Research Report

Implicit Memory, Age, and Time of Day

Paradoxical Priming Effects

Cynthia P. May,[1] Lynn Hasher,[2,3] and Natalie Foong[3]

[1]*College of Charleston;* [2]*The Rotman Research Institute of Baycrest Centre, Toronto, Ontario, Canada; and* [3]*University of Toronto, Toronto, Ontario, Canada*

ABSTRACT—*Memory retrieval can occur by at least two routes: a deliberate one, as when one attempts to retrieve an event or fact, and an unintentional one, as when one's behavior is triggered by the past without one's knowledge or awareness. We assessed the efficacy of these retrieval systems as a function of circadian arousal and time of day. Evening-type younger adults and morning-type older adults were tested at either peak (morning for old; evening for young) or off-peak times on implicit and explicit stem completion (Experiment 1) or on implicit category generation (Experiment 2). Results for explicit stem-cued recall replicated better performance for each age group at its peak time. In stark contrast, implicit performance was better at off-peak than at peak times of day, raising the possibility that the processes that serve explicit and implicit retrieval are on different circadian schedules, and highlighting the need to consider individual differences in circadian arousal when assessing either memory system.*

Recent research using both human and animal models shows that many cognitive processes are influenced by circadian patterns, such that participants who are tested at peak circadian periods tend to show better performance on tasks that require careful, deliberate, or strategic processing relative to participants who are tested at off-peak times of day (e.g., Bodenhausen, 1990; Hasher, Chung, & May, 2002; Hasher, Goldstein, & May, in press; Hasher, Zacks, & May, 1999; Intons-Peterson, Rocchi, West, McLellan, & Hackney, 1998; May, 1999; May & Hasher, 1998; May, Hasher, & Stoltzfus, 1993; West, Murphy, Armilio, Craik, & Stuss, 2002; Winocur & Hasher, 1999, 2002).[1] To our knowledge, nothing is currently known about the influence of circadian arousal patterns on implicit processes. In the study we report here, we examined circadian patterns for implicit memory using two different tasks, word-stem completion and category generation. For the sake of generality, we assessed performance for both younger and older adults, who generally have different circadian arousal patterns (see, e.g., Yoon, May, & Hasher, 1999). In keeping with the circadian norms for these age groups, we tested evening-type young adults and morning-type older adults. We report a surprising finding: better implicit retrieval at nonoptimal than at optimal times—that is, a complete reversal of the pattern found for explicit tasks.

EXPERIMENT 1

Young evening-type college students and older morning-type volunteers were tested on an implicit and an explicit stem-completion task, both using the first few letters of words as cues for retrieval. Half the participants in each age group were tested at peak times, and half at off-peak times. Participants first rated the pleasantness of target words, worked on a series of filler tasks, and then were tested implicitly with a list of stems that they were asked to complete with the first item that came to mind. On the explicit task that followed, participants were

Address correspondence to Cynthia May, Department of Psychology, College of Charleston, 66 George St., Charleston, SC 29424; e-mail: mayc@cofc.edu.

[1]In human studies, circadian patterns (or chronotype; Roenneberg, Wirz-Justice, & Merrow, 2003) can be determined by scores on the Morningness-Eveningness Questionnaire (MEQ; Horne & Ostberg, 1976), a valid and reliable paper-and-pencil survey that classifies individuals as evening, neutral, or morning types (e.g., Horne & Ostberg, 1977; Smith, Reilly, & Midkiff, 1989). MEQ scores correlate with circadian fluctuations in several physiological measures, including blood pressure, body temperature, and heart rate (e.g., Tankova, Adan, & Buela-Casal, 1994; Vitiello, Smallwood, Avery, & Pascualy, 1986). Normative MEQ studies demonstrate that circadian patterns change over the life span, with strong morningness tendencies in early childhood, a shift away from morningness in adolescence to eveningness in young adulthood, and a return to morningness late in life (ages 60+; Kim, Dueker, Hasher, & Goldstein, 2002; May & Hasher, 1998; Roenneberg et al., 2003).

asked to complete a different set of stems with words they remembered from the learning phase.

Method

Participants

Thirty-six college students (ages 18–23 years) and 48 older volunteers (ages 60–75 years) participated in this study. Participants were selected on the basis of their scores on the Horne-Ostberg (1976) Morningness-Eveningness Questionnaire (MEQ); specifically, we selected younger adults having peak circadian periods late in the day (called evening types) and older adults having peak circadian periods early in the day (called morning types). The younger adults received course credit for their participation, and the older adults received monetary compensation.

Materials

Ninety-six words served as critical items in this study. These items were selected on the basis of the following criteria: (a) Each was at least five letters long, (b) each began with a stem that could be completed with at least four other words in the English language (e.g., “LAT__” could be completed as *later*, *lather*, *Latin*, *lattice*, *latitude*, or *lateral*), and (c) each was neither the most frequent nor the least frequent completion for its stem.

Participants viewed 20 filler words and 48 critical items in the learning phase. Ten filler items were presented as buffers at the beginning of the learning list and 10 were presented as buffers at the end of the list. Twenty-four critical words appeared as target items, and 24 served as distractor items. The remaining 48 items served as control items in test phases, with 24 items appearing on the implicit word-stem task and the remaining 24 appearing on the explicit word-stem task. Items were counterbalanced so that each item served as a target item, a distractor item, an implicit control, and an explicit control an equal number of times within each age group and testing time.

Procedure

Half of all participants in each group were tested in the morning (8:00 to 9:00 a.m.) and half in the late afternoon (5:00 to 6:00 p.m.). First, participants viewed target-distractor word pairs and rated the pleasantness of target words on a scale from 1 to 7. The word pairs were presented with one item above and one below fixation, with the target item indicated by asterisks (*****). Participants were instructed to ignore the distractor words and to give pleasantness ratings for the target items only. Both words in a pair remained on screen until the participant gave a key-press response.

Participants then worked on a series of nonverbal distractor tasks for approximately 10 min. They then completed an implicit stem-completion task, in which they viewed 48 word stems (e.g., “MON__”) on a sheet of paper. They were to write the first word that came to mind to complete each stem. The task was introduced as a game that assessed word knowledge. Unbeknownst to participants, 12 of the stems could be completed with target items from the pleasantness rating task, and 24 were new control stems. The remaining items served as fillers.

Participants then completed an explicit test in which they were instructed to use presented stems as cues to retrieve words from the first phase of the study. They were also told that not all of the stems could be completed with words from the learning phase and that if they could not recall an item, they should report whatever word came to mind. Participants viewed 48 stems (none of which had been presented on the implicit task); 12 could be completed with target items from the learning phase, and 24 were control items. The remaining items served as fillers.

Finally, participants were given the Extended Range Vocabulary Test (ERVT; Educational Testing Service, 1976) and a questionnaire to assess their awareness of the connection between the learning phase and the implicit word-stem task.

Results

Participants

Nine younger adults (4 tested in the morning and 5 in the evening) and 4 older adults (3 tested in the morning and 1 in the evening) reported some awareness of the connection between the learning and the stem-completion tasks. Their data were omitted and replaced with data from new participants. The younger adults had an average MEQ score of 27.6, a mean vocabulary score of 16.2, and an average of 12.3 years of education. The older adults scored significantly higher on the MEQ ($M = 68.2$), $F(1, 80) = 703.0$, $d = 5.9$, and on the vocabulary test ($M = 25.7$), $F(1, 80) = 26.9$, $d = 1.1$). They also had reliably more years of education ($M = 14.0$), $F(1, 80) = 19.7$, $d = 1.2$.

Scoring

For the implicit task, baseline completion rates were determined by the percentage of control stems that were completed with critical words. Implicit priming was calculated as the difference in completion for the target stems versus control stems in the implicit task (see Fig. 1).

We also factored in baseline completion rates for control items when determining memory for target words. Thus, for explicit memory, performance was calculated as the difference in stem completion for the target versus control stems in the explicit task (see Fig. 1).

Implicit Priming Effects

Separate 2 (age: young vs. old) × 2 (testing time: optimal vs. nonoptimal) analyses of variance (ANOVAs) were conducted on baseline (control) completion rates and priming scores. Baseline scores did not differ across testing times, $F(1, 80) = 1.5$, $p > .20$, although younger adults completed slightly more

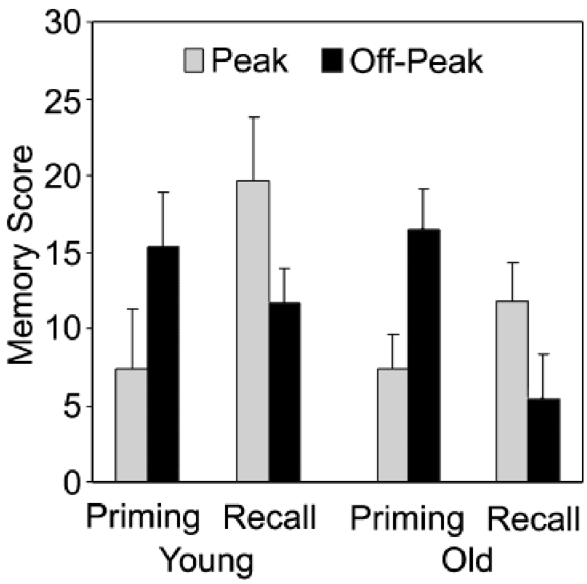

Fig. 1. Mean priming scores (target minus control) and mean recall scores (target minus control) in Experiment 1 as a function of age group and testing time.

control stems with critical items ($M = 8.3\%$) than did older adults ($M = 5.6\%$), $F(1, 80) = 4.1$, $p = .045$, $d = 0.42$.[2] There was no Age × Testing Time interaction, $F < 1.9$.

There were no age differences in the priming scores ($F < 1$), and both older and younger adults showed higher priming scores at nonoptimal than at optimal times of day, $F(1, 80) = 8.3$, $p < .01$, $d = 0.63$. The Age × Testing Time interaction was not significant, $F < 1$.

Explicit Stem Recall

The data for explicit stem recall were analyzed using the same plan as for the data on implicit performance. Baseline scores were stable across both ages and times of testing, largest $F = 1.34$, $p > .25$. Furthermore, baseline scores for the explicit task did not differ from those for the implicit task, and there were no interactions with age group or testing time, largest $F = 1.23$, $p > .27$.

Younger adults showed greater explicit recall ($M = 15.7\%$) than older adults ($M = 8.7\%$), $F(1, 80) = 5.4$, $d = 0.50$. In sharp contrast to performance on the implicit test, explicit recall was better at participants' peak times than at off-peak times, $F(1, 80) = 5.8$, $d = 0.52$. The Age × Testing Time interaction was not significant, $F < 1$.

Discussion

This study is the first to examine both implicit and explicit memory performance at peak and off-peak times of day. We used a stem-completion task to assess both implicit and explicit memory, ensuring that the materials and procedures were identical except for instructions. The time-of-day patterns were directly reversed for the implicit and explicit measures. For implicit memory, performance was better at an off-peak than a peak time of day, and this was true for both older and younger adults, despite the fact that their peaks are different. This finding stands in stark contrast to the findings for explicit memory reported here and elsewhere: Explicit performance is widely reported to be better at peak relative to off-peak times (e.g., Hasher, Goldstein, & May, in press; Hasher, Zacks, & May, 1999; May et al., 1993).

EXPERIMENT 2

For the sake of generality, in Experiment 2 we assessed priming at peak and off-peak times using an implicit category-generation task, which is a more strongly conceptually based task than is stem completion. We tested new evening-type college students and new morning-type older volunteers, and as in Experiment 1, participants began by performing a pleasantness rating task. They later generated exemplars for different categories, some of which (unbeknownst to participants) included items from the pleasantness rating task.

Method

Participants

Fifty-four new college students (ages 18–37 years) and 36 new older volunteers (ages 57–78 years) participated in this study. Participants were selected from the same populations as in Experiment 1, using the same MEQ criterion.

Materials

Two lists of 36 nouns were created, with each presented in two different sequences. Each list had 12 targets, 3 members of each of four different taxonomic categories. The targets were chosen according to norms (Howard, 1979) based on older and younger adults. With few exceptions, the target items were the 11th, 12th, 13th, or 14th most common exemplars produced by both age groups. The remaining 24 items in each list were filler items and were chosen to match the targets for word frequency (Carroll, Davies, & Richman, 1971). The target items were randomly interspersed in each list, with no more than 2 occurring in adjacent positions. The first and last 4 items on each list were fillers. Targets occupied the same positions in all input lists.

Procedure

The procedure used in this study was very similar to that used in Experiment 1, with the following modifications. Thirty-six items appeared individually in the pleasantness rating task, and the rate of presentation was partially determined by the participant; each study item appeared for 5 s, unless a response was made

[2]We note that although the age difference in control scores is reliable, it represents less than one item on the stem-completion task. In addition, this difference in baseline rates was not replicated in the explicit stem task, despite the fact that identical items were used for these tasks, suggesting that it is a spurious finding.

before that time. The word then disappeared, and the subsequent word was presented 1 s later.

For the implicit task, participants were asked to list up to eight exemplars from each of eight different categories. Four of the eight categories had been represented during the pleasantness rating task (with a total of 12 target exemplars, 3 in each category). Four categories were new, representing the target categories on the alternate list. Each category label (e.g., "occupation") was printed individually on an index card. Each card contained eight spaces for written answers.

Participants were given up to 1 min to write down as many exemplars as they could for each category, giving the first instances that came to mind. When all eight spaces on a card had been filled, or when 1 min had elapsed, the next category card was given. After completing this task, participants were given a questionnaire to assess their awareness of the connection between the learning phase and the implicit task.

Results and Discussion

Participants

Data from 22 young adults (10 tested in the morning and 12 in the evening) and 8 older adults (3 tested in the morning and 5 in the evening) who were aware of the association between the learning and implicit tasks were excluded from analyses. The remaining 32 younger adults (M age = 20.4 years, range: 18–27 years) had an average MEQ score of 32.7, a mean vocabulary score of 22.0, and an average of 14.6 years of education. The 28 unaware older adults (M age = 66.5 years, range: 57–76 years) had a reliably higher average MEQ score ($M = 67.3$), $F(1, 56) = 827.8$, $d = 7.3$; performed significantly better on the vocabulary test ($M = 30.3$), $F(1, 56) = 21.8$, $d = 1.2$; and had reliably more years of education ($M = 15.9$ years), $F(1, 56) = 4.0$, $d = 0.51$. No variable interacted with testing time.

Priming

Much as in Experiment 1, priming was calculated by subtracting baseline category-generation rates from target category-generation rates (see Table 1). Separate 2 (age) × 2 (testing time) ANOVAs were conducted on baseline and priming scores. For baseline scores, there were no reliable differences, largest $F < 1$.

TABLE 1
Mean Priming Scores by Age Group and Testing Time in Experiment 2

	Testing time	
Age group	Optimal	Nonoptimal
Young	7.7% (11.6)	18.7% (7.7)
Old	7.3% (13.4)	14.7% (10.4)

Note. Standard deviations are in parentheses.

For priming scores, the only reliable effect was that for testing time, $F(1, 56) = 11.2$, $d = 0.85$, all other Fs < 1. Both younger and older participants showed reliably more priming at off-peak than at peak times.

The category-generation data thus replicate and extend the results from our first study, which used a word-stem-completion task. For both a conceptually based implicit task and a perceptually based implicit task, priming was greater at nonoptimal than at optimal times of day.

GENERAL DISCUSSION

Synchrony effects, which show an advantage for individuals tested at optimal rather than nonoptimal times, are now well established, particularly for tasks involving careful, deliberate processing (e.g., Hasher et al., in press; Intons-Peterson et al., 1998; May, 1999; May & Hasher, 1998; May et al., 1993; West et al., 2002). Data from the explicit stem-completion task in Experiment 1 add to this list. It seems clear that conscious, deliberate efforts to process and retrieve information will be more successful at peak than at off-peak times. The present experiments, however, expose a very different time-of-day pattern for implicit performance. On both a perceptually based task and a conceptually based task, younger and older adults showed greater priming when tested at nonoptimal rather than optimal times.

The finding that automatic, unconscious responses are more likely to be produced at off-peak times of day suggests that the time at which individuals in different age groups are tested may directly influence the magnitude of memory effects observed within each age group, and consequently may artificially inflate or reduce the estimate of group differences in memory. Normative studies show clear developmental changes in circadian preferences, with morningness tendencies strong in childhood, a shift to eveningness in adolescence, and a return to morningness with advancing age (e.g., Kim, Dueker, Hasher, & Goldstein, 2002; May & Hasher, 1998; Tankova, Adan, & Buela-Casal, 1994; Yoon et al., 1999). Just as these developmental shifts in circadian patterns must be considered when deliberate memory or tasks involving executive functioning are evaluated (e.g., Hasher et al., 1999), so too must they be considered when priming is assessed.

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