Research Report

CAFFEINE REDUCES TIME-OF-DAY EFFECTS ON MEMORY PERFORMANCE IN OLDER ADULTS

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Abstract—*For most older adults, memory performance depends on the time of day, with performance being optimal early in the morning and declining during the late afternoon hours. In the present study, we asked whether this decline could be ameliorated by a simple stimulant, caffeine. Adults over the age of 65 who considered themselves "morning types" were tested twice over an interval of 5 to 11 days, once in the morning and once in the late afternoon. Participants ingested either coffee with caffeine or decaffeinated coffee at both sessions. Participants who ingested decaffeinated coffee showed a significant decline in memory performance from morning to afternoon. In contrast, those who ingested caffeine showed no decline in performance from morning to afternoon. The results suggest that time-of-day effects may be mediated by nonspecific changes in level of arousal.*

Most adults over the age of 65 (75% or more) describe themselves as "morning" people—they report feeling at their best, both physically and mentally, in the early hours of the morning. In contrast, few adults under the age of 65 (less than 10%) report a preference for morning (Intons-Peterson, Rocchi, West, McLellan, & Hackney, 1998; May, Hasher, & Stoltzfus, 1993). Subjective ratings of peak times of day correspond with peak performance on objective measures of cognitive functioning, including analytical thought and judgments (Bodenhausen, 1990; Rahhal, Abendroth, & Hasher, 1996), target detection (Horne, Brass, & Pettitt, 1980), memory for words and prose (May et al., 1993; Petros, Beckwith, & Anderson, 1990), and the ability to suppress irrelevant information (May & Hasher, 1998).

The correspondence between individual preference and optimal test performance has been referred to as the *synchrony effect*, and applies equally to younger and older adults (for review, see Yoon, May, & Hasher, 1999). This finding has particular practical implications for researchers interested in aging and cognition. Differences between young and older adults will be inflated if participants are tested in the afternoon, when younger adults are likely to be performing at their optimal time of day, but the majority of older adults will be performing at their worst time of day.

Relatively few time-of-day studies have employed tests of learning and memory. May et al. (1993) found that recognition hit rates for older adults remained constant on a verbatim sentence recognition test from morning to afternoon whereas false positive errors increased, suggesting that older adults have problems disregarding distractors in the afternoon, rather than a primary deficit in learning new materials. In the same study, young adults who were classified as evening types showed a decrease in recognition hit rates from evening to morning, along with an increase in false positives. In contrast, Yoon (1997) found that both hit and false positive rates were substantially affected by time of day in older adults, whereas young adults showed only a change in false positive rates. Petros et al. (1990) found decreased immediate recollection of difficult prose passages when college-age participants were tested at nonoptimal times of day, although the study did not include older adults. The question of what particular memory measures are influenced by time of day, especially in older adults, warrants further investigation.

The reason why circadian rhythm patterns shift across the adult life span is not known, although this change appears to begin around age 50 (Ishihara, Miyake, Miyasita, & Miyata, 1991), and occurs cross-culturally (e.g., Adan & Almirall, 1990; Ishihara et al., 1991). It is likely that cognitive dysfunction at nonoptimal times of day is related to a general decrease in physiological arousal or alertness, because self-reported time-of-day preferences correspond to cyclical fluctuations in physiological measures, including body temperature, skin conductance, and heart rate (Horne & Ostberg, 1976, 1977; Kerkhof, van der Geest, Korving, & Rietveld, 1981). If time-of-day effects are simply due to fluctuations in physiological energy, then one might expect that the performance of older adults during the afternoon might be facilitated by substances that increase arousal.

The most widely used stimulant in the general population is caffeine, which is available in many food sources, including coffee, tea, and chocolate (Lieberman, 1992). Participants report that a moderate dose of caffeine makes them feel more awake, alert, and attentive. Caffeine is highly lipid soluble, and thus crosses the blood-brain barrier quickly. In animals, the drug has been shown to reach peak accumulations in the brain within minutes of ingestion. Brain levels remain stable for at least an hour, with a slow, steady clearance over 3 to 4 hr and longer (for review, see Nehlig, Daval, & Debry, 1992). Caffeine is a nonspecific antagonist for adenosine receptors, which are distributed widely throughout the cortex. Regions mediating sleep, mood, and concentration, including the dorsal and medial raphe nuclei and the locus coeruleus, show substantial increases in activity at low doses of caffeine, and these increases probably collectively account for the general increase in alertness and well-being reported by individuals after ingesting caffeine (Nehlig, 2000).

The purpose of the present study was twofold. First, we revisited the issue of whether measures of learning and retention other than false positive errors in recognition are affected by time of day. We tested older adults on the California Verbal Learning Test (CVLT; Delis et al., 1991), a list-learning test that provides multiple memory measures for the same materials, including immediate free recall, free recall after short and long delays, and yes/no recognition. Second, we assessed whether caffeine eliminates or at least attenuates the time-of-day effect in older adults by administering coffee with caffeine or decaffeinated coffee to participants prior to memory testing at two times of day, early morning and late afternoon.

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METHOD

Participants

Participants ($n = 40$) over age 65 were recruited through advertisements in local newspapers. All were active seniors who were living independently in the community, and they were prescreened to exclude persons with neurological or psychiatric disorder, drug or alcohol abuse, and diseases (e.g., uncontrolled hypertension) that might interfere with normal cognitive functioning. Two questionnaires were administered by telephone. First, the Morningness-Eveningness Questionnaire (MEQ; Horne & Ostberg, 1976) was administered to assess participants' optimal time of day. The MEQ has been used widely to assess optimal time of day for cognitive and physical functioning. On the basis of the MEQ score, an individual is categorized as one of five types: definitely morning, moderately morning, moderately evening, definitely evening, or neutral (no clear time-of-day preference). Second, participants answered questions about their typical daily consumption of foods such as coffee, tea, sodas, and chocolate, so that the amount of caffeine they ingested during a typical day could be estimated (Lieberman, 1992). Individuals who were classified as definitely or moderately morning types and who reported ingesting some form of caffeine on a daily basis were included in the study.

Memory Testing

The CVLT measures recall and recognition for a list of 16 words from four semantic categories over a number of immediate- and delayed-memory trials. Participants recall the list immediately after each of five consecutive presentations. After five trials, an interference list of 16 words from four unrelated categories is presented for one trial. Following presentation of the interference list, participants are again tested for free recall of the original list (short-delay free recall). A 20-min delay occurs next, followed by both free recall of the original list (long-delay free recall) and yes/no recognition for items on the original list plus an equivalent set of distractor items. Two comparable forms of the test have been developed (Delis et al., 1991).

Procedure

Participants were tested twice, once at 8 a.m. and once at 4 p.m., in sessions occurring 5 to 11 days apart. Each participant was randomly assigned to one of two conditions, receiving either coffee with caffeine at both sessions or decaffeinated coffee at both sessions. Thus, the study tested whether coffee type (with caffeine, decaffeinated) interacted with time of day (morning, afternoon). Order of testing (morning followed by afternoon or afternoon followed by morning) was counterbalanced. Participants were asked not to ingest food or beverages with caffeine or chocolate for 4 hr prior to each test session. The coffee (Starbucks house-blend regular and decaffeinated coffee) was prepared using a standardized procedure to ensure that each cup contained about the same amount of caffeine. Lieberman (1992) estimated that the average 12-oz cup of coffee prepared by the drip method contains 220 to 270 mg of caffeine, whereas the average cup of decaffeinated coffee contains negligible amounts of caffeine (5–10 mg).

On arrival at the laboratory, participants reported all food that they had ingested within the last 4 hr so we could ensure that they had abstained from caffeine. (Two participants who ingested caffeine within the 4-hr window were replaced. No other participant reported ingesting caffeine prior to either the morning or the afternoon session.) Participants then drank a 12-oz cup of coffee and waited 30 min. Experimenters and participants were blind to the type of coffee ingested. The CVLT was administered according to standardized procedures. A speeded search task and a visual object perception test (not described here) were administered during the 20-min delay period, which was followed by the long-delay portion of the CVLT.

Participants returned to the laboratory 5 to 11 days later at the alternate time of day and were again given a 12-oz cup of coffee. After the 30-min interval, the alternate form of the CVLT was administered. When the second session was completed, participants were asked to guess whether their coffee at each session had contained caffeine. Their performance in guessing whether they ingested caffeine or not was at chance, and most participants reported incorrectly that they were given caffeine during one session and decaffeinated coffee during the other.

RESULTS

Demographic data are listed in Table 1. The two groups were well matched on age, education, and daily caffeine intake (Fs < 1).

Table 2 reports the CVLT measures of immediate recall (number of items recalled after five repeated presentations of the list), short-delay free recall (number of items recalled after presentation of the distractor list), long-delay free recall (number of items recalled after the 20-min delay), and number of hits and false positives on the recognition test. All scores are out of a possible total of 16. Data were analyzed using a mixed-factor analysis of variance, with time of day (morning, afternoon) as the within-subjects factor and coffee type (with caffeine, decaffeinated) as the between-subjects factor.

Free Recall Measures

Immediate free recall did not differ with time of day ($F < 1$) or coffee type, $F(1, 38) = 2.9$, $MSE = 9.12$, n.s., and there was no interaction effect ($F < 1$). Short-delay free recall also did not differ with time of day ($F < 1$), but participants who ingested caffeine recalled significantly more items than those who did not, $F(1, 38) = 4.86$, $MSE = 16.05$, $p < .05$. That is, after the presentation of an interference list, participants who drank decaf had more difficulty recalling the original list items than participants who drank coffee with caffeine. The decaf group did not, however, make more intrusion errors from the interference list. Intrusion errors were rare and were therefore not analyzed. Short-delay free recall did not show an interaction of coffee type with time of day ($F < 1$).

Table 1. *Demographic data for participants*

Variable	Decaffeinated coffee *M*	Decaffeinated coffee *SD*	Coffee with caffeine *M*	Coffee with caffeine *SD*
Age (years)	72.2	4.1	70.4	4.5
Education (years)	15.1	2.0	14.9	2.0
Daily caffeine intake (mg)	263	299	259	272

Table 2. *Mean raw scores on the California Verbal Learning Test*

	Group			
	Decaffeinated coffee		Coffee with caffeine	
Memory measure and session	*M*	*SD*	*M*	*SD*
Immediate free recall				
Morning	11.5	2.4	12.7	2.7
Afternoon	11.4	2.2	12.5	2.2
Short-delay free recall				
Morning	9.2	2.3	11.3	3.4
Afternoon	9.2	3.5	10.9	3.3
Long-delay free recall				
Morning	11.0	2.7	11.8	2.9
Afternoon	8.9	3.0	11.7	2.8
Recognition hits				
Morning	14.9	1.2	15.1	1.4
Afternoon	13.4	1.9	14.8	1.7
False positive errors				
Morning	1.0	1.9	0.7	0.8
Afternoon	2.5	1.7	0.9	0.9

Long-delay free recall, however, differed as a function of both time of day and coffee type. The effect of time of day depended on the type of coffee ingested, as indicated by a significant interaction, $F(1, 38) = 13.72$, $MSE = 1.53$, $p < .001$. Follow-up paired t tests showed that participants who drank decaf experienced a significant decline in performance from morning to afternoon, whereas those who had caffeine showed no change in performance—their ability to recall the items after a 20-min delay was equivalent in the morning and the afternoon. There was also an overall main effect of time of day, $F(1, 38) = 16.53$, $MSE = 1.53$, $p < .0001$, suggesting that all participants tended to recall more items during the morning session than during the afternoon session. Finally, there was a main effect for coffee type: Participants who had caffeine recalled more items overall than those in the decaf group, $F(1, 38) = 4.47$, $MSE = 14.89$, $p < .05$.

Recognition

Caffeine modified the time-of-day effect for hit rates also, as there was a significant interaction between time of day and coffee type, $F(1, 38) = 13.11$, $MSE = 0.65$, $p < .001$. Follow-up paired t tests indicated a significant drop in hit rate from morning to afternoon for participants who drank decaf, but there was no difference in hit rate for those who had caffeine. The main effect of time of day suggests that participants recognized more items overall in the morning than they did in the afternoon, $F(1, 38) = 27.99$, $MSE = 0.65$, $p < .001$. The main effect of coffee type was not significant, $F(1, 38) = 2.64$, $MSE = 4.3$, n.s.

False positives showed a similar interaction between coffee type and time of day, $F(1, 38) = 10.85$, $MSE = 0.72$, $p < .01$. Follow-up paired t tests indicated that decaf participants produced more false positives in the afternoon than in the morning, whereas the caffeine group did not differ by time of day. There was a general increase in false positives from morning to afternoon, suggested by a main effect of time of day, $F(1, 38) = 21.26$, $MSE = 0.72$, $p < .0001$. There was also a main effect of coffee type, suggesting that decaf participants made more false positive errors overall than caffeine participants, $F(1, 38) = 6.12$, $MSE = 3.1$, $p < .05$.

DISCUSSION

To summarize, older adults with a preference for morning showed significant decline from early morning to late afternoon in long-delay free recall and recognition hits, and an increase in false positive errors. However, caffeine ingested 30 min prior to testing eliminated the decline in memory performance.

Although it appears that delayed free recall and recognition performance are affected adversely by time of day, the underlying mechanism for this impairment cannot be discerned from the present study. The effect may be due to increased difficulty inhibiting irrelevant or distracting information, which in turn adversely affects memory performance, as May and her colleagues (May, 1999; Yoon et al., 1999) have suggested. This would be consistent with the present finding of increased false positive rates. Or the impairment may be attributable to poor encoding of new material in the afternoon due to a general lack of attentional resources. For example, Intons-Peterson et al. (1998) found that although young and older adults showed negative priming when they were tested at their optimal time of day, they showed no negative priming when they were tested at nonoptimal times. The authors suggested that participants with low levels of arousal do not attend sufficiently to the prior exposure of a target item, so target items have relatively little or no distracting effect on subsequent performance. The same general lack of attentional resources might impair older adults' ability to encode list items in the afternoon, leading to poorer delayed recall and an inability to discriminate new from old items on a recognition test (see also Craik, 1983).

The finding that caffeine improved performance in the afternoon on various memory measures including delayed recall, recognition hits, and false positive error rates is consistent with the hypothesis that time-of-day effects are related to decreased physiological arousal. As we noted earlier, caffeine is a nonspecific stimulant affecting widely distributed regions of cortex; it thus may affect a variety of cognitive functions. Other studies have also suggested that caffeine has generally positive effects in older adults. In a large epidemiological study, Jarvis (1993) found that adults who were heavy coffee drinkers had higher scores on tests of motor speed, verbal memory, and spatial reasoning than people who drank little coffee, and this effect was substantially larger for older than younger adults. In a more direct test, Lorist, Snel, Mulder, and Kok (1995) found that older adults given 250 mg of caffeine (approximately the same dose used in the present study) showed global increases in amplitude of event-related potential components across the whole scalp distribution. These authors also found decreased latency of the P3b response, suggesting that caffeine speeds up the evaluation of stimuli in older adults.

It is important to note that we are not making any claim regarding a specific effect for caffeine; indeed, we suspect that other stimulants would have worked equally well. In addition, other variables might moderate the effect of caffeine. Only participants who ingested at least some caffeine on a daily basis were included in this study. The same dose in nonusers might have deleterious effects, because nonusers show more negative side effects of caffeine, including shakiness, anxiety, and decreased concentration (Dager et al., 1999; Robertson & Curatolo, 1984). In summary, it appears that administration of a simple stimulant, caffeine, in a dose that most adults readily consume daily, ameliorates memory impairment arising from time-of-day effects in older adults. The fact that these effects are easily reduced is probably good news for older adults, and vindication for those of us who live with a coffeepot always at the ready.

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