasic oral contraceptives can be biphasic or triphasic, depending upon the progestin regimen used. Biphasic oral contraceptives contain two levels of progestin in the cycle During part of the cycle, a low level of progestin will be ingested, later in the cycle a higher level will be ingested. Triphasic oral contraceptives contain three levels of progestin. Again, the level of progestin varies according to the phase of the cycle. These different variable dose oral contraceptive regimens have been developed to accommodate individual differences among women in their physical tolerance of hormonal contraceptive agents in an effort to minimize side effects.

Combination oral contraceptives exert their influence by inhibiting ovulation through negative feedback effect on the hypothalamus which alters the release of gonadotropins from the anterior pituitary. Both the release of FSH during the menstrual and early follicular phases, and the midcycle surge of gonadotropins are inhibited by the estrogen components of the oral contraceptive.

Progestin containing minipills, on the other hand, exert their influence by causing the formation of a thick cervical mucus which is impenetrable by sperm and by increasing the amount of time required for the ovum to be transported through the Fallopian tube. Progestin-only oral contraceptives do not inhibit ovulation (American Medical Association, 1986).

A study of serum gonadotropin and ovarian steroid levels in women during the administration of a triphasic oral contraceptive preparation demonstrated that oral contraceptives exert their influence by inhibiting the midcycle surges of LH and FSH (Ling et al., 1985). Among women who were already using oral contraceptives, either at fixed doses or in triphasic preparations, the follicular increase in FSH was also inhibited. However, among women who had previously not used oral contraceptives, the follicular increase in FSH was within the normal range.

Medical research has contributed to knowledge about the interaction of caffeine and estrogen. Impaired elimination of caffeine by oral contraceptive steroids was demonstrated by Patwardhan, Desmond, Johnson, and Schenker (1980). Thirteen males, nine females taking oral contraceptives for longer than 6 months, and nine females not on contraceptives were administered 250 milligrams of caffeine. Subjects were all moderate coffee drinkers who had abstained from caffeine containing beverages and medications for at least 2 days. Blood samples were collected at 15, 30, 45 minutes and 1, 1-1/2, 2, 3, 4, 5, 6, 7, 8, 24, 32, and 48 hours. The rate of caffeine absorption was found to be equal in all groups with peak plasma levels reached within 30 to 60 minutes. The half-life of caffeine was significantly longer

for females using oral contraceptives than for females not using oral contraceptives (10.7 vs. 6.2 hours). No differences in the pharmacokinetic effects (i.e., the absorption time, distribution in the body, metabolism, and elimination) of caffeine were observed between women in the first half of their menstrual cycles versus those in the second half. Patwardhan et al. (1980) concluded that the observed decrease in the rate of elimination or clearance of caffeine from the body may be related to increased estrogen and/or progesterone load while taking oral contraceptives.

A more recent study (Abernethy & Todd, 1985) examining the effect of low dose estrogen containing oral contraceptives on caffeine clearance supports the findings of Patwardhan et al. (1980) with regard to the elimination of caffeine from the system. In this experiment, nine females who had been administered low dose estrogen-containing oral contraceptive for longer than 3 months were matched with nine non-smoking, drug free females. All subjects were within 20% of their body weight. Subjects were administered 325 milligrams of citrated caffeine with 100 milliliters of water, the equivalent of 162 milligrams of caffeine base. Blood samples were collected before the dose and after 5, 10, 15, 30, 45, and 60 minutes, and 2, 3, 4, 6, 8, 10, and 24 hours. Results indicated that oral contraceptive users experienced a half-life of caffeine that was significantly longer than non-oral contraceptive users (7.88 hours vs. 5.37 hours). However, contrary to the work of Patwardhan et al. (1980), Abernethy and Todd (1985) found that the length of time for caffeine to reach peak concentration was significantly longer for subjects on oral

contraceptives than for subjects not on oral contraceptives (91 vs. 47 minutes).

Impaired elimination of caffeine during the second and third trimesters of pregnancy has also been observed (Aldridge, Bailey, & Neims, 1981). Pregnancy subjects who had abstained from foods and beverages containing caffeine for at least 24 hours were administered 5 grams of coffee containing 177 milligrams of caffeine. Salivary samples were collected immediately before ingestion of caffeine and 2, 4, 8, 12, and 24 hours after ingestion. One group of eight subjects was tested once during the first trimester of pregnancy. Another group of seven subjects was tested longitudinally on at least five occasions during and after pregnancy. Results of the analysis of salivary samples indicated that the half-life of caffeine increased as pregnancy progressed from 5.3 hours during the 11th week to 18.1 hours during the 38th week, and dropped dramatically within the first week after birth to 5.4 hours. Aldridge et al. (1981) attribute this impaired elimination of caffeine during pregnancy to decreases in the rate at which caffeine undergoes biotransformation in the liver. The authors indicate that progesterone and estrogen can slow down the biotransformation of caffeine.

In a related area of medical research, estrogen and caffeine have been linked as factors in the postmenopausal loss of bone mass (Heaney, 1982). In a longitudinal study of women from premenopausal middle age to old age, subjects' self-selected dietary habits were observed. A 50% increase in the amount of caffeine ingested led to an increased loss of calcium both in the urine and in the intestinal tract. This

resulted in an overall negative calcium balance whereby the amount of calcium taken in was inadequate to maintain bone structure.

Menstrual Cycle and Cognitive Performance Research

The third general area of research pertinent to this project has investigated the effect of endogenous hormones such as estrogen on cognitive functioning. The effect of sex steroid hormones on task performance has been investigated by Broverman, Klaiber, Kobayashi, Vogel and others in a long series of studies. In an early review of research in this area (Broverman, Klaiber, Kobayashi, & Vogel, 1968), two categories of cognitive tasks were identified: automatized tasks and perceptual restructuring tasks. Automatized, or perceptual motor tasks are defined as simple, overlearned, repetitive behaviors measured in terms of speed, accuracy, or frequency of occurrence and which require minimal mediation by higher cognitive processes. Examples of automatized tasks include speed of naming colors, reading speed, a digit symbol task which requires subjects to rewrite digits into a predetermined code of simple symbols, typing, eye-blink conditioning, and visual acuity. Perceptual restructuring tasks include complex behaviors which require problem solving, delay, or reversal of usual habits. Some examples of perceptual restructuring tasks include maze performance, the ability to retard overpracticed motor movements, counting backwards, and habit reversal.

Broverman et al. (1968) hypothesized that "sex differences in cognitive abilities are reflections of differences in relationships between adrenergic activating and cholinergic inhibitory neural processes which, in turn, are sensitive to the 'sex' hormones,

androgens and estrogens" (Broverman et al., 1968, p. 24). Sex differences in the performance of these tasks have been demonstrated in humans and animal species such that females outperform males on automatized tasks while males outperform females on perceptual restructuring tasks. According to Broverman et al. (1968), sympathetic nervous system domination facilitates performance on simple perceptual motor tasks requiring activation while parasympathetic domination facilitates performance on perceptual restructuring tasks which require inhibition. The theory is based upon the results of drug and hormonal studies which have manipulated adrenergic and cholinergic systems. Interestingly, caffeine is mentioned as one of a class of adrenergic stimulants which increases sympathetic nervous system activation and thus facilitates performance on automatized tasks.

According to this theory, sex differences in task performance are related to the sex steroid hormones estrogen and androgen (testosterone). The effect of steroids upon the sympathetic nervous system is accomplished by fluctuations in levels of monoamine oxidase (MAO), an enzyme which breaks down adrenergic (sympathetic nervous system) neurotransmitters such as norepinephrine and epinephrine. Facilitation of neural transmission in the sympathetic nervous system is accomplished by reducing levels of monoamine oxidase (MAO). Estrogen and testosterone both suppress MAO activity in the hypothalamus, resulting in increased activation of the sympathetic nervous system. While both steroids increase the activation of the sympathetic nervous system, estrogen activates the sympathetic nervous system to a much greater extent than does testosterone because it is a more potent MAO inhibitor.

According to Broverman et al. (1968), evidence of an effect of steroids on the parasympathetic nervous system comes from experimental demonstration that behavioral activity decreases following removal of the ovaries and testes and the level of choline acetylase, an enzyme which is responsible for the synthesis of acetylcholine, rises in the hypothalamus. It has been speculated that increased production of acetylcholine is responsible for the inhibition of behavior. The administration of estrogen reverses both the inhibition of behavior and the increased level of choline acetylase.

Thus, the effects of steroids upon both the sympathetic (activation) and parasympathetic (inhibitory) systems are hypothesized by Broverman et al. (1968) to be responsible for the sex differences in performance of automatized and perceptual restructuring tasks, with females more likely to experience sympathetic domination (activation) while males are more likely to experience parasympathetic domination (inhibition).

Since high levels of estrogen are hypothesized to facilitate performance on automatized tasks and impair performance on perceptual restructuring tasks, Broverman et al., (1981) investigated the effect of menstrual cycle related changes in estrogen on the performance of these tasks. Specifically, they hypothesized that the performance of females would be facilitated on automatized tasks and impaired on perceptual restructuring tasks by the preovulatory peak in estrogen which occurs immediately prior to midcycle. They further predicted that the progesterone peak which occurs during the second half of the cycle would inhibit the effect of the concomitant postovulatory estrogen peak. This inhibitory effect of progesterone would result in

impaired performance on automatized tasks and improved performance on perceptual restructuring tasks.

Eighty-seven women who were not taking any form of medication, including oral contraceptives, participated in the Broverman et al. (1981) study. Daily basal body temperatures were taken and recorded by subjects each morning throughout the study before arising and before eating, drinking, or smoking. Subjects were administered a battery of two automatization tasks and two perceptual restructuring tasks on two separate occasions, Day 10 (± 2 days) and Day 20 (± 2 days) of their menstrual cycle. Half of the subjects began their sequence on Day 10 and the other half began their sequence on Day 20.

One of the automatization tasks required the subject to read, as fast as possible, 10 lines of the words "red," "green," or "blue." The second automatization task required the subject to name, as fast as possible, 10 lines of small red, green, or blue color patches. On both of these tasks, the subject's score was the amount of time it took to complete the task.

One perceptual restructuring task consisted of five items from Witkin's Embedded Figures Test, which requires the subject to detect a figure embedded in a ground of random lines. The subject's score was the average time it took her to identify all five items. The second perceptual restructuring task included four items from the WAIS block design subtest. These were scored in the standard manner. Different sets of items were administered at each of the two sessions. Subject's scores on all of these tests were computed according to a formula to arrive at an Automatization Index which reflected the degree of each subject's automatization cognitive pattern, with positive values

indicating strong automatizers and negative values indicating weak automatizers.

The basal body temperature records for each subject enabled the experimenters to retrospectively determine the proximity of the testing sessions to each subject's estrogen and progesterone peaks. Among those subjects who had ovulatory cycles, four groups were established: (a) Group 1, where Day 10 testing occurred within 3 days of the thermal nadir (i.e., the lowest basal body temperature of the cycle) and Day 20 testing occurred on or after the thermal peak; (b) Group 2, where Day 10 testing occurred within 3 days of the thermal nadir but Day 20 testing occurred before the thermal peak; (c) Group 3, where Day 10 testing occurred more than 3 days before the thermal nadir and Day 20 testing occurred on or after the thermal peak; and (d) Group 4, where Day 10 testing occurred more than 3 days before the thermal nadir and Day 20 testing occurred before the thermal peak. The subjects were divided into these groups because it was hypothesized that proximity to the estrogen and progesterone peaks would correlate with task performance. Results of analysis indicated that only the means of Group 1 showed significant differences between Day 10 and Day 20 scores. This was the group in which testing had occurred in closest proximity to the estrogen and progesterone peaks. These significant differences for Group 1 occurred for three out of the four tasks, reading color names, naming colors, and embedded figures. The speed of reading color names was significantly faster at Day 10 than at Day 20; the speed of naming colors was marginally faster at Day 10 than at Day 20, $p = .08$. Both of these were automatization tasks. Conversely, on embedded figures,

the perceptual restructuring task, performance was significantly slower on Day 10 than on Day 20.

Thus, Broverman et al. (1981) demonstrated that changes in performance on automatization and perceptual restructuring tasks occur and that these changes are temporally related to the estrogen and progesterone peaks of the ovulatory menstrual cycle. Apparently the magnitude of change is so slight that it can be observed only when subjects are tested at times close to the hormonal peaks.

Another study which found a relationship between performance on cognitive tasks and estrogen levels was conducted by Graham (1980) who looked at both within subject and between subject differences in estrogen. It was hypothesized that differences in cognitive behavior would occur between the period of low estrogen level and high estrogen level. Furthermore, it was hypothesized that during the luteal phase of the cycle when estrogen levels were not at their peak and progesterone was exerting some antiestrogen effect, cognitive behavior would be more inhibited, i.e., that initial automatized response tendencies would be delayed, resulting in better performance on more complex problem solving types of tasks which require some delay in order to think through the problem before responding.

Forty-eight women between the ages of 20 and 35 with fairly regular menstrual cycles participated in this study. Each subject kept a record of daily basal body temperatures for 1 month prior to participation and during the month in which the testing occurred. This was done in order to help estimate the location within the cycle of the thermal shift which is known to occur with ovulation.

Subjects were tested at three phases of the cycle: the early follicular phase (Days 3-4; some testing done on Day 5 or 6), the ovulatory phase (Days 13-14 with a range from Day 10 to Day 19) and the mid-luteal phase (Days 20-25). Estrogen levels during the early follicular and ovulatory phases were determined from 24-hour urine specimens. Testing sessions were counterbalanced so that one-third of the subjects entered the study at each of the three phases.

At each session, subjects were administered a battery of eight tests. The Rod and Frame Test required the subject to adjust a luminescent rod to vertical in a darkened room when the rod was within a tilted luminescent frame. The digit symbol task was a timed, written task which consisted of transforming numbers into simple symbols as quickly as possible. The embedded figures task consisted of finding a figure within a ground of random lines. The time estimation test required subjects to estimate a predetermined time interval and measured the difference between their estimation and the actual time interval. Subtraction and addition tasks consisted of a number of basic arithmetic problems which subjects completed as quickly as they were able. Naming colors was a Stroop task which consisted of looking at rectangular patches of different colors lined up on a piece of paper like words, and naming the colors as fast as possible. Reading color names, another Stroop task, consisted of reading as fast as possible the names of colors written on a sheet of paper. Porteus Mazes consisted of mazes from two series of mazes, both the Vineland and Extension series; a Q score was derived from each.

Results of this study indicated that cognitive test battery scores were significantly related to the phase of the cycle during which

subjects were tested. Specifically, performance on the color reading, color naming, and subtraction tasks was significantly improved during the luteal phase (Days 20-25), relative to the early follicular and ovulatory phases. The improvement in performance on both automatization (color reading and color naming) and perceptual restructuring (subtraction) tasks, which occurred during the luteal phase, is somewhat inconsistent with the results of Broverman et al. (1981) which yielded a crossover in task performance with decrement in the performance of automatization tasks (color naming and color reading) during the luteal phase.

In a further analysis of the data, three estrogen level groups were formed: a high, medium, and low group. Analysis of the data from these groups indicated that subjects with high levels of estrogen gave their poorest performance on the color naming, color reading, and subtraction tasks at midcycle and their best performance during the luteal phase. Subjects with medium and low estrogen levels performed better on color naming and color reading tasks at midcycle than during the early phase; however, they performed more poorly at midcycle than during the early phase on the subtraction task.

While the Graham (1980) study does little to clarify the activation-inhibition dimension outlined by Broverman et al. (1968), it provides evidence that changes in cognitive task performance do occur at different phases of the menstrual cycle. One criticism leveled by Graham at her own study was that the cognitive task battery contained no tasks that were very difficult from an intellectual point of view. A word list task, such as that used by Erikson et al. (1985) and Arnold et al. (1987), would place a greater demand on processing

capacity. Further recommendations for future studies were that older women be used to minimize the incidence of anovulatory cycles, that estrogen levels be measured more accurately using blood plasma levels, and that levels of progesterone be measured to verify that ovulation had, in fact, occurred.

The Present Study

The purpose of the present study was to investigate the effect of caffeine upon the recall of word lists during two phases of the menstrual cycle when estrogen levels are very different. Two previous studies have yielded discrepant findings regarding the effect of caffeine on females' recall of word lists. Erikson et al. (1985) tested female subjects without controlling for phase of menstrual cycle and without regard to oral contraceptive usage. The Arnold et al. (1987) study controlled for endogenous hormonal fluctuation by testing all female subjects between Days 1 and 5 of the menstrual cycle, and by testing only subjects who were not using estrogen containing oral contraceptives which artificially alter endogenous estrogen levels. Thus, the Arnold et al. (1987) study contained a more homogeneous population of females with regard to endogenous hormone level. Caffeine impaired the recall performance of females in the Erikson et al. (1985) study but facilitated recall performance for females according to Arnold et al. (1987). The most parsimonious explanation for these discrepant findings is that endogenous hormone levels modulated the effect of caffeine.

In the present study, females using oral contraceptives and females not using oral contraceptives were administered either 0, 2, or

4 milligrams of caffeine per kilogram of body weight. Subsequently, they listened to lists of words presented at four rates: one word every half second, one word every second, one word every 3 seconds, and one word every 5 seconds. Subjects immediately recalled the words remembered from each list. Subjects were tested at one of two different phases of the menstrual cycle: on or before the fifth day of the menstrual cycle, or on approximately day 11 of their cycle. It was hypothesized that the pattern of caffeine effects would be different at each of these two phases for females not using oral contraceptives. It was further hypothesized that the recall performance of females using oral contraceptives would not change between the menstrual and pre-ovulatory phases since the level of estrogen fluctuates only slightly in females using oral contraceptives (Ling et al., 1985).

METHOD

Subjects

Two hundred and eight females enrolled in undergraduate level courses at the University of North Dakota served as subjects in this experiment. Subjects received either extra class credit or movie passes for their participation. In a preexperimental screening session, subjects completed the Eysenck Personality Inventory (EPI). Subjects scoring six or lower on the lie scale of the EPI (range 0-9) qualified for participation in the study. At the screening session, subjects also completed a calendar indicating the approximate date on which they expected their menstrual period to begin.

Subjects were contacted by telephone prior to the experiment and were screened for a variety of medical conditions which might have made them ineligible to participate. These conditions included a personal past history of cardiovascular problems, epilepsy, hypertension, migraine headaches, ulcers, diabetes, kidney disorders, seizures, or blackouts. In addition, only subjects who had previously consumed caffeine at least once in the form of coffee, tea, or pop, and were not allergic to caffeine, sugar, or orange juice (substances they would consume in the experiment) were invited to participate. Finally, subjects who reported that they took any medication on a regular basis were eliminated.

Subjects meeting the medical criteria for participation were asked to meet the following four conditions. Subjects were asked to abstain from alcohol for 48 hours prior to their experimental session and they were asked to refrain from taking any medication for 24 hours prior to their participation. These requirements ensured that subjects had no other substance in their systems which might interact with caffeine. Subjects were asked to refrain from consuming any substance containing caffeine after 10:00 p.m. the night before their experimental appointment. Finally, they were asked to get a minimum of 5 hours of sleep the night before the experiment to assure that fatigue was not a determining factor in their performance.

Subjects were divided into two groups: those using oral contraceptives and those who were not using oral contraceptives. These groups were further divided according to phase of menstrual cycle: either menstrual phase (Days 1-5) or pre-ovulatory phase (Days 9-13). Subjects in each group were assigned to one of three dose levels: 4 milligrams of caffeine per kilogram of body weight, 2 milligrams of caffeine per kilogram of body weight, or 0 milligrams of caffeine per kilogram of body weight (placebo). This yielded a total of 12 groups. The mean scores for each group on various demographic variables are listed in Table 1.

Materials

Thirteen word lists comprised of 12 nouns each were used as stimulus material. Words for the lists were selected from a list of word frequency norms (Kuchera & Francis, 1967) such that each list had a mean syllable range and mean word frequency comparable to those of

Table 1

Demographic Characteristics of Subjects

Phase of cycle:	Days 1-5						Days 9-13					
Dose of caffeine:	0 mg/kg		2 mg/kg		4 mg/kg		0 mg/kg		2 mg/kg		4 mg/kg	
Oral contraceptive use:	Pill	No pill	Pill	No pill	Pill	No pill	Pill	No pill	Pill	No pill	Pill	No pill
N	16	16	16	16	17	16	16	22	16	20	16	21
Age	21.2	21.1	21.9	20.1	20.4	21.9	20.9	21.5	20.7	20.7	20.5	20.1
Weight	144.1	144.4	138.6	139.6	144.2	140.2	137.7	145.8	142.0	147.5	132.5	141.2
WAIS-R raw	40.00	35.87	45.06	40.12	39.76	44.12	38.33	44.45	40.60	43.70	42.12	42.80
WAIS-R scaled	9.37	9.31	10.25	9.44	9.59	10.25	9.20	10.18	9.60	10.25	9.25	10.30
Introversion/extraversion	14.69	13.87	13.06	14.56	15.19	14.37	14.62	13.09	13.12	13.35	13.56	13.29
Lie	2.93	2.62	3.19	3.44	1.56	1.75	2.00	2.59	2.44	2.55	2.50	2.57
Sociability	8.87	8.62	7.06	8.25	8.56	8.44	8.81	7.54	7.37	7.60	7.62	7.81
Impulsivity	4.62	4.50	4.87	4.75	5.63	4.69	4.50	4.45	4.56	4.60	4.87	4.57
Caffeine consumption Questionnaire I	198.12	105.00	176.94	73.25	101.41	179.94	82.00	148.36	139.56	107.00	159.81	131.24
Caffeine consumption Questionnaire II	204.56	121.50	196.69	110.69	121.65	220.31	80.75	133.36	161.00	90.90	138.69	79.29
Amount of caffeine last consumed	78.62	55.80	52.50	43.79	40.94	62.06	38.13	66.95	70.62	37.50	61.37	47.14

Table 1 (Continued)

Phase of cycle:	Days 1-5						Days 9-13					
Dose of caffeine:	0 mg/kg		2 mg/kg		4 mg/kg		0 mg/kg		2 mg/kg		4 mg/kg	
Oral contraceptive use:	Pill	No pill	Pill	No pill	Pill	No pill	Pill	No pill	Pill	No pill	Pill	No pill
Hours since caffeine last consumed	21.4	20.9	17.3	24.6	20.8	27.9	22.1	21.0	21.4	16.5	29.2	25.3
Cigarette consumption	1.06	3.06	1.56	1.06	1.53	1.69	0.19	0.41	1.37	0.50	1.75	4.14
Pretest Thayer Activation Deactivation Checklist	17.44	15.87	14.56	17.13	16.12	15.12	19.50	15.64	16.27	16.85	14.80	15.43
Posttest Thayer Activation Deactivation Checklist	16.50	15.75	15.19	18.31	18.53	16.06	17.06	15.23	16.94	18.15	17.44	17.76
Pretest blood pressure	114.12 / 70.81	111.75 / 70.50	107.94 / 70.75	112.87 / 72.25	110.59 / 73.88	109.75 / 68.50	111.19 / 73.56	115.54 / 72.68	113.25 / 70.62	112.50 / 73.75	109.50 / 66.81	110.00 / 71.48
Posttest blood pressure	109.19 / 70.25	108.00 / 70.07	114.40 / 75.67	114.69 / 75.25	112.47 / 76.00	111.87 / 73.69	109.07 / 70.87	112.04 / 72.09	110.00 / 72.19	111.95 / 74.30	113.31 / 73.62	111.95 / 75.33
Pretest pulse	74.94	73.12	69.62	68.27	74.94	73.12	75.62	70.09	70.00	70.90	79.37	72.05
Posttest pulse	71.12	68.27	63.60	60.40	66.75	65.69	71.60	65.64	66.13	64.40	71.00	66.95
Length of menstrual cycle	29.19	29.19	28.44	31.13	30.18	29.81	27.73	29.14	28.19	28.45	29.56	29.29

the word lists used by Erikson et al. (1985). Words were recorded on cassette tapes at four rates of presentation, one word every .5 seconds (fastest), one word per second (fast), one word every 3 seconds (slow), and one word every 5 seconds (slowest). Stimulus materials were presented to subjects on a cassette recorder/player.

Procedure

All experimental sessions were held between 8:00 a.m. and 12:00 a.m. (c.f. Erikson et al., 1985) in order to control for diurnal variations in arousal. Subjects were tested individually. Ninety-six subjects participated during Phase 1, i.e., either on or before the fifth day of the menstrual cycle, while one subject was run on the sixth day. One hundred and eleven subjects participated during Phase 2, i.e., on approximately the 11th day 2 days.

Upon arrival for their session, subjects were given a consent form to sign which informed them of the experimental procedure and notified them of their rights. Subjects' weight and blood pressure were taken and recorded. Any subject with blood pressure higher than 140/90 was dismissed from the study. Subjects were administered a written form of the WAIS-R vocabulary subtest to obtain an estimate of their verbal ability. Each subject was allowed as much time as needed to complete this.

Next, subjects were given a series of self-report questionnaires including several caffeine consumption questionnaires. The caffeine consumption questionnaires assessed the amount of caffeine ingested from various sources such as coffee, tea, cola beverages, and over-the-counter pain relievers. Caffeine Consumption Questionnaire I

(see Appendix A) was used to estimate the subject's typical level of caffeine consumption. Caffeine Consumption Questionnaire II (see Appendix B), which assessed the amount of caffeine consumed by the subject during the 3 days prior to the experimental session, was used to provide an estimate of the subject's current level of consumption.

Subsequently, subjects were administered either 0, 2, or 4 milligrams of caffeine per kilogram of body weight dissolved in 6 ounces of orange flavored breakfast drink. Subjects were unaware of the dose level to which they had been assigned. Following this, there was a 30-minute absorption period to allow caffeine to reach peak blood plasma level (cf. Gilbert, 1976).

The Thayer Activation Deactivation Checklist was administered to each subject prior to and 30 minutes following the administration of caffeine to measure the subject's self-reported level of arousal. Physiological changes in arousal were measured by blood pressure and pulse readings taken upon arrival for the experiment and again 25 minutes after the caffeine was administered.

Following the absorption period, each subject was run in the recall portion of the experiment by a second experimenter who was blind to the dose level of caffeine which had been administered to the subject. Subjects were presented with 13 lists of 12 words each. Subjects listened to each list, then immediately wrote down the words they remembered from the list. The first list was a practice list. The following 12 lists were experimental lists. Two short breaks (3-5 minutes) were given following the fourth and ninth lists.

Each subject heard three lists at each of four rates of presentation. The 12 experimental lists were presented in such a

manner that each list appeared in each ordinal position equally often across subjects. Also, presentation rates were arranged such that for each successive four lists, each presentation rate was used once. Rates were counterbalanced among subjects so that each rate occurred in each ordinal position equally often across subjects. After all of the word lists were presented and the recall for each list written, subjects wrote a final free recall of words from all of the lists. Subjects completing the final free recall in less than 5 minutes were encouraged to continue searching their memory in order to ensure that all subjects gave some effort to this task.

Finally, subjects were debriefed. Upon request subjects were informed of the dose group to which they had been assigned.

Design

The study employed three between subject factors and three within subject factors. The between subject factors included subjects' use of oral contraceptives (either oral contraceptive users or non-oral contraceptive users), the dose level of caffeine (0, 2, or 4 milligram per kilogram) and phase of the menstrual cycle (first five days or near Day 11). The within subject factors were rate of presentation--one word every 5 seconds (slowest), one word every 3 seconds (slow), one word every second (fast), and one word every .5 second (fastest); serial position (primacy, middle, and recency); and level of practice, such that each of the four rates was presented three times, yielding three levels of practice.

RESULTS

Recall Data

Each subject's written recall was scored by determining the proportion of words recalled from the primacy (first four words), middle (second four words), and recency portion (last four words) of each word list. A 3(Caffeine Dose) x 2(Pill) x 2(Phase of Cycle) x 3(Level of Practice) x 4(Rate of Presentation) x 3(Serial Position) ANOVA was performed with the proportion of words recalled as the dependent variable. The level of significance was set at .05 for all analyses. Newman-Keuls procedures were utilized for all post hoc tests with alpha set at .05.

A significant main effect of practice was observed, $F(2, 292) = 7.99$, with mean recalls of .539, .555, and .558 for the first, second, and third levels of practice, respectively. This effect indicated that recall at the second and third levels of practice was significantly greater than at the first level of practice. However, recall at the second and third levels of practice were not significantly different from each other.

A significant dose x pill x practice interaction was also found, $F(4, 392) = 2.52$ (see Table 2). At the first level of practice, oral contraceptive users receiving the 2 milligram per kilogram dose of caffeine recalled a significantly greater proportion of words than those who received the placebo, while recall under the 4 milligram per

Table 2

Mean Proportion of Words Recalled as a Function of Caffeine Dose and Level of Practice by Oral Contraceptive Usage

Oral contraceptive usage:	Pill			No pill		
Level of practice:	1	2	3	1	2	3
Caffeine dose						
0 mg/kg	.520	.546	.561	.529	.547	.526
2 mg/kg	.558	.579	.571	.535	.556	.566
4 mg/kg	.543	.532	.555	.549	.570	.569

kilogram dose was not significantly different than either the placebo or the 2 milligram per kilogram dose. There were no significant dose differences for non-oral contraceptive users at the first level of practice. At the second level of practice, recall was significantly greater for oral contraceptive users who received the 2 milligram per kilogram dose of caffeine than for those receiving either the 4 milligram per kilogram dose or the placebo and there was no significant difference between the 4 milligram per kilogram dose and the placebo. In addition, there were no dose differences among non-oral contraceptive users at the second level of practice. At the third level of practice, no significant dose differences occurred among oral contraceptive users. However, among non-oral contraceptive users at the third level of practice, both the 2 and 4 milligram per kilogram doses of caffeine produced significantly greater recall than the placebo, with the 2 and 4 milligram per kilogram doses not being significantly different from each other.

A significant main effect of rate was found, $F(3, 588) = 15.67$. Recall proportion means were .653, .600, .497, and .452 for the 5 second, 3 second, 1 second, and .5 second rates. Results indicated that recall declined significantly as the rate of presentation increased.

A significant main effect of serial position occurred, $F(2, 392) = 103.51$ with recall proportion means of .499, .376, and .776 for the primacy, middle, and recency portions of the word lists, respectively. Subsequent analysis of this effect indicated that subjects recalled a significantly greater proportion of words from the recency portion of the lists than from either the primacy or middle portions, and that

recall from the primacy portion was significantly greater than recall from the middle portion.

Next, a significant dose x serial position interaction was noted, $F(4, 392) = 3.092$. As may be seen in Table 3, both the 2 and 4 milligram per kilogram doses of caffeine produced significantly greater recall than the placebo condition for words in the primacy position, although the effects of the 2 and 4 milligram per kilogram doses were not significantly different from each other. No dose effects were observed at either the middle or recency portions of the lists.

In addition, a significant pill x serial position interaction was found, $F(2, 392) = 3.648$ (see Table 4). Non-oral contraceptive users recalled a significantly larger proportion of words from the recency portion of the lists than did oral contraceptive users. There were no significant differences between users and non-users at either the primacy or middle positions.

A significant dose x phase x practice x serial position interaction was also found, $F(8, 784) = 2.096$ (see Table 5). A subsequent analysis of this interaction revealed that no significant dose differences occurred among subjects tested during Phase 1 for the first two levels of practice. At the third level of practice, both the 2 and 4 milligram per kilogram doses of caffeine produced significantly better recall relative to the placebo for words in the primacy position, while no significant differences occurred for words in the middle or recency positions. Among subjects tested during Phase 2, recall at practice level one for words in the primacy position was significantly greater under the 4 milligram per kilogram dose than

Table 3

Mean Proportion of Words Recalled as a Function of Caffeine Dose and Serial Position

	Serial position		
	Primacy	Middle	Recency
Caffeine dose			
0 mg/kg	.466	.362	.787
2 mg/kg	.511	.396	.775
4 mg/kg	.519	.371	.768

Table 4

Mean Proportion of Words Recalled as a Function of Oral Contraceptive Usage and Serial Position

	Serial position		
Oral contraceptive usage	Primacy	Middle	Recency
Pill	.505	.386	.763
No pill	.492	.366	.790

Table 5

Mean Proportion of Words Recalled as a Function of Caffeine Dose, Level of Practice, and Serial Position, According to Phase of Menstrual Cycle

Phase of cycle:	Days 1-5			Days 9-13		
Serial position:	P	M	R	P	M	R
Practice level:			One			
Caffeine dose						
0 mg/kg	.457	.348	.752	.463	.354	.771
2 mg/kg	.500	.340	.781	.487	.412	.757
4 mg/kg	.494	.352	.789	.552	.366	.722
Practice level:			Two			
0 mg/kg	.473	.340	.814	.447	.409	.794
2 mg/kg	.523	.400	.779	.524	.398	.779
4 mg/kg	.502	.385	.785	.514	.368	.750
Practice level:			Three			
0 mg/kg	.443	.348	.787	.511	.371	.801
2 mg/kg	.525	.389	.809	.505	.377	.745
4 mg/kg	.525	.381	.777	.527	.437	.783

under either the 2 milligram per kilogram dose or the placebo, which were not significantly different from each other. At practice level two, recall was significantly greater under both the 2 and 4 milligram per kilogram doses of caffeine than under the placebo for words in the primacy position. However, recall under the 2 milligram per kilogram dose was not significantly different than under the 4 milligram per kilogram dose. There were no significant dose differences for the middle or recency positions at either of the first two levels of practice. At the third level of practice, there was no effect of caffeine for words in the primacy position among subjects tested during Phase 2. However, recall for words in the middle position was significantly greater among subjects receiving the 4 milligram per kilogram dose of caffeine than among those receiving either the 2 milligram per kilogram dose or the placebo. The difference in recall between the 2 milligram per kilogram dose and the placebo was not significant, and there was no effect of caffeine for words in the recency position.

Next, a significant rate x serial position interaction was found, $F(6, 1176) = 124.08$ (see Table 6). At the three slowest rates, words from the recency position were recalled more than words from the primacy position which, in turn, were recalled more than words from the middle position, with the recall differences between the three positions being significant. At the .5 second rate, the difference in recall between the primacy and middle position was not significant, and recall at the recency position was significantly greater than at either the primacy or middle position.

Table 6

Mean Proportion of Words Recalled as a Function of Rate of Presentation and Serial Position

	Rate of presentation			
Serial position	1 word/ 5 seconds	1 word/ 3 seconds	1 word/ 1 second	1 word/ .5 seconds
Primacy	.707	.607	.383	.276
Middle	.508	.425	.296	.295
Recency	.743	.767	.817	.782

A significant practice x rate x serial position interaction was observed, $F(12, 2352) = 4.67$ (see Table 7). In general, recall from the recency position was significantly greater than recall from the primacy position which, in turn, was significantly greater than recall from the middle position. Some exceptions to this occurred at practice levels one and three. At the first level of practice, when words were presented at the rate of 1 word every 5 seconds, recall at the recency and primacy positions were not significantly different from each other, but both were significantly greater than recall at the middle position. In addition, at the first level of practice when words were presented at the rate of 1 word every .5 seconds, recall was significantly greater for words in the recency position than for either the primacy or middle positions which were not significantly different from each other. At practice level three, when words were presented at the rate of 1 word per second, words from the recency position were recalled significantly more than words from either the primacy or middle positions, which were not significantly different from each other.

Finally, a significant dose x pill x phase x rate x serial position interaction was found, $F(12, 1176) = 2.295$ (see Table 8). Analysis of this five-way interaction indicated that during Phase 1, dose effects occurred only for oral contraceptive users, only in the primacy position, and only at the two slowest rates. At the 1 word per 5 second rate, the 2 milligram per kilogram dose produced significantly greater recall than either the 4 milligram per kilogram dose or placebo, which were not significantly different from each other. At the 1 word per 3 second rate, both the 2 and 4 milligram per kilogram doses produced significantly greater recall than the placebo,

Table 7

Mean Proportion of Words Recalled as a Function of Level of Practice, Rate of Presentation and Serial Position

Rate of presentation:	1 word/ 5 seconds	1 word/ 3 seconds	1 word/ 1 second	1 word/ .5 second
Level of practice:		One		
Serial position				
Primacy	.711	.578	.373	.306
Middle	.511	.414	.262	.261
Recency	.719	.731	.817	.781
Level of practice:		Two		
Primacy	.712	.610	.410	.258
Middle	.497	.418	.283	.336
Recency	.764	.800	.813	.758
Level of practice:		Three		
Primacy	.698	.633	.365	.329
Middle	.517	.444	.343	.231
Recency	.747	.771	.810	.807

Table 8

Mean Proportion of Words Recalled as a Function of Caffeine Dose, Oral Contraceptive Usage, Phase of Menstrual Cycle, Rate of Presentation, and Serial Position

	Phase 1						Phase 2					
Oral contraceptive usage:	Pill			No pill			Pill			No pill		
Serial position:	P	M	R	P	M	R	P	M	R	P	M	R
Rate of presentation:	1 word/5 seconds											
Caffeine dose												
0 mg/kg	.641	.458	.740	.703	.505	.745	.702	.526	.750	.652	.428	.777
2 mg/kg	.792	552	.766	.661	.469	.802	.661	.557	.755	.721	.517	.683
4 mg/kg	.721	.490	.696	.755	.557	.797	.714	.479	.729	.762	.560	.679
Rate of presentation:	1 word/3 seconds											
0 mg/kg	.479	.417	.786	.552	.370	.828	.677	.432	.734	.511	.409	.758
2 mg/kg	.618	.479	.813	.599	.391	.781	.583	.458	.755	.633	.454	.754
4 mg/kg	.677	.436	.735	.609	.427	.797	.609	.443	.745	.734	.387	.722
Rate of presentation:	1 word/1 second											
0 mg/kg	.354	.286	.792	.307	.276	.839	.375	.313	.823	.314	.295	.860
2 mg/kg	.370	.331	.813	.406	.281	.833	.409	.323	.781	.437	.325	.787
4 mg/kg	.387	.225	.765	.401	.323	.839	.464	.307	.766	.365	.266	.865
Rate of presentation:	1 word/.5 seconds											
0 mg/kg	.307	.240	.750	.318	.208	.797	.297	.318	.813	.261	.303	.795
2 mg/kg	.365	.250	.698	.260	.245	.813	.286	.396	.781	.312	.296	.783
4 mg/kg	.279	.279	.799	.286	.250	.844	.349	.271	.724	.250	.250	.786

with the difference between the 2 and 4 milligram per kilogram doses not being significant. There were no significant dose effects at any other rate or any other position for oral contraceptive users tested during Phase 1, nor were there any significant dose effects for non-oral contraceptive users during Phase 1.

During Phase 2, dose effects were observed for non-oral contraceptive users at the three slowest rates, and for oral contraceptive users at the fastest rate. At the 1 word per 5 second rate among non-oral contraceptive users, the 4 milligram per kilogram dose produced significantly greater recall than either the 2 milligram per kilogram dose or the placebo for words in the middle position, the difference between the 2 milligram per kilogram dose and the placebo not being significant. At this rate there were no significant dose differences at either the primacy or recency positions. When words were presented at the rate of 1 word every 3 seconds, recall for words in the primacy position was significantly greater under the 4 milligram per kilogram dose than under the 2 milligram per kilogram dose which, in turn, was significantly greater than under the placebo. At the rate of 1 word per second, recall for words in the primacy position was significantly greater under the 2 milligram per kilogram dose than under either the 4 milligram per kilogram dose or the placebo, with the difference between these being non-significant. There were no significant differences at either the middle or recency positions for words presented at the 1 word every 3 seconds or the 1 word per second rates. At the 1 word per .5 second rate, no dose effects were found for non-oral contraceptive users. However, for oral contraceptive users, recall for words in the middle position was significantly

greater under the 2 milligram per kilogram dose of caffeine than under either the 4 milligram per kilogram dose or the placebo. Recall under the placebo and 4 milligram per kilogram dose were not significantly different from each other. No dose effects were found for either the primacy or recency position at the 1 word per .5 second rate.

Word intrusions, i.e., words written in the recall which were not presented, were tallied according to the rate of presentation in the list in which they occurred. A 3(Caffeine Dose) x 2(Phase of Cycle) x 2(Pill) x 4(Rate of Presentation) ANOVA was computed with the number of word intrusions as the dependent variable. Serial position was not a factor in this analysis since it would not be meaningful to assign a serial position to words which were not included in the word list.

A significant main effect of rate was observed, $F(3, 588) = 7.352$. Mean intrusions were .826, .848, 1.025, and 1.204 for the 5 second, 3 second, 1 second, and .5 second rates, respectively. Significantly more intrusions occurred when words were presented at the rate of 1 word per .5 seconds than at either 1 word per 5 seconds or at 1 word per 3 seconds. Differences between other rates were not significant.

In addition, a significant phase x pill x rate interaction was found, $F(3, 588) = 3.478$. According to the analysis of this interaction (see Table 9), the significant difference occurred only among oral contraceptive users, who wrote more intrusions when tested during Phase 1 than during Phase 2 for lists presented at the rate of 1 word per .5 seconds. There were no significant differences in the number of intrusions for any other rate or among non-oral contraceptive users.

Table 9

Mean Number of Word Intrusions as a Function of Rate of Presentation, Oral Contraceptive Usage, and Phase of Menstrual Cycle

Oral contraceptive usage:	Pill		No pill	
Phase of cycle:	Days 1-5	Days 9-13	Days 1-5	Days 9-13
Rate of presentation				
1 word/5 seconds	.696	.875	.875	.859
1 word/3 seconds	1.025	.917	.729	.722
1 word/1 second	.877	1.146	.896	1.180
1 word/.5 seconds	1.396	.792	1.167	1.461

Organizational Output Data

The Relative Index of Priority (RIP) procedure was developed by Flores and Brown (1974) to provide an indication of the strategy employed by subjects in their recall of word lists. The RIP scoring procedure involves assigning a score to each word recalled on the basis of its order among the words recalled. All of the words recalled from a list receive a score between -1.000 and +1.000, with words recalled first receiving a positive score and words recalled last receiving a negative score. These scores are summed for each serial position and divided by the number of words recalled for that serial position, yielding a relative index of priority (RIP) score for organizational output which is independent of the number of words recalled.

In general, the most efficient strategy for recalling words from lists would be to recall words from the recency position first, i.e., those words still in short-term memory, followed by rehearsed words from the primacy position next, and the less well rehearsed words from the middle position last. This strategy would yield a high negative RIP score for the primacy position, a low negative RIP score for the middle position, and a positive RIP score for the recency position.

A relative index of priority score was calculated for every subject separately for each serial position (primacy, middle, and recency) at every word list. A 3(Caffeine Dose) x 2(Phase of Cycle) x 2(Pill) x 3 (Level of Practice) x 4(Rate of Presentation) x 3(Serial Position) ANOVA was performed with RIP scores as the dependent variable.

A significant main effect of serial position was observed, $F(2, 384) = 113.11$. The mean RIP scores were -.165, -.212, and +.17[illegible] for the primacy, middle, and recency positions, respectively. Subjects

recalled words from the recency position significantly earlier than words from either the primacy or middle positions. RIP scores from the primacy and middle positions were not significantly different from each other.

A significant phase x serial position interaction occurred, $F(2, 384) = 3.327$ (see Table 10). During both phases, subjects recalled words from the recency position significantly earlier than words from either the primacy or middle positions. However, Phase 1 subjects recalled words from the recency position significantly earlier than Phase 2 subjects, and they recalled words from the middle position significantly later than Phase 2 subjects.

A significant practice x serial position interaction was found, $F(4, 768) = 2.97$. At the first two levels of practice (see Table 11), words from the recency portion of the lists were recalled significantly earlier than words from the primacy portion which, in turn, were recalled significantly earlier than words from the middle portion. At practice level three, neither primacy nor middle words were recalled earlier than each other, although both were recalled significantly later than words from the recency portion.

Final Free Recall Data

The final free recall task was included to provide an indication of the effectiveness of the subjects' rehearsal by determining the proportion of words that had moved into long-term memory from each serial position at each rate of presentation.

The proportion of words recalled from each subject's written final free recall was computed as a function of serial position and rate of

Table 10

Organizational Output of Words Recalled as a Function of Phase of Menstrual Cycle and Serial Position

Serial position	Phase of cycle	
	Days 1-5	Days 9-13
Primacy	-.191	-.138
Middle	-.234	-.190
Recency	+.212	+.136

Table 11

Organizational Output of Words Recalled as a Function of Level of Practice and Serial Position

Serial position	Level of practice		
	One	Two	Three
Primacy	-.134	-.150	-.210
Middle	-.205	-.242	-.189
Recency	+.162	+.182	+.177

presentation. A 3(Caffeine Dose) x 2(Phase of Cycle) x 2(Pill) x 4(Rate of Presentation) x 3(Serial Position) ANOVA was performed with the proportion of words recalled as the dependent variable.

A significant main effect of dose occurred, $F(2, 196) = 3.045$ with means of .136, .158, and .159 for the placebo, 2 milligram per kilogram dose, and 4 milligram per kilogram dose, respectively. Subjects who received caffeine recalled significantly more words than those who received the placebo. The difference in recall between the 2 and 4 milligram per kilogram doses was not significant.

A significant dose x phase x pill interaction also occurred, $F(2, 196) = 3.078$ (see Table 12). A subsequent analysis of this interaction revealed that oral contraceptive users tested during Phase 1 had significantly higher recall under the 2 milligram per kilogram dose of caffeine than under the placebo. Recall under the 4 milligram per kilogram dose was not significantly different than the 2 milligram per kilogram dose or the placebo. In addition, no significant dose differences occurred for non-oral contraceptive users or for oral contraceptive users tested during Phase 2.

A significant main effect of rate occurred, $F(3, 588) = 209.35$, with recall means of .243, .199, .095, and .067 for the rates of 5 seconds, 3 seconds, 1 second, and .5 second, respectively. Significant differences were observed between each rate of presentation with the proportion of words recalled declining as the rate of presentation increased.

A significant main effect of serial position was observed, $F(2, 392) = 74.88$. Recall means of .190, .139, and .123 were found for the primacy, middle, and recency positions, respectively. Words from the

Table 12

Mean Proportion of Words Recalled in the Final Free Recall as a Function of Caffeine Dose, Oral Contraceptive Usage, and Phase of Menstrual Cycle

Oral contraceptive usage:	Pill		No pill	
Phase of menstrual cycle:	Days 1-5	Days 9-13	Days 1-5	Days 9-13
Caffeine dose				
0 mg/kg	.121	.160	.139	.123
2 mg/kg	.182	.150	.142	.159
4 mg/kg	.160	.164	.151	.160

primacy portion of the lists were recalled significantly more than words from the middle portion and these, in turn, were recalled significantly more than words from the recency portion of the list.

Finally, a significant rate x serial position interaction occurred, $F(6, 1176) = 33.97$. Analysis of this interaction (see Table 13) indicated that the main effect of rate occurred for words in the primacy and middle positions, with recall declining significantly as the rate increased at each of the four rates. This effect was modified somewhat for words in the recency position. Words presented at the 1 word per 5 seconds rate were recalled significantly more than words at the 1 word per 3 seconds. However, the difference in recall between words presented at the 1 word per second rate and those presented at the 1 word per .5 second rate was not significant, although the rate of recall at both of these rates was significantly less than at the 1 word per 3 seconds rate.

The number of word intrusions occurring in each subject's final free recall was tallied. The number of intrusions ranged from 0 to 17, with group means ranging from 1.94 to 3.37 intrusions. A 3(Caffeine Dose) x 2(Pill) x 2(Phase of Cycle) ANOVA was computed with the number of word intrusions occurring in the final free recall as the dependent variable. No significant differences among the groups were found.

Individual Differences

In order to determine if the effects observed in this experiment may have been the result of differences among groups on individual characteristics, a series of ANOVAs was computed using a variety of individual difference measures as the dependent variable. In instances

Table 13

Mean Proportion of Words Recalled in the Final Free Recall as a Function of Rate of Presentation and Serial Position

	Serial position		
Rate of presentation	Primacy	Middle	Recency
1 word/5 seconds	.318	.238	.173
1 word/3 seconds	.271	.185	.141
1 word/1 second	.113	.086	.086
1 word/.5 seconds	.058	.048	.094

where data were missing, the ANOVA was computed based upon the number of observations available. The means for each group are displayed in Table 1.

Two 3(Caffeine Dose) x 2(Pill) x 2(Phase of Cycle) ANOVAs were computed with subjects' age and weight as dependent variables. No significant differences among groups occurred for these measures.

Two 3(Caffeine Dose) x 2(Pill) x 2(Phase of Cycle) ANOVAs were computed using subjects' WAIS-R vocabulary subtest raw and scaled scores. The analysis of the raw scores revealed a significant pill x phase interaction, $F(1, 193) = 4.26$ (see Table 14). A subsequent analysis of this interaction indicated that non-oral contraceptive users tested during Phase 2 had significantly higher WAIS-R raw scores than those tested during Phase 1. There were no significant phase differences among oral contraceptive users or among subjects tested during Phase 1.

In addition, a significant dose x pill x phase interaction was observed for subjects' WAIS-R raw scores, $F(2, 193) = 3.365$. A subsequent analysis of this three-way interaction (see Table 15) indicated that among subjects tested during Phase 1, oral contraceptive users receiving the 2 milligram per kilogram dose had WAIS-R vocabulary raw scores which were significantly higher than those receiving either the 4 milligram per kilogram dose or the placebo. There was no significant difference between the 4 milligram per kilogram dose group and the placebo group on WAIS-R raw scores. However, among non-oral contraceptive users tested during Phase 1, those receiving the 4 milligram per kilogram dose had significantly higher WAIS-R raw scores than those receiving either the 2 milligram per kilogram dose or

Table 14

Mean Raw Scores on WAIS-R Vocabulary Subtest as a Function of Oral Contraceptive Usage and Phase of Cycle

Oral contraceptive usage	Phase of cycle	
	Days 1-5	Days 9-13
Pill	41.609	40.353
No pill	40.042	43.652

Table 16

Mean Lie Score on the Eysenck Personality Inventory as a Function of Caffeine Dose and Phase of Menstrual Cycle

	Phase of cycle	
Dose of caffeine	Days 1-5	Days 9-13
0 mg/kg	2.78	2.29
2 mg/kg	3.31	2.49
4 mg/kg	1.66	2.54

cigarettes smoked as dependent variables. No significant differences among groups occurred for any of these measures.

Two 3(Caffeine Dose) x 2(Pill) x 2(Phase of Cycle) ANOVAs were computed using subjects' pretest and posttest scores on the Thayer Activation Deactivation Checklist as dependent variables. No significant differences among groups occurred for either pretest or posttest scores.

A series of 3(Caffeine Dose) x 2(Pill) x 2(Phase of Cycle) ANOVAs was computed using measures from subjects' pretest and posttest blood pressure readings as the dependent variables. The measures included the systolic reading, the diastolic reading, the difference (systolic minus diastolic), and the ratio of systolic to diastolic reading.

Among the pretest measures, no significant differences among groups were noted for either the systolic or diastolic readings. For the difference reading, a significant dose x pill x phase interaction was observed, $F(2, 196) = 3.68$. Subsequent analysis of this interaction using the Newman-Keuls procedure failed to reveal significant differences among groups. However, as may be seen in Table 17, there appeared to be a trend among oral contraceptive users tested during Phase 1 toward higher difference scores in the placebo group than in either the 2 milligram per kilogram or 4 milligram per kilogram group.

A significant dose x pill x phase interaction was also found for the pretest ratio systolic to diastolic reading, $F(2, 196) = 4.33$ (see Table 18). Analysis of this interaction revealed that among subjects receiving the 4 milligram per kilogram dose who were tested during Phase 1, non-oral contraceptive users had significantly higher ratio

Table 17

Mean Difference (Systolic Minus Diastolic) Readings of Pretest Blood Pressure as a Function of Caffeine Dose, Oral Contraceptive Usage, and Phase of Menstrual Cycle

Phase of cycle:	Days 1-5		Days 9-13	
Oral contraceptive usage:	Pill	No pill	Pill	No pill
Caffeine dose				
0 mg/kg	43.313	37.688	41.250	42.864
2 mg/kg	37.188	42.625	40.625	38.750
4 mg/kg	37.706	42.688	41.250	38.524

Table 18

Mean Ratio (of Systolic to Diastolic) Readings of Pretest Blood Pressure as a Function of Caffeine Dose, Oral Contraceptive Usage, and Phase of Menstrual Cycle

Phase of cycle:	Days 1-5		Days 9-13	
Oral contraceptive usage:	Pill	No pill	Pill	No pill
Caffeine dose				
0 mg/kg	1.632	1.522	1.597	1.602
2 mg/kg	1.540	1.612	1.574	1.532
4 mg/kg	1.502	1.653	1.615	1.548

blood pressures than oral contraceptive users. This difference in ratio blood pressure between oral contraceptive users and non-oral contraceptive users occurred only in the 4 milligram per kilogram dose group and only during Phase 1.

Among the posttest blood pressure ANOVAs, a significant main effect of dose was observed using subjects' diastolic blood pressure readings as the dependent variable, $F(2, 193) = 5.16$. The mean diastolic readings were 70.819, 74.351, and 74.661 for the placebo, 2 milligram per kilogram and 4 milligram per kilogram doses, respectively. Subjects who received caffeine had significantly higher diastolic readings than those who received the placebo. The difference between the 2 milligram per kilogram and 4 milligram per kilogram doses was not significant. No significant differences occurred on any other posttest blood pressure measures.

Two 3(Caffeine Dose) x 2(Pill) x 2(Phase of Cycle) ANOVAs were computed using subjects' pretest and posttest pulse readings as dependent variables. For the pretest pulse measure, a significant main effect of dose was observed, $F(2, 194) = 3.79$. Mean pretest pulse readings were 73.445, 69.698, and 74.872 for the placebo, 2 milligram per kilogram, and 4 milligram per kilogram doses, respectively. A subsequent analysis of this effect indicated that subjects receiving the 4 milligram per kilogram dose had significantly higher pretest pulse readings than those receiving the 2 milligram per kilogram dose, with the difference observed between the 4 milligram per kilogram dose and the placebo being non-significant.

The posttest pulse ANOVA revealed a significant main effect of dose, $F(2, 190) = 6.72$, with mean pulse readings of 69.175, 63.633, and

67.597 for the placebo, 2 milligram per kilogram and 4 milligram per kilogram doses, respectively. This effect indicated that subjects receiving the placebo or 4 milligram per kilogram dose had significantly higher posttest pulse readings than those receiving the 2 milligram per kilogram dose. The placebo was not significantly different from the 4 milligram per kilogram dose.

In addition, the posttest pulse ANOVA revealed a significant main effect of pill, $F(1, 190) = 6.145$, with means of 68.368 and 65.224 for the pill and no pill groups, respectively. Oral contraceptive users had significantly higher posttest pulse readings than non-oral contraceptive users.

The length of the menstrual cycle during which subjects were tested was determined by contacting subjects to ascertain when their next menstrual period, subsequent to the experiment, had occurred, and computing the number of days since their last period. The cycle length was obtained for 206 out of 208 subjects. Cycle lengths obtained ranged from 20 days to 49 days. The range and mean menstrual cycle length for each caffeine dose and phase for oral contraceptive and non-oral contraceptive users are given in Table 19. A 3(Caffeine Dose) x 2(Pill) x 2(Phase of Cycle) ANOVA was computed using the length of subjects' menstrual cycle as the dependent variable. No significant differences among groups were found for the length of the cycle.

Table 19

Range and Mean Length of Menstrual Cycle as a Function of Caffeine Dose, Oral Contraceptive Usage, and Phase of Cycle

Phase of cycle:	Days 1-5			Days 9-13		
Caffeine dose:	0 mg/kg	2 mg/kg	4 mg/kg	0 mg/kg	2 mg/kg	4 mg/kg
Oral contraceptive usage:	Pill					
Range (in days)	27-35	26-33	27-49	23-30	26-35	27-43
Mean	29.19	28.44	30.18	27.73	28.19	29.56
	No pill					
Range (in days)	21-44	24-49	25-40	20-44	23-41	21-37
Mean	29.19	31.13	29.81	29.14	28.45	29.29

DISCUSSION

The results of this experiment extend the work of Arnold et al. (1987) to suggest that caffeine facilitates word recall performance at differential levels of practice, yet the pattern of effects depends upon endogenous hormone levels. The caffeine dose x serial position interaction indicated that the facilitory effect of caffeine occurred primarily for words in the primacy portion of the lists. This suggests that caffeine influenced the efficiency of rehearsal processes or the efficiency with which the information was manipulated in working memory (Brodie & Prytulak, 1975).

Previous caffeine research (Arnold et al., 1987; Erikson et al. 1985) had not demonstrated a clear relationship between caffeine dose and serial position, with the caffeine and serial position effects being additive. No consistent relationship between caffeine dose and rate of presentation had been observed either. The larger cell sizes in the present experiment relative to earlier research might have allowed a more sensitive test of this interaction in the present study. In the present experiment, there was a minimum of 16 subjects per cell. In Arnold et al. (1987), the smallest cell contained 12 subjects, while in Erikson et al. (1985), some cells contained as few as six subjects. Previous research has demonstrated that the effect of caffeine on memory performance is subtle and difficult to pinpoint. The significant main effect of caffeine and the interaction of caffeine with other factors such as serial position and rate of presentation in

the present experiment may be attributed to the fact that the sample size was large enough to provide the power necessary to detect effects which are subtle. Brodie and Prytulak (1975) found that rate of presentation and serial position both affected the efficiency of rehearsal, with slower rates providing longer time for rehearsal prior to recall, especially for words at the beginning of a word list. This is relevant in the present experiment where caffeine effects were observed primarily at the slower presentation rates. Brodie and Prytulak (1975) demonstrated that rate of presentation affects rehearsal efficiency, with a slower rate of presentation improving rehearsal efficiency for words in the primacy portion of word lists by allowing a longer time to practice items between presentation of new items and prior to recall. In the present experiment, it appears that caffeine boosted the efficiency of word rehearsal for words in the primacy position when those words were presented at rates slow enough to allow rehearsal time. It seems likely that the combined effect of caffeine dose, serial position, and rate of presentation in the present experiment may be attributable to the fact that this experiment employed a sample size large enough to detect this subtle, previously elusive effect of caffeine.

The effect of caffeine on the efficiency of rehearsal processes and the transfer of information into long-term memory is further supported by the main effect of caffeine dose in the final free recall task. Craik (1970) demonstrated better recall for words from the primacy position than the recency position of word lists in a task which required subjects to write a final free recall of 10 lists which had been presented and recalled. The present study found a main effect

of caffeine dose for the final free recall task which indicated that recall of words from the primacy portion of the word lists was significantly better among subjects who had received caffeine than among subjects who had received the placebo.

The fact that caffeine facilitated recall for words in the primacy portion of the lists, suggesting increased efficiency of working memory operations (i.e., rehearsal), is inconsistent with the Humphreys and Revelle model (1984). The model suggests that trait levels of impulsivity interact with stimulant drugs such as caffeine to produce a state level of arousal. The model postulates that high levels of arousal will impair performance on tasks that place heavy demands on working memory operations and require that information be maintained in working memory. The present word list recall task would be such a task, requiring subjects to divide their attention and taxing their information processing capacity. The model predicts that stimulant drugs would increase arousal and impair performance on tasks placing heavy demands on working memory. In the present experiment, no performance impairment was observed; rather, performance was facilitated among subjects administered the stimulant drug caffeine. The finding of a facilitory effect of caffeine under these conditions is inconsistent with the predictions of Humphreys and Revelle (1984). Alternatively it could be argued that word list recall does not place heavy demands on working memory operations. However, developmental differences and adult age differences (Perlmutter, 1978) are frequently found in studies of word list recall, suggesting that the task requires effortful cognitive processing for successful performance (Hasher & Zacks, 1979), as failures in task performance are explained as

inefficient working memory operations (Hagen & Stanovich, 1977). Although no study has directly assessed the amount of working memory capacity expended when processing word lists, the sensitivity of the task to individual differences in age clearly suggests that it places demands on working memory operations.

Previous research had yielded conflicting results concerning the effect of caffeine on memory for word lists among women. Erikson et al. (1985) found a sex difference in the effect of caffeine such that caffeine impaired memory among females when words were presented at a slow (1 word every 3 seconds) rate. In a replication of the work of Erikson et al. (1985), Arnold et al. (1987) found that caffeine facilitated recall among females after practice with the task. In the Erikson et al. (1985) study, female subjects were tested without regard to oral contraceptive usage or phase of menstrual cycle. In the work of Arnold et al. (1987), female subjects were tested only during one of the first 5 days of the menstrual cycle in order to ensure that the hormone levels of all female subjects would be similar. In addition, individuals taking medications, including oral contraceptives which might alter their hormone levels, were eliminated from the Arnold et al. (1987) study as were women who did not experience menstrual cycles. One explanation for these differences was that the cyclical fluctuations in hormones present in a female subject's system might modulate any effect of caffeine. Thus, the effect of caffeine in a woman might vary according to the phase of the menstrual cycle during which she was tested.

The present study tested subjects during one of two distinct points during the menstrual cycle. Phase 1 subjects were tested

during one of the first 5 days of the menstrual cycle, the time during the cycle when the level of estrogen is lowest (Asso, 1983). Phase 2 subjects were tested between Day 9 and Day 13, the time during the cycle when estrogen reaches its peak level (Asso, 1983). In addition, this study contrasted the performance of non-oral contraceptive users who experienced naturally occurring cyclical fluctuations in their level of endogenous hormones with that of oral contraceptive users whose level of estrogen remained relatively stable across the cycle because of the synthetic estrogen contained in oral contraceptives (American Medical Association, 1986).

Support for the hypothesis that fluctuating hormone levels modulate the effect of caffeine is found in the interpretation of several of the higher order interactions involving caffeine in the present study. The caffeine dose x pill x phase of cycle x rate x serial position interaction provides some evidence that estrogen interacts with caffeine to affect performance on a memory task. Caffeine effects occurred only among oral contraceptive users during Phase 1 and primarily among non-oral contraceptive users during Phase 2 (see Table 8). This is consistent with the hypothesis that estrogen would interact with caffeine to facilitate recall performance. During the first five days of the menstrual cycle, oral contraceptive users should have a higher level of estrogen in their systems than non-oral contraceptive users because the oral contraceptive inhibits the naturally occurring drop in estrogen levels during the menstrual phase. The hypothesis that estrogen would facilitate the effect of caffeine is consistent with oral contraceptive users' better performance during this time. During Phase 2, the time of the naturally occurring

estrogen peak among non-oral contraceptive users, the level of estrogen among oral contraceptive users should be considerably lower than that of non-oral contraceptive users (American Medical Association, 1986). Thus, the better recall among non-oral contraceptive users during Phase 2 is also consistent with the hypothesis.

Unfortunately, the clarity of the five-way interaction involving caffeine and phase of cycle is complicated by the fact that caffeine facilitated recall performance for words in the middle position among oral contraceptive users during Phase 2 (i.e. those subjects whose level of estrogen is held artificially low during this time in order to prevent ovulation) when words were presented at the fastest rate of 1 word every .5 second. One possible explanation of this is that the extremely rapid rate may have influenced the effect of caffeine in ways that are unclear. In the task of recalling words presented at the rapid rate of 1 word per .5 second, there is minimal time for rehearsal and the item retention interval, i.e., the length of time between presentation of the word and recall, is extremely short. In addition, when using lists of 12 words in length, it becomes less clear whether words in the middle position of the list receive additional rehearsals as well.

A similar argument may explain the significantly greater recall with caffeine for words in the middle position during Phase 2 among non-oral contraceptive users when words were presented at the slowest rate of 1 word every 5 seconds. One possible explanation of the significant difference for words in the middle position is that extreme rate modified the effect of caffeine. When words were presented at the rate of one word every 5 seconds, there was ample time for rehearsal.

However, the item retention interval for words in the primacy position was extremely long and may account for the fact that significant dose effects did not occur for words in the primacy position (Brodie & Prytulak, 1975). Recall means for words in the primacy position among non-oral contraceptive users at the slowest rate during Phase 2 were .652, .721, and .762 for the placebo, 2 milligram per kilogram and 4 milligram per kilogram doses, respectively. An examination of these means indicates that subjects' recall was improved with caffeine, particularly under the 4 milligram per kilogram dose; however, the improvement was not large enough to achieve significance. Thus, one can argue that caffeine did facilitate performance for words in the primacy position at the slowest rate; however, the effect was not great enough to be statistically significant.

The significant caffeine dose x phase of cycle x practice x serial position interaction further supports the hypothesis that estrogen interacts with caffeine to facilitate long-term memory performance. According to this interaction, at the first two levels of practice, there was no effect of caffeine during Phase 1, when the level of estrogen is low (averaged across oral contraceptive users and non-oral contraceptive users). During Phase 2, the estrogen peak, caffeine facilitated recall of words from the primacy portion of the list at both the first and second levels of practice. At the third level of practice, caffeine effects occurred during both phases and, during Phase 2, caffeine significantly increased recall for words in the middle position, rather than in the primacy position. The finding that caffeine facilitated recall at the third level of practice but not the first two levels of practice during Phase 1 is congruent with

the results of earlier research. Arnold et al. (1987) found that caffeine facilitated recall at the third level of practice among females tested during the first 5 days of the menstrual cycle. One could speculate that estrogen interacts with caffeine to affect performance at repetitive tasks, with more practice required to facilitate recall when the level of estrogen is low. It could be hypothesized that practice improves performance with caffeine when estrogen levels are low, but the facilitory effect of high estrogen on caffeine diminishes with practice.

The reason for the shift in the facilitory effect of caffeine and estrogen at the third level of practice during Phase 2 for words in the middle position is unknown, especially since the facilitory effect for the words in the primacy position failed to occur. The possibility exists that task repetition caused a shift in the focus of subjects' attention.

The hypothesis that caffeine and estrogen interact to facilitate long-term memory recall is further supported by the finding of a significant caffeine dose x pill x phase of cycle interaction for words written in the final free recall task. Oral contraceptive users tested during Phase 1, the group with the higher level of estrogen, had a higher proportion of recall under the 2 milligram per kilogram caffeine dose than non-oral contraceptive users, the group with the lower level of estrogen during Phase 1. During Phase 2, a reversal of this effect occurred with non-oral contraceptive users who received caffeine recalling a higher proportion of words than oral contraceptive users. An examination of the means (see Table 12) reveals a large difference between the caffeine and placebo doses for the high estrogen

groups, i.e. Phase 1 oral contraceptive users and Phase 2 non-oral contraceptive users. For oral contraceptive users tested during Phase 1, both the 2 milligram per kilogram and 4 milligram per kilogram doses produce greater recall than the placebo, although only the 2 milligram per kilogram dose produces a significant difference. For non-oral contraceptive users tested during Phase 2, a similar pattern exists with greater recall occurring under the 2 milligram per kilogram and 4 milligram per kilogram doses, although in this case, the differences are not large enough to reach significance. Among the low estrogen groups, i.e., non-oral contraceptive users tested during Phase 1, and oral contraceptive users tested during Phase 2, there is little difference among the means for different doses.

Analysis of word intrusions, i.e., words written in the recall which were not presented in the lists, revealed a significant phase x pill x rate of presentation interaction wherein oral contraceptive users tested during the first 5 days of the menstrual cycle had significantly more intrusions than the other groups. This result seems inconsistent with our hypothesis that caffeine and estrogen interact to facilitate performance on this cognitive task. The occurrence of an intrusion is typically interpreted to reflect an imprecise memory for the original information. The fact that caffeine dose did not influence the number of intrusions suggests that perhaps the increased rate of intrusions occurred for some other reason.

As in previous research, there appeared to be no clear relationship between the 2 milligram per kilogram dose and the 4 milligram per kilogram dose of caffeine. At times, both dosages produced effects; however, only infrequently was the relationship

linear, i.e., increasing effects with increasing dose levels. More frequently, the 2 milligram per kilogram dose produced a significant effect while the placebo and 4 milligram per kilogram dose produced no effect, or else the 4 milligram per kilogram dose produced the effect while the 2 milligram per kilogram dose was not significant. The reasons for this are unclear, and no discernible pattern seems to occur. A possible explanation for the variability of effect is that there may be variability in subjects' caffeine consumption habits or other habits to account for differences in dose effects. The analysis of caffeine consumption scores does not support this since no difference between groups emerged in the analysis of either typical caffeine consumption or caffeine consumption during the 3 days prior to the experiment. However, perhaps some variable which was not measured is a causal factor.

Individual Differences

Several potential confounding variables were uncovered in the analyses of individual differences. In the analysis of WAIS-R vocabulary subtest raw scores, two interactions were observed. In the first of these, non-oral contraceptive users tested during the second phase had significantly higher WAIS-R vocabulary subtest raw scores than non-oral contraceptive users tested during the first phase. In the second interaction, oral contraceptive users tested during Phase 1 who received the 2 milligram per kilogram dose of caffeine had significantly higher WAIS-R vocabulary subtest raw scores than those under the placebo. However, no significant differences emerged when the WAIS-R vocabulary scaled scores were analyzed. The scaled scores

were taken from Appendix D of the WAIS-R Manual (Weschler, 1981) which gives the scaled score equivalent of the raw scores by age groups. The purpose of these scaled scores is to permit a subject's score "to be interpreted in relation to the performance of the subject's age peers" (p. 139). Thus, when individual subject's raw scores on the vocabulary test were compared with other subjects in the same age bracket, there were no significant differences among the dose x phase x pill groups. Therefore, it may be argued that the WAIS-R vocabulary subtest raw scores were not a serious confounding factor.

Another potential confounding variable was the lie score on the Eysenck Personality Inventory. Analysis of this variable revealed a significant main effect of dose as well as a significant caffeine dose x phase of cycle interaction indicating that subjects receiving the 4 milligram per kilogram dose during Phase 1 had significantly lower lie scores than the rest of the subjects at either of the phases. The fact that the lie scores were lower rather than higher seems to indicate that this group of subjects was significantly more honest and self-aware in responding to the questions on the Eysenck Personality Inventory. Apparently, their candor in answering the questions did not cause them to be significantly different from the other groups with regard to introversion/extraversion, sociability, or impulsivity, since these analyses revealed no significant differences among groups. Since subjects took the Eysenck Personality Inventory prior to being selected for the experiment, and since they were assigned to groups based upon their impulsivity scores rather than their lie scores, it can reasonably be argued that the concentration of low lie scores in

this group is due to random chance rather than to some difference in this group which would affect caffeine dose or phase of cycle.

Analysis of the systolic (i.e., the greatest pressure caused by the contraction of the heart) and diastolic (i.e., the pressure during the relaxation phase between heart beats) blood pressures and the ratio blood pressure dependent measures revealed some differences between groups. The ANOVA of the difference scores (i.e., the systolic reading minus the diastolic reading) indicated that oral contraceptive users tested during Phase 1 who received the placebo had higher pretest difference scores than those receiving caffeine. This effect failed to achieve significance in the post hoc analysis and, thus, is not considered a robust finding which seriously compromises the experiment. Analysis of the pretest ratio blood pressure measure indicated that, among non-oral contraceptive users tested during Phase 1, those receiving the 4 milligram per kilogram dose had significantly higher ratio blood pressure scores than those receiving either the 2 milligram per kilogram dose or the placebo. That this group is different than the other groups on this measure is clear; less clear is the meaning of this particular measure. This measure is achieved by dividing the systolic blood pressure reading by the diastolic blood pressure reading. Analyses of the systolic and diastolic measures failed to reveal any significant differences among groups. Therefore, the difference among groups on the ratio score reflects some difference in the way the systolic and diastolic readings combined in the Phase 1 oral contraceptive users who received the 4 milligram per kilogram dose.

Among the posttest blood pressure readings, a significant difference among groups was observed for subjects' diastolic readings.

Caffeine is known to increase blood pressure (Rall, 1980); in fact, this was the rationale for eliminating subjects from the study who had greater than high average blood pressure readings (over 140/90). Therefore, it was not unexpected that subjects receiving either the 2 milligram per kilogram or the 4 milligram per kilogram dose of caffeine had significantly higher posttest diastolic readings. This finding provided some physiological evidence that the amount of caffeine administered to subjects was adequate to have an impact upon them.

The blood pressure readings were indirect, external measurements taken manually by experimenters using a sphygmomanometer with a dial and a stethoscope. In using this device, the needle moves along the dial as the experimenter listens for the beat in order to determine the appropriate blood pressure reading. It is possible that differences in experimenters' auditory thresholds could have been a complicating factor in all of the physiological measures which may have resulted in differences among groups on some measures. However, since experimenters were randomly distributed across the cells of the design, one would not expect to find individual differences between groups on physiological measures.

Each subject's pulse was taken before and 25 minutes after receiving caffeine or the placebo. Analysis of the pretest pulse readings revealed a significant main effect of caffeine dose, such that subjects receiving the 4 milligram per kilogram dose had significantly higher pretest pulse readings than subjects receiving the 2 milligram per kilogram dose. Thus there were differences in the groups in their rate of heartbeat, even prior to the administration of caffeine. The

significantly higher pulse readings of this group extended to the posttest reading as well. Furthermore, in the posttest pulse ANOVA, oral contraceptive users had significantly higher pulse rates than non-oral contraceptive users. The reasons for these differences in pulse rates are unknown and constitute potential confounding variables in the present experiment. However, the selected appearance of caffeine effects argues against this as a robust confound. That is, if it were a serious confound, then dose effects should have occurred consistently throughout the analysis.

Critique of the Present Study

One potential shortcoming of the present study was that level of impulsivity was not included as a separate factor. The decision not to include impulsivity as a factor was made for practical reasons. The number of subjects needed to include impulsivity as a separate factor would be extremely large. Also, previous research (Arnold et al., 1987; Erikson et al., 1985) failed to find any effect of impulsivity on word list recall. The focus of the present study was to examine the potential interactive effect of endogenous hormone levels and caffeine. Therefore, it was decided that levels of impulsivity, as measured by the impulsivity subscale of the Eysenck Personality Inventory, would be balanced across cells so that both high and low impulsive subjects were included in each cell. This ensured that the effect of caffeine would not be the result of group differences on the variable of impulsivity; yet it weakened the ability of the experiment to detect any effect of impulsivity. However, since previous caffeine research has failed to support the theoretical interaction of caffeine and impulsivity, the

decision not to include impulsivity as a separate factor in the present study seemed prudent.

One of the major shortcomings of the present study was the lack of clarity and precision in distinguishing among estrogen levels. Subjects were assigned to groups based upon their self-reported first day of the menstrual period. The usual concerns about inaccurate self-report data apply to this study although every effort was made to double check information in order to identify and resolve discrepancies. Subjects were asked to identify the date on which their period began both at the time of setting up the appointment and again upon arrival for their appointment. At that time, they were reminded that they would be contacted to find out when their next period began, and were contacted periodically subsequent to their appointment in order to insure accuracy on their report of the date on which their period following the experiment began. Despite these precautions, it is likely that some of the self-report data of menstrual cycles is inaccurate.

The problems caused by the self-report nature of the data are further complicated by variation among subjects in length of menstrual cycle. Phase 2 subjects were tested during a 5-day period beginning 9 days following the self-reported onset of menstruation. This time frame was chosen based upon the theoretical 28-day cycle, as described by Asso (1983). Some subjects had menstrual cycles as short as 20 days, others as long as 49 days. According to Asso, the time of ovulation, which follows the estrogen peak within a day or two, can be determined only by counting backward from the onset of the next menstrual period. Thus, for a subject with a 49-day period, her

estrogen peak may have occurred on Day 33 of her cycle, whereas for a subject with a 20-day period, her estrogen peak may have occurred on Day 5. Therefore, since all Phase 2 subjects were tested 9 to 13 days after the onset of menstruation, it is very probable that the estrogen peak was missed for some of the subjects. Since the data from all of the subjects was included in the analysis, it is certain that some of the Phase 2 data does not truly reflect the performance of subjects tested during their estrogen peak. However, subjects tested during Phase 2 undoubtedly had somewhat higher estrogen levels than those tested during Phase 1, because of the fact that estrogen is at its lowest level of the menstrual cycle only during the first 5 days, i.e., during Phase 1. While the cyclical estrogen peaks of Phase 2 subjects may have been missed, it is likely that their estrogen levels were higher than those of Phase 1 subjects. This suggests that the present data underestimate the true extent of estrogen effects that would be observed if the estrogen peak were precisely determined.

A further shortcoming of the present experiment is that there was no way to identify subjects who had anovulatory cycles, another condition which would indicate possible irregular levels of estrogen. In previous menstrual cycle research which utilized basal body temperature as an indicator of ovulation (Broverman et al., 1981), 24% of subjects were identified as having anovulatory cycles. The Broverman et al. (1981) study was conducted on a college population similar to that employed in the present study. In the present experiment, identifying subjects with anovulatory cycles was not possible because temperatures were not taken. It is very likely that the present sample included subjects with anovulatory cycles and the

level of estrogen in their systems remains unknown without blood sampling to provide that information. The finding of phase effects despite this conservative manipulation of estrogen suggests that the modulatory effect of estrogen on caffeine may be underestimated in the present study.

Lack of information concerning the specific level of estrogen in the body also presents difficulty among the oral contraceptive using groups. In some of the interpretations of the interactive effects of caffeine and estrogen, the point was made that caffeine facilitated recall among groups with high levels of estrogen in their systems, i.e., oral contraceptive users during Phase 1 and non-oral contraceptive users during Phase 2. However, estrogen containing oral contraceptives keep blood levels of estrogen relatively stable across the menstrual cycle (Ling et al., 1985). Thus, oral contraceptive users tested during Phase 1 should have estrogen levels approximately equivalent to oral contraceptive users tested during Phase 2, and one might logically expect the effects of caffeine on oral contraceptive users to be the same during both phases. This was not the case in the present experiment. It is impossible to tell from the information gathered in this experiment if the effect of phase of cycle, which is hypothesized to reflect different endogenous levels of estrogen, is actually attributable to different estrogen levels without independent confirmation of estrogen levels, especially in oral contraceptive users. Radioimmunoassay of blood samples would provide such a confirmation.

Another shortcoming of this experiment which is related to the issue of oral contraceptives concerns the comparability of different

oral contraceptives with regard to level of estrogen. In the present study, only subjects who used estrogen containing oral contraceptives were included in the oral contraceptive sample. However, this still leaves a great deal of variability in this sample, since some subjects used oral contraceptives which contained low doses of estrogen, as low as 35 micrograms, while others used products containing as much as 100 micrograms of estrogen. Furthermore, some subjects were using biphasic oral contraceptives while others used a triphasic variety. Phasic oral contraceptives contain a variable dose of progestin depending upon the day of the cycle. Biphasic regimens consist of two types of pills, with each type containing a different level of progestin. Triphasic regimens contain three types of pills with different levels of progestin. Thus, oral contraceptive users in the experiment are ingesting somewhat different levels of synthetic progestin at various points of the menstrual cycle. While information regarding exact brand of oral contraceptive was obtained for each subject, it is still difficult to make a determination of the level of estrogen present in a subject's system without the use of blood analysis. In the present study, the inclusion of subjects with various levels of estrogen in their systems resulted in a conservative manipulation of estrogen which may underestimate its effect.

Recommendations for Future Research

Since it has been difficult traditionally to produce significant effects in experiments examining variations in performance associated with the menstrual cycle, it would seem prudent to replicate the present experiment to see if the results obtained in this experiment are valid.

In future research, it would be useful to test subjects during at least one other phase of the menstrual cycle. Doing so would provide a more comprehensive picture of the cyclical variability of caffeine-influenced memory performance. Previous caffeine research has demonstrated that caffeine both facilitates (Arnold et al., 1987) and impairs (Erikson et al., 1985) the performance of women on word list recall. The central hypothesis of the present study has been that estrogen interacts with caffeine to influence performance. A facilitory effect was observed in the present work. It is likely that the relationship between hormones and caffeine is far more complex and has greater variation than has been observed in the present experiment. Since some evidence of memory impairment was found by Erikson et al. (1985), studying the effect of caffeine during other phases of the menstrual cycle might clarify the nature of any caffeine induced memory impairment. Other research has focused on different aspects of hormonal variation such as estrogen versus progesterone (Broverman et al., 1981). It would be interesting to study the effect of caffeine on memory during the mid-luteal phase when the level of estrogen is at midpoint and the level of progesterone peaks. A study such as this would provide three points of comparison with regard to estrogen level and two very distinct points of comparison for progesterone level.

A further recommendation for future research is that greater attention be given to pinpointing of the pre-ovulatory estrogen peak for individual subjects. In the present study, no attempt was made to do this except for eliminating subjects who reported that they had very irregular or extremely long cycles. Other researchers (Broverman et al., 1981; Graham, 1980) have attempted to do this by a variety of

methods. Broverman et al. (1981) used basal body temperature readings to determine whether ovulation occurred for individual subjects and made the assumption that if ovulation had occurred then the preovulatory estrogen peak had also occurred. Medical research seems to support this inference. Graham (1980) varied the time of the testing according to an estimate of when ovulation would occur, based upon basal body temperature readings from the previous cycle. A shortcoming of this method is that among younger subjects in particular, cycle length one month may not be a good predictor of cycle length the following month.

Thirdly, it would be useful to include additional tasks in future research. The results of the present study fit well into the caffeine literature; however, this type of task, i.e., word list recall, has not been attempted before in studying cyclical variations in cognitive performance. The use of this task adds a new, rather rich dimension to that literature. However, it would be useful to tie this measure into the existing literature by including some perceptual restructuring tasks used in previous studies when replicating the present study. This might provide a more comprehensive interpretation of the variation in cognitive performance that has been available up to this point.

Finally, the strongest asset to any future design aimed at examining variations in performance associated with estrogen level would be the use of analysis of estrogen levels and other hormone levels in the blood. This is the only truly accurate way of determining the concentration of estrogen in a subject's system at a particular time. Graham (1980) utilized assays from subjects' urine samples but indicated that this was too gross a measure. Her

recommendation that menstrual cycle research needs to employ blood sampling techniques still stands. Unfortunately, the high cost of such sampling makes its use prohibitive for researchers without sources of funding.

APPENDICES

APPENDIX A

CAFFEINE CONSUMPTION QUESTIONNAIRE I

CAFFEINE CONSUMPTION QUESTIONNAIRE I

1. Do you drink coffee regularly? _____Yes _____No

2. If yes, how many cups per day? (Circle one)

   1 2 3 4 5 6 7 8 9 10 or more

3. What time of day, primarily, do you drink coffee?

   _____Morning _____Noon to evening

   _____After supper _____Throughout the day

4. Do you regularly drink soda pop? _____Yes _____No

5. If so, what kind do you usually drink? _____

6. If you do regularly drink soda pop, about how many ounces per day? (one can = 12 oz.)

   _____(0-4) _____(5-8) _____(9-12) _____(11-16)

   _____(17-24) _____(More than 24 oz.)

7. What time of day, primarily, do you drink your pop?

   _____Morning _____Noon to evening

   _____After supper _____Throughout the day

8. Do you regularly drink tea? _____Yes _____No

9. If so, how many cups per day? (Circle one)

   1 2 3 4 5 6 7 8 9 10 or more

10. What time of day do you regularly drink your tea?

    _____Morning _____Noon to evening _____After supper

11. Do you regularly take No-Doz? _____Yes _____No

12. If so, how often do you take No-Doz? _____

13. Do you regularly take Vivarin? _____Yes _____No

14. If so, how often do you take Vivarin? _____

15. Do you regularly take diet pills? _____Yes _____No

16. If so, what kind do you take and how often do you take diet pills?

_____

17. Do you regularly take over the counter medication (i.e., Aspirin, Excedrin, Midol, Alka Seltzer, etc. . . .)?

_____Yes _____No

18. If you do regularly take over the counter medication, what kind do you take and how often do you take these medications?

APPENDIX B

CAFFEINE CONSUMPTION QUESTIONNAIRE II

CAFFEINE CONSUMPTION QUESTIONNAIRE II

1. Did you drink coffee during the last three days?

_____Yes _____No

2. If yes, how many cups per day? (Circle one)

Less than 1 1 2 3 4 5 6 7 8 9 10 More than 10

3. Did you drink soda pop during the last three days?

_____Yes _____No

4. If so, what kind did you drink? _____

5. If you did drink soda pop during the last three days, about how many ounces per day: (one can = 12 oz.)

_____(0-4) _____(5-8) _____(9-12) _____(11-16)

_____(17-24) _____(More than 24 oz.)

6. Did you drink tea during the last three days?

_____Yes _____No

7. If yes, how many cups per day? (Circle one)

Less than 1 1 2 3 4 5 6 7 8 9 10 More than 10

8. Did you take No-Doz in the last three days?

_____Yes _____No

9. If yes, how many per day did you take?

Less than 1 1 2 3 4 5 6 7 8 9 10 More than 10

10. Did you take Vivarin during the last three days?

_____Yes _____No

11. If yes, how many per day did you take?

Less than 1 1 2 3 4 5 6 7 8 9 10 More than 10

12. Did you take any diet pills in the last three days?

_____Yes _____No

13. If so, what kind did you take? _____

14. If you did take diet pills, how many per day did you take?

Less than 1 1 2 3 4 5 6 7 8 9 10 More than 10

15. Did you take any over the counter medication in the last three days (i.e., Aspirin, Excedrin, Midol, Alka Seltzer, etc. . . .)?

_____Yes _____No

16. If so, what kind did you take? _____

17. If you did take over the counter medication, how much of the medication did you take per day?

_____

18. How many hours has it been since you have last taken any substance with caffeine in it (i.e., any of the substances mentioned above)?

1 2 3 4 5 6 7 8 9 10

14_____ 15-18_____ 19-22_____ 23-26_____

30_____ 31-34_____ 35-38_____

42_____ 43-46_____

r 46_____

t was the substance?_____

much did you consume?_____

APPENDIX C

ANALYSIS OF VARIANCE TABLES

Table 20

Caffeine Dose by Oral Contraceptive Usage by Phase of Menstrual Cycle by Level of Practice by Rate of Presentation by Serial Position Analysis of Variance Summary: Proportion of Words Recalled

Source	df	Sum of squares	Mean square	F
Dose (D)	2	.652	.326	1.517
Pill (PL)	1	.006	.006	.030
Phase (PH)	1	.039	.039	.180
D x PL	2	.453	.226	1.052
D x PH	2	.164	.082	.381
PL x PH	1	.174	.174	.807
D x PL x PH	2	.507	.254	1.179
Error	196	42.162	.215	
Practice (PR)	2	.518	.259	7.991***
D x PR	4	.083	.021	.641
PL x PR	2	.063	.031	.967
PH x PR	2	.043	.021	.663
D x PL x PR	4	.327	.082	2.522*
D x PH x PR	4	.138	.035	1.066
PL x PH x PR	2	0.51	.025	.781
D x PL x PH x PR	4	.047	.012	.360
Error	392	12.705	.032	
Rate (R)	3	47.012	15.671	339.647***
D x R	6	.222	.037	.801
PL x R	3	.091	.030	.661
PH x R	3	.213	.071	1.538
D x PL x R	6	.329	.055	1.189
D x PH x R	6	.271	.045	.979
PL x PH x R	3	.065	.022	.468
D x PL x PH x R	6	.424	.071	1.533
Error	588	27.129	.046	
Serial position (SP)	2	207.017	103.509	940.659***
D x SP	4	1.361	.340	3.092*
PL x SP	2	.803	.401	3.648*
PH x SP	2	.575	.288	2.614
D x PL x SP	4	.110	.028	.250
P x PH x SP	4	.351	.088	.798
PL x PH x SP	2	.100	.050	.455
D x PL x PH x SP	4	.818	.204	1.857
Error	392	43.135	.110	

Table 20--(Continued)

Source	df	Sum of squares	Mean square	F
PR x R	6	.314	.052	1.649
D x PR x R	12	.313	.026	.822
PL x PR x R	6	.046	.008	.241
PH x PR x R	6	.099	.016	.518
D x PL x PR x R	12	.286	.024	.751
D x PH x PR x R	12	.235	.020	.616
PL x PH x PR x R	6	.130	.022	.683
D x PL x PH x PR x R	12	.418	.035	1.098
Error	1176	37.329	.032	
PR x SP	4	.075	.019	.318
D x PR x SP	8	.266	.033	.565
PL x PR x SP	4	.236	.059	1.004
PH x PR x SP	4	.047	.012	.200
D x PL x PR x SP	8	.501	.063	1.065
D x PH x PR x SP	8	.985	.123	2.096*
PL x PH x PR x SP	4	.185	.046	.790
D x PL x PH x PR x SP	8	.278	.035	.591
Error	784	46.048	.059	
R x SP	6	44.026	7.338	124.076***
D x R x SP	12	.719	.060	1.012
PL x R x SP	6	.397	.066	1.118
PH x R x SP	6	.536	.089	1.510
D x PL x R x SP	12	.743	.062	1.047
D x PH x R x SP	12	.724	.060	1.020
PL x PH x R x SP	6	.252	.042	.711
D x PL x PH x R x SP	12	1.629	.136	2.295**
Error	1176	69.548	.059	
PR x R x SP	12	3.262	.272	4.670***
D x PR x R x SP	24	.762	.032	.546
PL x PR x R x SP	12	.378	.031	.541
PH x PR x R x SP	12	.530	.044	.759
D x PL x PR x R x SP	24	1.221	.051	.874
D x PH x PR x R x SP	24	1.766	.074	1.264
PL x PH x PR x R x SP	12	.981	.082	1.404
D x PL x PH x PR x R x SP	24	.980	.041	.701
Error	2352	136.886	.058	
Total	7487	741.278	.099	

Table 21

Caffeine Dose by Oral Contraceptive Usage by Phase of Menstrual Cycle by Level of Practice by Rate of Presentation by Serial Position Analysis of Variance Summary: Organizational Output Scores

Source	df	Sum of squares	Mean square	F
Dose (D)	2	.273	.136	1.439
Pill (PL)	1	.227	.227	2.391
Phase (PH)	1	.094	.094	.994
D x PL	2	.033	.017	.176
D x PH	2	.653	.327	3.444*
PL x PH	1	.040	.040	.427
D x PL x PH	2	.188	.094	.992
Error	192	18.206	.095	
Practice (PR)	2	.282	.141	2.367
D x PR	4	.243	.061	1.019
PL x PR	2	.045	.022	.375
PH x PR	2	.130	.065	1.089
D x PL x PR	4	.211	.053	.885
D x PH x PR	4	.292	.073	1.226
PL x PH x PR	2	.148	.074	1.241
D x PLx PH x PR	4	.106	.027	.447
Error	384	22.874	.060	
Rate (R)	3	2.584	.861	11.869***
D x R	6	.133	.022	.306
PL x R	3	.218	.073	1.000
PH x R	3	.104	.035	.476
D x PL x R	6	.559	.093	1.284
D x PH x R	6	.653	.109	1.499
PL x PH x R	3	.087	.029	.399
D x PL x PH x R	6	.170	.028	.391
Error	576	41.802	.073	
Serial Position (SP)	2	212.847	106.423	113.107***
D x SP	4	3.952	.988	1.050
PL x SP	2	.194	.097	.103
PH x SP	2	6.261	3.131	3.327*
D x PL x SP	4	2.406	.602	.639
D x PH x SP	4	2.698	.675	.717
PL x PH x SP	2	.172	.086	.092
D x PL x PH x SP	4	3.581	.895	.951
Error	384	361.310	.941	

Table 21--(Continued)

Source	df	Sum of squares	Mean square	F
PR x R	6	.270	.045	.755
D x PR x R	12	.489	.041	.683
PL x PR x R	6	.413	.069	1.154
PH x PR x R	6	.495	.082	1.363
D x PL x PR x R	12	.651	.054	.910
D x PH x PR x R	12	.349	.029	.487
PL x PH x PR x R	6	.154	.026	.430
D x PL x PH x PR x R	12	.681	.057	.951
Error	1152	68.687	.060	
PR x SP	4	3.634	.908	2.966*
D x PR x SP	8	2.275	.284	.929
PL x PR x SP	4	1.177	.294	.960
PH x PR x SP	4	1.565	.391	1.277
D x PL x PR x SP	8	3.752	.469	1.531
D x PH x PR x SP	8	2.536	.317	1.035
PL x PH x PR x SP	4	1.080	.270	.881
D x PL x PH x PR x SP	8	2.683	.335	1.095
Error	768	235.253	.306	
R x SP	6	13.459	2.243	7.261***
D x R x SP	12	4.287	.357	1.157
PL x R x SP	6	3.815	.636	2.058
PH x R x SP	6	1.301	.217	.702
D x PL x R x SP	12	5.152	.429	1.390
D x PH x R x SP	12	2.420	.202	.653
PL x PH x R x SP	6	1.801	.300	.971
D x PL x PH x R x SP	12	5.271	.439	1.422
Error	1152	355.877	.309	
PR x R x SP	12	.931	.078	.279
D x PR x R x SP	24	7.860	.327	1.180
PL x PR x R x SP	12	5.487	.457	1.647
PH x PR x R x SP	12	2.541	.212	.763
D x PL x PR x R x SP	24	6.407	.267	.962
D x PH x PR x R x SP	24	5.197	.217	.780
D x PL x PH x PR x R x SP	24	7.397	.308	1.110
Error	2304	639.687	.278	
Total	7343	2082.014	.284	

REFERENCES

References

Abernethy, D. R., & Todd, E. L. (1985). Impairment of caffeine clearance by chronic use of low-dose estrogen-containing oral contraceptives. European Journal of Clinical Pharmacology, 28, 425-428.

Aldridge, A., Bailey, J., & Neims, A. (1981). The disposition of caffeine during and after pregnancy. Seminars in Perinatology, 5(4), 310-314.

American Medical Association. (1986). Drug evaluations (6th ed.; pp. 717-733). Chicago: Author.

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

Anderson, K., & Revelle, W. (1983). The interactive effects of caffeine, impulsivity, and task demands on a visual search task. Personality Individual Differences, 4(2), 127-134.

Arnold, M. F., Petros, T., Beckwith, B., Coons, G., & Gorman, N. (1987). The effects of caffeine, impulsivity, and sex on memory for word lists. Physiology and Behavior, 41(1), 25-30.

Asso, D. (1983). The real menstrual cycle. New York: John Wiley & Sons.

Bowyer, P., Humphreys, M., & Revelle, W. (1983). Arousal and recognition memory: The effects of impulsivity, caffeine and time on task. Personality Individual Differences, 4, 41-49.

Brodie, D., & Prytulak, L. (1975). Free recall curves: Nothing but rehearsing some items more or recalling them sooner? Journal of Verbal Learning and Verbal Behavior, 14, 549-563.

Broverman, D., Klaiber, E., Kobayashi, Y., & Vogel, W. (1968). Roles of activation and inhibition in sex differences in cognitive abilities. Psychological Review, 75(1), 23-50.

Broverman, D., Vogel, W., Klaiber, E., Majcher, D., Shea, D., & Paul, V. (1981). Changes in cognitive task performance across the menstrual cycle. Journal of Comparative and Physiological Psychology, 95(4), 646-654.

Carlson, N. (1986). Physiology and behavior (3rd ed.). Boston: Allyn and Bacon, Inc.

Craik, F. (1970). The fate of primary memory items in free recall. Journal of Verbal Learning and Verbal Behavior, 9, 143-148.

Cutler, W., & Garcia, C. (1980). The psychoneuroendocrinology of the ovulatory cycle of woman: A review. Psychoneuroendocrinology, 5, 89-111.

Easterbrook, J. A. (1959). The effect of emotion on cue utilization and the organization of behavior. Psychological Review, 66, 183-201.

Erikson, G., Hager, L., Houseworth, C., Dungan, J., Petros, T., & Beckwith, B. (1985). The effects of caffeine on memory for word lists. Physiology and Behavior, 35, 47-51.

Eysenck, H. J. (1967). The biological basis of personality. Springfield, IL: Thomas.

Federman, D. (1981). General principles of endocrinology. In R. H. Williams (Ed.), Textbook of endocrinology (6th ed.; pp. 1-15). Philadelphia: Sanders.

Flores, L. M., & Brown, S. C. (1974). Methods and designs: Comparison of output order in free recall. Behavior Research Methods and Instrumentation, 6(4), 385-388.

Gilbert, R. (1976). Caffeine as a drug of abuse. In R. G. Gibbins, Y. Israel, H. Kalant, R. Popham, W. Schmidt, & R. G. Smart (Eds.), Research advances in alcohol and drug problems (Vol. 3; pp. 49-176). New York: Wiley.

Gilliland, K. (1980). The interactive effect of introversion-extraversion with caffeine induced arousal on verbal performance. Journal of Research in Personality, 14, 482-492.

Graham, E. (1980). Cognition as related to menstrual cycle phase and estrogen level. In A. Dan, E. Graham, & C. Beecher (Eds.), The menstrual cycle (Vol. 1; pp. 190-208). New York: Springer.

Hagen, J. W., & Stanovich, K. G. (1977). Memory: Strategies of acquisition. In R. V. Kail & J. W. Hagen, Perspectives on the development of memory and cognition (pp. 89-111). Hillsdale, NJ: Lawrence Erlbaum Associates.

Hasher, L., & Zacks, R. T. (1979). Automatic and effortful processes in memory. Journal of Experimental Psychology: General, 108, 356-388.

Heaney, R. (1982). Nutritional factors and estrogen in age-related bone loss. Clinical and Investigative Medicine, 5(2-3), 147-155.

Humphreys, M., & Revelle, W. (1984). Personality, motivation, and performance: A theory of the relationship between individual differences and information processing. Psychological Review, 91(2), 153-184.

Hunt, E., Frost, N., & Lunneborg, C. (1973). Individual differences in cognition: A new approach to intelligence. In G. Bower (Ed.), Psychology of learning and motivation: Research and theory (Vol. 7; pp. 87-122). New York: Academic Press.

Kuchera, M., & Francis, W. (1967). Computational analysis of present-day American English. Providence, RI: Brown University Press.

Ling, W., Johnston, D., Lea, R., Bent, A., Scott, J., & Toews, M. (1985). Serum gonadotropin and ovarian steroid levels in women during administration of a norethindrone-ethinylestradiol triphasic oral contraceptive. Contraception, 32(4), 367-375.

Murdoch, B. (1972). The serial position effect in free recall. Journal of Experimental Psychology, 64, 482-488.

Patwardhan, R., Desmond, P., Johnson, R., & Schenker, S. (1980). Impaired elimination of caffeine by oral contraceptive steroids. Journal of Laboratory and Clinical Medicine, 95, 603-608.

Perfetti, C., & Hogaboam, T. (1975). The relationship between single word decoding and reading comprehension skill. Journal of Educational Psychology, 67, 461-469.

Perfetti, C., & Lesgold, A. (1979). Coding and comprehension in skilled reading and implications for reading instruction. In L. B. Resnick,, & P. A. Weaver (Eds.), Theory and practice of early reading (Vol. I; pp. 57-84). Hillsdale, NJ: Lawrence Erlbaum Associates.

Perlmutter, M. (1978). What is memory aging the aging of? Developmental Psychology, 14, 330-345.

Rall, T. (1980). The xanthines. In A. G. Gilman, L. S. Goodman, & A. Gilman (Eds.), The pharmacological basis of therapeutics (pp. 592-607). New York: Macmillan.

Revelle, W., Amaral, P., & Turiff, S. (1976). Introversion/extraversion, time stress, and caffeine: Effect on verbal performance. Science, 192, 149-150.

Revelle, W., Humphreys, M., 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), 1-31.

Shaw, R. (1978). Neuroendocrinology of the menstrual cycle in humans. Clinics in endocrinology and metabolism, 7, 531-559.

Weschler, D. (1981). Weschler adult intelligence scale-revised manual. New York: Psychological Corporation.

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. Journal of Comparative Neurology and Psychology, 18, 459-482.