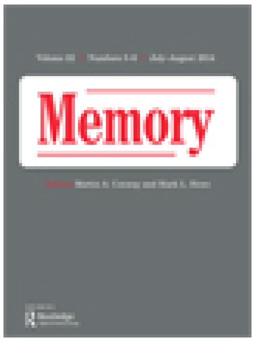

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Optimal testing time for suppression of competitors during interference resolution

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ABSTRACT
Interference between competing memory traces is a common cause of memory failure. Recent research has demonstrated a suppression mechanism that operates at retrieval to resolve interference. Using an adaptation of the suppression paradigm in Healey, Ngo, and Hasher [(2014). Below-baseline suppression of competitors during interference resolution by younger but not older adults. *Psychological Science*, *25*(1), 145–151. doi:10.1177/0956797613501169], we tested whether the ability to suppress competing memory traces varies with the synchrony between optimal arousal period and time of testing. We replicate the below-baseline suppression effect for young adults tested at optimal times of day, and present novel evidence that they do not show competitor suppression during non-optimal times of day. In fact, competitors are actually strengthened at non-optimal times. Our results suggest that the ability to resolve interference by suppression varies with circadian arousal.

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When retrieving a memory, such as the surname of your friend John, the cues that guide retrieval often activate related memory traces, likely including surnames of other friends named John. Several decades of research have shown that activation of competing traces in memory interferes with retrieval of a target memory (e.g., Anderson, 1974; Anderson & Neely, 1996; Postman, 1971). Many researchers have argued that suppression is required to control or down-regulate interfering memories (e.g., Aslan & Bäuml, 2011; Healey, Campbell, Hasher, & Ossher, 2010; Healey, Ngo, & Hasher, 2014; Norman, Newman, & Detre, 2007; Storm, 2011).

We have previously provided evidence for suppression of competitors at retrieval as a decrease in accessibility for rejected words (Healey et al., 2010). In that study, participants in the critical condition were exposed to pairs of orthographically similar words (e.g., ALLERGY and ANALOGY) after which they solved word fragments that resembled both words (e.g., A_L_ _GY), but could only be solved by one (here, ALLERGY). Suppression of competitors (e.g., ANALOGY) was subsequently measured using naming time. The competitors were named no faster than control words that had not been presented. This was taken as evidence that in resolving competition, items are suppressed at least to their pre-exposure semantic memory baseline level (see also, for example, Blaxton & Neely, 1983; Healey, Hasher, & Campbell, 2013; Higgins & Johnson, 2009; Storm, 2011).

Subsequently, we reported the very rare finding of below-baseline suppression of competitors (Healey et al., 2014). In that study, participants generated related or unrelated responses to each of a series of cue words (e.g., PEPPERONI) which had been selected to activate strong associates (e.g., PIZZA). Producing an unrelated response to the cue was assumed to require the suppression of its strong associate. Accessibility of the strongest associate of each cue was measured by naming time. Participants showed *below-baseline* naming times (or accessibility) to the rejected words. That is, it took longer to name those words than to name control items.

Because there are few reports of below-baseline suppression, one goal of the present study is to assess the replicability of this finding. We also considered whether the synchrony between circadian arousal and testing time would influence the degree to which suppression of competitors would be seen. The logic here is tied to findings that attention regulation is better at times that match ones' arousal pattern than at times that mismatch the pattern (e.g., Hahn et al., 2012; Hasher, Zacks, & May, 1999; May, 1999).

Circadian arousal patterns (Morning, Evening or Neutral chronotypes) can be reliably measured using a paper and pencil instrument, the Horne–Ostberg Morningness–Eveningness Questionnaire (MEQ), which correlates highly with physiological measures (e.g., Horne & Östberg, 1976; Roenneberg, Wirz-Justice, & Merrow, 2003). Differences in performance at optimal and non-optimal times of day have been found in a broad range of cognitive tasks including implicit learning (Delpouve, Schmitz, & Peigneux, 2014), semantic retrieval (Fabbri, Mencarelli, Adan, & Natale,

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2013), memory for words and sentences (May, Hasher, & Stoltzfus, 1993; Petros, Beckwith, & Anderson, 1990; Yoon, 1997), and in creativity and problem solving tasks (Weith & Zacks, 2011). Of central concern here are reports of synchrony effects (i.e., better performance at testing times that match versus mismatch individual arousal patterns) seen in tasks requiring suppression of inappropriate responses including the ability to ignore distraction at encoding (Anderson, Campbell, Amer, Grady, & Hasher, 2014; May, 1999; Rowe, Valderrama, Hasher, & Lenartowicz, 2006), the ability to suppress stereotypes (Bodenhausen, 1990), and other strong but incorrect responses (Marek et al., 2010; May & Hasher, 1998; Schmidt et al., 2012), as well as in the ability to resist proactive interference (Hasher, Chung, May, & Foong, 2002). This latter finding is particularly relevant to present concerns because successful suppression of competitors is critical for reducing proactive interference.

Here, we used a variant of the Healey et al.'s (2014) procedure and tested whether the ability to suppress competing memory traces would vary with the synchrony between optimal arousal period and time of testing. Given the chronotype patterns typical of young adults (e.g., Hasher, Goldstein, & May, 2005; Yoon, May, & Hasher, 1999), we tested evening and neutral chronotype individuals at an optimal time (afternoon) or non-optimal time (morning). We anticipated a replication of the suppression effect at optimal times (in the afternoon) but less so, or perhaps not at all at non-optimal times (in the morning), suggesting that the ability to resolve competition by suppression varies with the match between circadian arousal and time of testing.

Methods

Overview

In the first of two phases, participants were prompted to generate aloud a related response to some cue words and an unrelated response to others. Since the cue words were chosen to activate strong associates, producing an unrelated response likely involved suppressing the closest associate, but producing a related response did not. In the second phase, accessibility was measured using a lexical decision task that included the closest associate of each of the Phase 1 cue words. A baseline measure for the lexical decision task was obtained using counterbalanced control words that were not seen in the context of the experiment. Following Healey et al. (2014), slower lexical decision times were expected for words participants had to suppress in order to produce an unrelated response compared to control words. Furthermore, and based on evidence suggesting reduced cognitive control at off-peak times of day (e.g., May, 1999), suppression effects were expected at an optimal time of testing, but less so or not at all at an off-peak time.

Participants

Participants were 60 university students (39 females), all native English speakers compensated with course credit. Since young adults' general circadian preference and period of peak arousal falls in the afternoon (Hasher et al., 2005; Yoon et al., 1999), participants were screened for evening or neutral chronotype using the MEQ and tested during an "optimal" time of day (afternoon, 1:00 pm–4:00 pm) versus a "non-optimal" time of day (morning, 9:00 am–12:00 pm). Participants tested at the two times of day did not differ in age, years of education, vocabulary (Shipley, 1946), or MEQ scores (Table 1). The data from two participants who scored below 50% on the Shipley vocabulary test, and three participants who scored within the morning-type range (above 59) on the MEQ were replaced with data from new participants.

Stimuli

Seventy-five cue-target pairs (e.g., PEPPERONI-PIZZA) were selected from the University of South Florida Free Association database (Nelson, McEvoy, & Schreiber, 1998) using the same selection criteria as Healey et al. (2014). Each target was the strongest associate to its cue. The word pairs were equated on forward and backward association strength, word length, word frequency, normed naming time, standard deviation of normed naming time, concreteness, and the strength of the next highest cue-to-target association. Three 25-pair lists were created and randomly assigned to be the Related, Unrelated, and Control conditions for each participant, with list-condition assignments counterbalanced across participants. The control items were used as a lexical decision speed baseline against which to test the presence versus absence of suppression effects for words in the unrelated condition. The average word length of the target words was used to generate 75 pronounceable non-words using the English Lexicon Project database for the lexical decision task (Balota et al., 2007).

Procedure

During Phase 1, participants verbally generated semantically related or unrelated responses to cue words into a microphone. A fixation cross appeared (1500 ms) before each trial, then "Related" in green font or "Unrelated" in red font indicated the task command for the next word for 1000 ms. Following the task command, a cue word appeared on the screen for 1500 ms followed by a question mark which remained on screen for up to 4000 ms or until the microphone detected a verbal response. A fixation cross appeared once again in the 1500 ms interstimulus interval (ISI) to indicate the end of each trial. Phase 1 lasted approximately 10 minutes.

For the Related condition, participants were instructed to "say the first word that comes to mind that is

Table 1. Participant demographic information.

Testing time	n	Age (years) M	Age (years) Range	Years of education (M)	Vocabulary	MEQ
PM	30	19.6(2.2)	17–27	13.7(2.1)	30.0(3.7)	41.2(7.5)
AM	30	19.0(1.4)	17–24	13.5(1.2)	29.0(3.6)	43.7(7.1)

Note: Vocabulary measured using the Shipley (1946) vocabulary test (maximum score = 40). MEQ (Horne & Östberg, 1976) scores range from 16 to 86; evening-type chronotypes are denoted by scores below 41, neutral for scores from 42 to 58, and morning-type chronotypes for scores above 59. Standard deviations are in parentheses.

meaningfully related or strongly associated to the cue word". For the Unrelated condition, they were instructed to "say a word with as little relationship to the cue word as possible". Cue words from two word lists were presented in the generation task, while the remaining list served as Control items. Twenty-five words of each cue type (Related or Unrelated) were randomly intermixed using a single random order with the constraint that no more than two trials of the same type occurred consecutively. Word list-condition assignments were counterbalanced across participants.

Informing participants about which type of response to give prior to seeing the cue word is a change from the procedure used by Healey et al. (2014). In that study, participants first saw a word and then were given instructions to produce a related or unrelated response. This change was made, along with the response task used here (from naming time to lexical decision) to assess the replicability and generalisability of the original finding of below-baseline suppression of competitors.

Following immediately in Phase 2, participants used a key press to indicate whether each of a series of letter strings presented on screen was a word or non-word. The stimuli consisted of 75 target words from all 3 word lists and 75 non-words (e.g., GRIKE). Each stimulus was presented on screen for up to 4000 ms or until a response was given, followed by a 1500 ms ISI. Phase 2 lasted approximately 15 minutes. Participants practised the tasks prior to the experimental trials to ensure proper understanding of the task instructions and appropriate timing of verbal responses into the microphone to minimise the number of missed trials.

Results

Data processing

As an initial step, trials from the first phase were removed if the participant repeated a response from an earlier trial, if extra sounds (i.e., "um") advanced the trial before a response could be produced, or if a response was not generated within the time allowed. Accordingly, the target words corresponding to the skipped cue words were removed for the lexical decision trial analysis. The trimming rate was 2.8% of responses. Then, reaction times in both phases were trimmed at 2.5 standard deviations of the mean per participant per condition; no additional trials were removed from Phase 1 and 2.7% of trials were removed from Phase 2.

The response time data for the first phase were analysed using a mixed ANOVA with testing time (AM vs. PM) as a between subjects factor and item type (Related vs. Unrelated) as a within subjects factor. Only the effect of item type was reliable, $F(1, 58) = 111.82$, $p < .001$, $\eta_p^2 = 0.66$. The main effect of testing time and the interaction showed p values >.26. Participants in both testing periods were faster to generate a related word (AM: $M =$ 802.52 ms, $SD = 240.15$; PM: $M = 736.27$ ms, $SD = 173.53$) than an unrelated word (AM: $M = 1198.89$ ms, $SD =$ 432.02; PM: $M = 1229.47$ ms, $SD = 422.68$).

The lexical decision time data are shown in Figure 1. The mixed ANOVA plan now included testing time and three item types (Related, Unrelated, and Control), based on their functions in the first phase of the study. Only the interaction between item type and time of testing was significant ($F(2, 116) = 4.71$, $p = .011$, $\eta_p^2 = .075$). Participants tested in the afternoon (an optimal time) were slower to decide on the lexical status of the strong associates in the Unrelated condition compared to control words, $t(29) = 2.22$, $p = .034$, $d = .20$. By contrast, participants tested in the morning, at their non-optimal time of day show a substantially different pattern, facilitation – or a speed up in naming time relative to control times, $t(29) = 2.11$, $p = .044$, $d = .13$.

Following Healey et al. (2014), the lexical decision times were also analysed by calculating suppression scores as residuals from a regression predicting Unrelated RTs from Control RTs. The standardised residuals serve as a measure of reaction time influenced by factors unique to the Unrelated condition. Independent samples t-tests on the standardised residuals indicated that participants tested in the afternoon ($M = 0.32$, $SD = 1.09$) showed better suppression abilities than those tested in the morning ($M = -0.32$, $SD = 0.77$), $t(58) = -2.59$, $p = .012$, $d = 0.24$. The lexical decision results suggest that young adults tested at periods of low cognitive arousal may experience higher interference than those tested at an optimal time of day due to circadian fluctuations in inhibitory control, a finding consistent with behavioural evidence that proactive interference is greater at non-optimal than at optimal times of day (Hasher et al., 2002).

Discussion

In an adaptation of the suppression paradigm (Healey et al., 2014) using lexical decision as the dependent measure, we demonstrated below-baseline access of associates for one

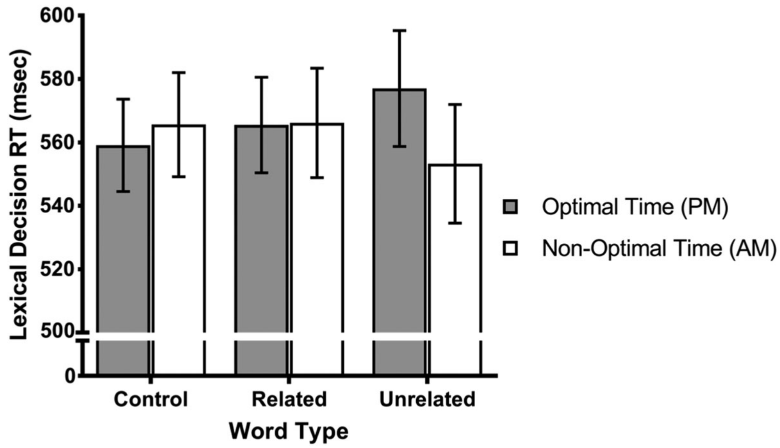

Figure 1. Mean reaction time on lexical decision task (Phase 2), as a function of word type (Control, Related, or Unrelated) for participants tested at optimal vs. non-optimal times of day. Error bars show standard errors.

group of participants and facilitated access for the other group – two groups that only differed in the synchrony between their circadian arousal and time of testing. In the current experiment, cue words were presented to elicit activation of strong associates: Unrelated trials involved suppression of activated associates while Related trials did not. We replicated the below-baseline suppression effect (Healey et al., 2014) for participants tested in the afternoon, an optimal testing time that resulted in efficient suppression, and consequently, slowed lexical decision responses for associates of Unrelated cues. Conversely, participants tested in the morning showed speeded access of associates, suggesting that instead of suppression, activated competitors were strengthened by their elicitation.

Inhibitory control is critical for restricting access of activated competing information to enable the resolution of potential interference (e.g., Storm, Bjork, & Bjork, 2007). Our findings demonstrate that the ability to resolve interference by suppressing competitors varies with circadian fluctuations in cognitive arousal. It has been known that performance on tasks requiring inhibitory control is greatly affected by time of testing, and that adolescents (Hahn et al., 2012) and young adults generally show poor performance on tasks requiring cognitive control at off-peak times (e.g., Fabbri et al., 2013; Petros et al., 1990; Yoon, 1997). Although synchrony effects are typically absent on tasks that rely on well-learned knowledge (May & Hasher, 1998), it has been widely reported for tasks that require strategic processing and rejection of dominant responses (i.e., Intons-Peterson, Rocchi, West, McLellan, & Hackney, 1999; May, 1999; Schmidt et al., 2012), similar to the tasks in the current study. Such established time of day differences in behavioural performance have been supported by recent neuroimaging data showing differences in brain activation patterns across the day (e.g., Anderson et al., 2014; Anderson et al., 2016; Schmidt et al., 2015). Connectivity changes in brain areas identified to be involved in inhibitory functioning, monitoring, and resolution of cognitive conflict suggest that variations in neuroanatomical networks underlie circadian arousal patterns and cognitive output.

Reductions in the ability to resolve interference have been associated not just with changes in circadian arousal, but also with aging (Healey et al., 2013; Rowe et al., 2006), developmental disorders (e.g., Lindenberger, 2008), and individual differences in fluid intelligence (e.g., Burgess, Gray, Conway, & Braver, 2011). Poor cognitive control and ineffective suppression of activated competing information may have a variety of consequences, including the potential strengthening of competitors. Our findings replicate the below-baseline suppression of Unrelated cue associates for participants tested at an optimal time of day (Healey et al., 2014). By contrast, participants tested at a non-optimal time maintained activation of rejected associates, as evident in the speeded lexical decision performance. Rather than restricting access to competitors in the face of interference, poor cognitive control at non-optimal times allowed competitors to be implicitly rehearsed, producing the observed facilitation effect. These findings are consistent with previous studies showing that inefficient inhibitory control can elicit processing of non-target information, which may act as an implicit rehearsal opportunity to enhance memory for that information on subsequent tasks (e.g., Biss, Ngo, Hasher, Campbell, & Rowe, 2013).

We note that the facilitation patterns seen at off-peak times is similar to that shown by older adults who are less able to suppress competitors relative to young adults in a variety of tasks (e.g., Healey et al., 2013), potentially resulting in greater accessibility of competitors. Those findings are consistent with others in the literature showing that older adults are more susceptible to proactive interference relative to young adults (Kane & Hasher, 1995; Lustig & Hasher, 2001; Winocur & Moscovitch, 1983), and show less efficient neural network organisation at off-peak than peak times of day (Anderson et al., 2016). Similar to the facilitatory effect observed in the current study, age-related memory failures may be partially accounted by inhibitory deficits that allow competitors to be maintained, contributing to greater interference, and thus reducing retrieval (e.g., Anderson & Neely, 1996; Campbell, Hasher, & Thomas, 2010; Healey et al., 2010; Healey et al., 2014). It is worth noting that "ineffective" suppression may also benefit some aspects of performance including creativity (Weith & Zacks, 2011), learning environmental regularities and knowledge of non-relevant information (e.g., Amer, Campbell, & Hasher, 2016; Campbell et al., 2010; see also Thompson-Schill, Ramscar, & Chrysikou, 2009).

In the present study, we provide evidence that (a) below-baseline suppression of competing memory traces is a replicable finding and further, (b) that it varies with circadian fluctuations in cognitive arousal. Difficulties in resolving interference to retrieve specific memories may be partially attributed to time of day changes that compromise our inhibitory control.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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References

Amer, T., Campbell, K. L., & Hasher, L. (2016). Cognitive control as a double-edged sword. *Trends in Cognitive Sciences*, *20*(12), 905–915. doi:10.1016/j.tics.2016.10.002

Anderson, J. A., Campbell, K. L., Amer, T., Grady, C. L., & Hasher, L. (2014). Timing is everything: Age differences in the cognitive control network are modulated by time of day. *Psychology & Aging*, *29*(3), 648–657. doi:10.1037/a003724

Anderson, J. R. (1974). Retrieval of propositional information from long-term memory. *Cognitive Psychology*, *6*(4), 451–474. doi:10.1016/0010-0285(74)90021-8

Anderson, M. C., & Neely, J. H. (1996). Interference and inhibition in memory retrieval. In E. L. Bjork & R. A. Bjork (Eds.), *Memory. Handbook of perception and cognition* (2nd ed., pp. 237–313). San Diego, CA: Academic Press.

Anderson, J. A., Sarraf, S., Amer, T., Bellana, B., Man, V., Campbell, K. L., … Grady, C. L. (2016). Task-linked diurnal brain network reorganization in older adults: A graph theoretical approach. *Journal of Cognitive Neuroscience*, *29*, 560–572. Advance online publication.

Aslan, A., & Bäuml, K. H. T. (2011). Individual differences in working memory capacity predict retrieval-induced forgetting. *Journal of Experimental Psychology Learning Memory and Cognition*, *37*(1), 264–269. doi:10.1037/a0021324

Balota, D. A., Yap, M. J., Cortese, M. J., Hutchison, K. A., Kessler, B., Loftis, B., … Treiman, R. (2007). The english lexicon project. *Behavior Research Methods*, *39*, 445–459. doi:10.3758/BF03193014

Biss, R. K., Ngo, K. W. J., Hasher, L., Campbell, K. L., & Rowe, G. (2013). Distraction can reduce age-related forgetting. *Psychological Science*, *24*, 448–455.

Blaxton, T. A., & Neely, J. H. (1983). Inhibition from semantically related primes: Evidence of a category-specific inhibition. *Memory & Cognition*, *11*, 500–510. doi:10.3758/BF03196987

Bodenhausen, G. V. (1990). Stereotypes as judgmental heuristics: Evidence of circadian variations in discrimination. *Psychological Science*, *1*, 319–322.

Burgess, G. C., Gray, J. R., Conway, A. R. A., & Braver, T. S. (2011). Neural mechanisms of interference control underlie the relationship between fluid intelligence and working memory span. *Journal of Experimental Psychology: General*, *140*, 674–692. doi:10.1037/a0024695

Campbell, K. L., Hasher, L., & Thomas, R. C. (2010). Hyper-binding: A unique age effect. *Psychological Science*, *21*, 399–405. doi:10.1177/0956797609359910

Delpouve, J., Schmitz, R., & Peigneux, P. (2014). Implicit learning is better at subjectively defined non-optimal time of day. *Cortex*, *58*, 18–22.

Fabbri, M., Mencarelli, C., Adan, A., & Natale, V. (2013). Time-of-day and circadian typology on memory retrieval. *Biological Rhythm Research*, *44*(1), 125–142. doi:10.1080/09291016.2012.656244

Hahn, C., Cowell, J. M., Wiprzycka, U. J., Goldstein, D., Ralph, M., Hasher, L., & Zelazo, P. D. (2012). Circadian rhythms in executive function during the transition to adolescence: The effect of synchrony between chronotype and time of day. *Developmental Science*, *15* (3), 408–416. doi:10.1111/j.1467-7687.2012.01137.x

Hasher, L., Chung, C., May, C. P., & Foong, N. (2002). Age, time of testing, and proactive interference. *Canadian Journal of Experimental Psychology*, *56*, 200–207.

Hasher, L., Goldstein, D., & May, C. P. (2005). It's about time: Circadian rhythms, memory, and aging. In C. Izawa & N. Ohta (Eds.), *Human learning and memory: Advances in theory and application*. The 4th Tsukuba International Conference on Memory (pp. 199–217). Mahwah, NJ: Erlbaum.

Hasher, L., Zacks, R. T., & May, C. P. (1999). Inhibitory control, circadian arousal, and age. In D. Gopher & A. Koriat (Eds.), *Attention & performance, XVII, cognitive regulation of performance: Interaction of theory and application* (pp. 653–675). Cambridge: MIT Press.

Healey, M. K., Campbell, K. L., Hasher, L., & Ossher, L. (2010). Direct evidence for the role of inhibition in resolving interference in memory. *Psychological Science*, *21*(10), 1464–1470. doi:10.1177/0956797610382120

Healey, K. M., Hasher, L., & Campbell, K. L. (2013). The role of suppression in resolving interference: Evidence for an age-related deficit. *Psychology and Aging*, *28*(3), 721–728. doi:10.1037/a0033003

Healey, K. M., Ngo, K. W. J., & Hasher, L. (2014). Below-baseline suppression of competitors during interference resolution by younger but not older adults. *Psychological Science*, *25*(1), 145–151. doi:10.1177/0956797613501169

Higgins, J. A., & Johnson, M. K. (2009). The consequence of refreshing for access to non-selected items in young and older adults. *Memory & Cognition*, *37*, 164–174. doi:10.3758/MC.37.2.164

Horne, J. A., & Östberg, O. (1976). A self-assessment questionnaire to determine morningness–eveningness in human circadian rhythms. *International Journal of Chronobiology*, *4*, 97–110.

Intons-Peterson, M. J., Rocchi, P., West, T., McLellan, K., & Hackney, A. (1999). Age, testing at preferred or nonpreferred times (testing optimality), and false memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *25*, 23–40.

Kane, M. J., & Hasher, L. (1995). Interference. In G. Maddox (Ed.), *Encyclopedia of aging* (2nd ed., pp. 514–516). New York, NY: Springer-Verlag.

Lindenberger, U. (2008). Age-related decline in brain resources magnifies genetic effects on cognitive functioning. *Frontiers in Neuroscience*, *2*, 234–244. doi:10.3389/neuro.01.039.2008

Lustig, C., & Hasher, L. (2001). Interference. In G. Maddox (Ed.), *Encyclopedia of aging* (3rd ed., pp. 553–551). New York, NY: Springer-Verlag.

Marek, T., Fafrowicz, M., Golonka, K., Mojsa-Kaja, J., Oginska, H., Tucholska, K., … Domagalik, A. (2010). Diurnal patterns of activity of the orienting and executive attention neuronal networks in subjects performing a Stroop-like task: A functional magnetic resonance imaging study. *Chronobiology International*, *27*, 945–958. doi:10.3109/07420528.2010.489400

May, C. P. (1999). Synchrony effects in cognition: The costs and a benefit. *Psychonomic Bulletin & Review*, *6*, 142–147. doi:10.3758/BF03210822

May, C. P., & Hasher, L. (1998). Synchrony effects in inhibitory control over thought and action. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 363–379.

May, C. P., Hasher, L., & Stoltzfus, E. R. (1993). Optimal time of day and the magnitude of age differences in memory. *Psychological Science*, *4*, 326–330.

Nelson, D. L., McEvoy, C. L., & Schreiber, T. A. (1998). *The University of South Florida word association, rhyme, and word fragment norms*. Retrieved from http://w3.usf.edu/FreeAssociation/

Norman, K. A., Newman, E. L., & Detre, G. (2007). A neural network model of retrieval induced forgetting. *Psychological Review*, *114* (4), 887–953. doi:10.1037/0033-295X.114.4.887

Petros, T. V., Beckwith, B. E., & Anderson, M. (1990). Individual differences in the effects of time of day and passage difficulty on prose memory in adults. *British Journal of Psychology*, *81*, 63–72.

Postman, L. (1971). Transfer, interference, and forgetting. In J. W. Kling & L. A. Riggs (Eds.), *Woodworth and schlosberg's: Experimental psychology* (3rd ed., pp. 1019–1132). New York, NY: Holt, Rienhart, and Winston.

Roenneberg, T., Wirz-Justice, A., & Merrow, M. (2003). Life between clocks: Daily temporal patterns of human chronotypes. *Journal of Biological Rhythms*, *18*, 80–90. doi:10.1177/0748730402239679

Rowe, G., Valderrama, S., Hasher, L., & Lenartowicz, A. (2006). Attention disregulation: A benefit for implicit memory. *Psychology and Aging*, *21*, 826–830. doi:10.1037/0882-7974.21.4.826

Schmidt, C., Collette, F., Reichert, C. F., Maire, M., Vandewalle, G., Peigneux, P., & Cajochen, C. (2015). Pushing the limits: Chronotype and time of day modulate working memory-dependent cerebral activity. *Frontiers in Neurology*, *25*(6:199), 1–9.

Schmidt, C., Peigneux, P., Leclercq, Y., Sterpenich, V., Vandewalle, G., Phillips, C., … Yamazaki, S. (2012). Circadian preference modulates the neural substrate of conflict processing across the day. *PloS One*, *7*, e29658. doi:10.1371/journal.pone.0029658

Shipley, W. C. (1946). *Institute of living scale*. Los Angeles, CA: Western Psychological Services.

Storm, B. C. (2011). The benefit of forgetting in thinking and remembering. *Current Directions in Psychological Science*, *20*(5), 291–295.

Storm, B. C., Bjork, E. L., & Bjork, R. A. (2007). When intended remembering leads to unintended forgetting. *The Quarterly Journal of Experimental Psychology*, *60*, 909–915. doi:10.1080/17470210701288706

Thompson-Schill, S. L., Ramscar, M., & Chrysikou, E. G. (2009). Cognition without control: When a little frontal lobe goes a long way. *Current Directions in Psychological Science*, *18*(5), 259–263. doi:10.1111/j.1467-8721.2009.01648.x

Weith, M. B., & Zacks, R. T. (2011). Time of day effects on problem solving: When the non-optimal is optimal. *Thinking & Reasoning*, *17*(4), 387–401. doi:10.1080/13546783.2011.625663

Winocur, G., & Moscovitch, M. (1983). Paired associate learning in institutionalized and non-institutionalized old people. *Journal of Gerontology*, *38*, 455–464.

Yoon, C. (1997). Age differences in consumers' processing strategies: An investigation of moderating influences. *Journal of Consumer Research*, *24*, 329–342.

Yoon, C., May, C. P., & Hasher, L. (1999). Aging, circadian arousal patterns, and cognition. In N. Schwarz, D. Park, B. Knauper, & S. Sudman (Eds.), *Aging, cognition, and self reports* (pp. 117–143). Washington, DC: Psychological Press.