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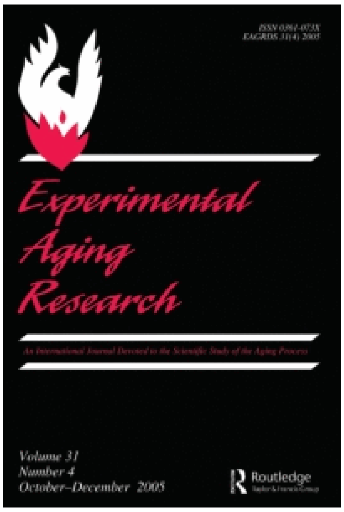

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Optimal Time-of-Day and Consolidation of Learning in Younger and Older Adults

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OPTIMAL TIME-OF-DAY AND CONSOLIDATION OF LEARNING IN YOUNGER AND OLDER ADULTS

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*The current study investigated the relationship between intraindividual variability and associative learning in younger and older adults. The authors hypothesized that higher levels of intraindividual variability would be associated with a reduction in the benefits of practice during learning, and that nonoptimal testing times would magnify these effects. Results indicated that older adults showed an increase in reaction time (RT) standard deviation (*SD*) relative to mean RT in the evening. Although time-of-day did not have a significant effect on rate of learning or total learning, intraindividual variability did predict learning rate of younger adults at nonoptimal testing times. Results are discussed in light of theoretical models of aging and learning.*

When the cognitive architecture underlying age-related decline is examined, basic properties of information-processing capacity, such as the speed and variability of information processing, executive/attentional control, and working memory capacity, account for a large portion of the age-related variance in higher level abilities, including measures of memory and reasoning (c.f. Anderson & Craik, 2000; Hasher & Zacks, 1988; Salthouse, 1996; Strauss, MacDonald, Hunter, Moll, & Hultsch, 2002). Practice and training can increase processing speed and efficiency of performance for both younger and older adults. However, the benefits observed appear to be dependent on the task and conditions of learning. Some studies have reported that older adults do not improve as much as younger adults with extended practice on performance tasks (Fisk, Cooper, Hertzog, & Anderson-Garlach, 1995; Fisk & Warr, 1998; Jenkins & Hoyer, 2000; Rogers, Hertzog, & Fisk, 2000). Conversely, other studies have shown that older adults can benefit at least as much from practice as younger adults (Kramer, Hahn, & Gopher, 1999; Kramer, Larish, Weber, & d Bardell, 1998; Scialfa, Jenkins, Hamaluk, & Skaloud, 2000).

One constraint on the rate of practice-related learning may be the extent to which younger and older adults can maintain stable performance from trial to trial. Increased intraindividual variability is a generic aspect of system aging and there is growing interest in mapping its various manifestations, causes, and consequences (Hogan et al., 2006; Nesselroade & Ram, 2004). For example, early theories (Crossman & Szafran, 1956; Welford, 1962) attributed the cause of cognitive aging deficits to age-related increase in neural noise in the central nervous system. Neural network models of cognitive aging (Li & Lindenberger, 1998) suggest that an increase in the level of intranetwork variability may be causally related to the patterns of cognitive decline typically observed in older adults. In other words, as the signal-to-noise ratio of the system decreases, there is greater disruption of engaged performance. One recent study suggests that electrophysiological variability (i.e., variability in the amplitude of event-related potentials) predicts not only greater reaction time (RT) variability, but slower mean RT and poorer memory performance (Hogan et al., 2006).

Hogan (2004) suggested that age-related decline in frontocerebellar feedforward and feedback loops may account for the relationship between intraindividual variability and developmental automaticity (i.e., learning to asymptote). No studies have tested this hypothesis. Although an increasing number of studies have consistently observed age-related increases in intraindividual variability using measures of reaction time (Hogan, 2003; Myerson & Hale, 1993; Salthouse, 1996) and sensorimotor and cognitive abilities (Hertzog, Dixon, & Hultsch, 1992; Hultsch, MacDonald, & Dixon, 2002; Li & Lindenberger, 1998; Rabbitt, Osman, Moore, & Stollery, 2001; Rabbitt & Patrick, 2001; Strauss et al., 2002), no study has directly examined if age-associated variability is related to the *rate* of acquisition of learning on novel tasks, or if contextual factors associated with optimal arousal, such as time-of-day, are related to this hypothesized variability—learning relationship.

The Morningness-Eveningness Questionnaire has been used to assess individual and group differences in time-of-day preferences by reference to subjective assessment of intellectual and physical peak times. There are reliable differences between morning and evening types on both physiological (e.g., body temperature, heart rate, skin conductance, amplitude of evoked potentials; Adan, 1991; Horne, Brass, & Pettitt, 1980; Horne & Ostberg, 1977; Kerkhof, 1985) and psychological (e.g., sleep-wake behaviours, perceived alertness, personality variables; Buela-Casal, Caballo, & Cueto, 1990; Horne & Ostberg, 1977; Mecacci, Zani, Rocchetti, & Lucioli, 1986; Webb & Bonnett, 1978; Wilson, 1990) measures. Importantly, younger and older adults have different time-of-day preferences (e.g., Intons-Peterson, Rocchi, West, McLellan, & Hackney, 1999; May & Hasher, 1998; May, Hasher, & Stoltzfus, 1993). For intellectual and physical activities, younger adults prefer the afternoon or evening, whereas older adults prefer the morning, with as few as 2% of older adults reporting an evening preference (Yoon, Goldstein, May, & Hasher, 2006). These preferences have implications for performance. The circadian patterns of arousal that are associated with predictable peaks and declines in body temperature, heart rate, and hormone secretion across the day (Dijk & Czeisler, 1993; Dijk, Duffy, Riel, Shanahan, & Czeisler, 1999; Horne & Ostberg, 1976, 1977; Hrushesky, 1989) are correlated with corresponding peaks and declines in cognitive performance (e.g., Folkard, 1983; Bodenhausen, 1990; May et al., 1993; Petros, Beckwith, & Anderson, 1990). Older adults also show a *larger* relative performance decrement associated with nonoptimal times of day (defined by reference to time-of-day preferences) than do younger adults (Hasher, Chung, May, & Foong, 2002; May et al., 1993; May & Hasher, 1998; see Hasher, Zacks, & May, 2000, for a review).

Based on the theoretical models and research to date, we hypothesized that (1) the regulation of intraindividual variability is related to the consolidation of new learning; and (2) older age and nonoptimal testing times result in greater difficulty regulating variability during the course of learning.

Quantifying the Benefits of Practice during Learning

When using reaction time (RT) as an indicator of performance efficiency of cognitive processes, learning is well defined by a power function (Logan, 1992):

$$\mathrm{RT} = \mathrm{a} + \mathrm{bN}^{-\mathrm{c}}, \tag{1}$$

where a is the asymptote, reflecting an irreducible limit on performance, b is the difference between initial and asymptotic performance, and c is the learning rate. Although people will naturally differ in the speed with which they can perform accurately on any novel complex RT task, the benefits of additional practice can be well quantified using estimates of b and c derived from a power function. In the current study, we assumed that when presented with a novel task, and controlling for initial performance levels, an efficient learner would demonstrate little deviation from power law learning during practice and, all other things being equal, have larger b and c components (i.e., a larger R^2 fit, a larger difference between prepractice and postpractice levels, and a faster learning rate, respectively). Conversely, it was assumed that less efficient learners would show greater deviation from power law learning during practice and have smaller b and c components.

Participants in the current study performed a test of paired-associate learning (i.e., the Wechsler Paired Associates Test) and alternate versions of a four-choice digit-symbol RT task in the morning and the evening. Following May and Hasher (1998) and May, Hasher, and Foong (2005), we tested morning-type older adults and evening-type younger adults. We tested them twice, early in the morning and late in the afternoon (i.e., between 9 and 10 am and between 6 and 7 pm). Analyses of variance (ANOVAs) were used to examine the effects of age and time-of-day on learning.

METHODS

Participants

Participants aged 60 to 80 years and older were recruited from five organizations for retirees and were paid 20 euro for participation. Forty-eight older adults (*M* age = 69.70 years, *SD* = 4.86, 28 females and 21 males) who expressed a 'moderately' or 'definitely' morning preference (*M* = 63.6, *SD* = 3.68) on the Horn & Ostberg "Morningness-Eveningness Questionnaire" (MEQ; Horne & Ostberg, 1976) agreed to participate. The younger sample consisted of 48 undergraduate students (*M* age = 20.17 years, *SD* = 3.53, 37 females and 11 males) characterized as 'moderately' or 'definitely' evening types (MEQ; *M* = 35.55; *SD* = 3.62) who received course credit for their participation. Prospective participants were excluded if they were not right-handed; did not currently live independently in the community; suffered from any medical conditions associated with a head injury, limb injury, spinal injury, epilepsy, stroke, or heart attack; did not have English as a first language; were currently on antidepressant medication, sedatives or tranquillisers; or did not possess normal or corrected-to-normal vision and hearing. Informed consent was obtained from all participants.

The number of years formal education was significantly longer ($F(1, 93) = 10.78$, $p < .001$) in the younger group ($M = 13.63$, $SD = 1.20$) than the older adult group ($M = 12.20$, $SD = 2.73$). However, no age-group differences were observed ($F(1, 93) = 2.67$, $p > .05$) when younger ($M = 31.95$, $SD = 7.33$) and older ($M = 34.39$, $SD = 7.20$) subjects were compared on National Adult Reading Test scores (NART; Nelson, 1982), a marker test from the broad crystallized domain or the cognitive pragmatics (Baltes, 1997). Younger adults reported higher anxiety and depression ($M = 8.70$, $SD = 3.98$) on the Hospital Anxiety and Depression Scale (HAD; Zigmond & Snaith, 1983) than did older adults ($M = 6.00$, $SD = 3.30$; $F(1, 93) = 12.96$, $p < .001$). The group of younger and older adults tested first in morning did not differ from their corresponding peer group tested first in the evening on any of the above measures.

Experimental Task and Procedure

Participants were tested in a quiet, well-lit room. The task was presented on a 15-inch monitor interfaced with a Gateway E-4400 computer. Participants responded to the tasks with the V, B, N, M keys on a standard keyboard using the right hand. The labels 3, 4, 5, and 6 marked the keys. The experimental task were designed and run on E-Prime (version 1.0) software. Stimulus presentation was synchronized with the video display refresh cycle, and RTs were recorded with greater than 1-ms accuracy. Each participant was seated comfortably with head approximately 18 inches from the center of the computer screen. Participants were asked to respond as fast and accurately as possible throughout.

Participants were presented with a four choice digit-symbol array to learn. Two versions of the task were created and participants studied the array for 60s prior to 40 practice trials and 288 experimental trials (presented as 6 blocks of 48 trials). Practice trials were continued until at least 80% accuracy was achieved. During both practice and experimental task, one of the four symbols was presented on the screen until participants made a response. Error feedback was provided. A rest interval of 40s was provided between trial blocks.

The older participants received and returned the MEQ and background information questionnaires via post; younger adults completed both questionnaires outside of class time and returned them to the researcher. Younger and older adults were selected for inclusion in the study if they were classified as evening and morning types, respectively, and if they satisfied other inclusion criteria. Both groups were tested twice: once between 9 and 10 am and a second time between 6 and 7 pm. Testing sessions were separated by a period of between 7 and 10 days and testing order was counterbalanced.

Upon arrival in the testing room, participants completed the NART followed by the HAD. After instruction and practice trials, participants performed the experimental task. After finishing the experimental task, participants were given a rest period of 5 min, followed by the Wechsler Paired Associates Memory Test (Wechsler, 1971). During their second testing session, participants performed the alternate version of the experimental task followed by the alternate version of the Wechsler Paired Associates Memory Test. At the end of session 2, participants were debriefed and thanked.

Computation of Relative Variability

RT *SD* is closely tied to RT mean (Myerson & Hale, 1993). However, the age-related variance shared by the mean and *SD* of RT does not overlap completely (Eysenck, 1982; Jensen, 1992; Salthouse, 1996) and can vary from one task to another (Hogan, 2003; West, Murphy, Armilio, Craik, & Stuss, 2002). Importantly, age-related differences in one or other parameter of the RT distribution can be significant when the other is statistically controlled. Given our interest in the effect of circadian arousal on intraindividual variability in younger and older adults, we computed a coefficient of variation for each participant using the formula (cf. Morse, 1993, for a similar method):

$$(\text{RT } SD/\text{RT mean}) \times 100 \tag{2}$$

This coefficient, named *relative variability*, was computed separately for each of the six blocks in the morning and evening. This allowed comparisons of age-group differences in variability not confounded by generalized slowing (cf. Salthouse, 1996) and comparison of differences between morning and evening not confounded by differences in processing speed across testing times.

Statistical Analyses

A series of ANOVAs were conducted. The first was a 2 (age group: younger and older adults) × 2 (time: morning, evening) ANOVA run on Wechsler memory performance in the morning and evening. Next, two 2 (age group: younger and older adults) × 2 (time: morning, evening) × 6 (trial blocks) mixed-factor ANOVAs were computed on both mean and relative variability of RT during learning. Two additional ANOVAs were run on parameters of learning curves. Specifically, a power function was fit to each participant's data in the morning and evening, based on their performance across 288 trials; the parameters a, b, and c from Equation 1, along with the corresponding R^2 fit index were extracted in each case. The first ANOVA on learning curve parameters was conducted entering z-scores of a, b, and c components as a repeated-measure factor in a 2 (age group) × 2 (time) × 3 (parameter) mixed-factor ANOVA. The second ANOVA entered z-scores of R^2 fit and relative fit indices (i.e., controlling for total learning; see below). Finally, we looked at the correlations between *relative variability* across blocks (i.e., RT SD/RT mean) and total learning in both younger adults and older adults separately. Digit-symbol error rates were low and are not discussed here. Testing order did not contribute to interpretation of ANOVA findings reported below and is not discussed further here.

RESULTS

Wechsler Paired Associates Memory Test

Results of a 2 (age group: younger and older adults) × 2 (time: morning, evening) ANOVA run on memory performance in the

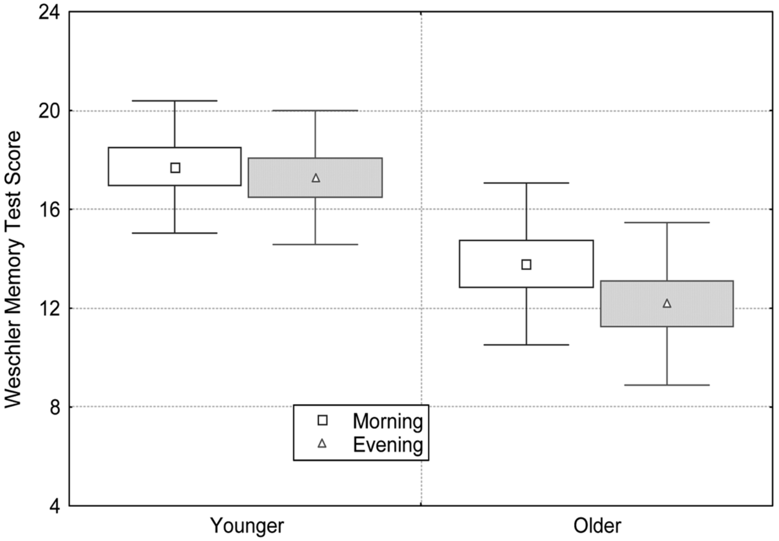

Figure 1. Wechsler Memory Test performance of younger and older adults in the morning and evening.

morning and evening revealed a main effect of age group, $F(1, 95) = 76.85$, $p < .0001$, with older adult having poorer memory than younger adults overall. There was a main effect of time, $F(1, 95) = 9.69$, $p < .005$, and an Age Group × Time interaction effect, $F(1, 95) = 5.54$, $p < .05$. Post hoc analyses indicated that older, $F(1, 95) = 14.78$, $p < .001$, but not younger adults, $F(1, 95) = .29$, $p > .05$, had poorer memory in the evening (i.e., their nonoptimal time-of-day; Figure 1).

Digit-Symbol Paired Associate Learning

RT Mean

There were no differences in RT performances in the morning and the evening, $F(1, 92) = .03$, $p > .05$. There was a main effect of age group ($F(1, 92) = 131.31$, $p < .0001$; M young = 822 m, M older = 1328 ms). There was also a main effect of block, $F(5, 460) = 230.68$, $p < .001$, with RTs getting progressively faster with extended practice. There was a significant Age Group × Block interaction effect ($F(5, 460) = 32.27$; $p < .001$; Figure 2). No other effects were observed.

Simple main effects analysis revealed that both younger and older adults got faster with practice during both morning and evening sessions ($p < .001$ for all four comparisons). However, the benefit of

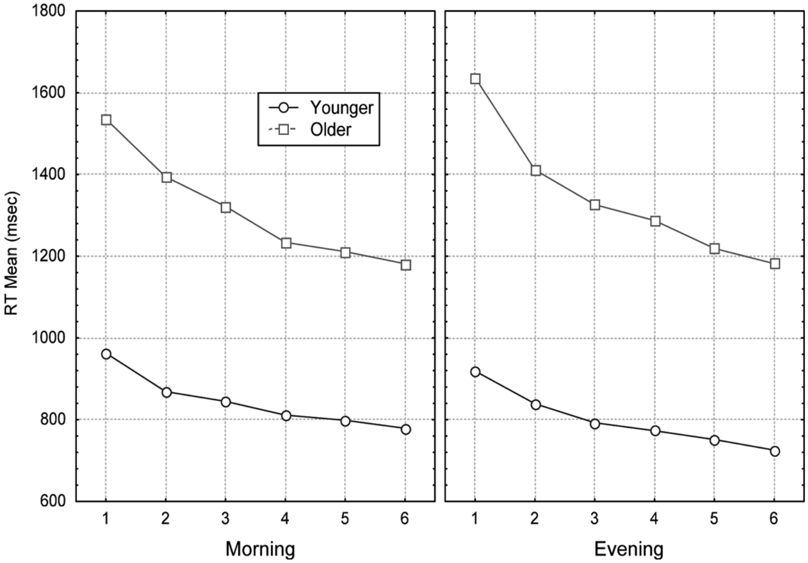

Figure 2. Digit-Symbol RT mean across blocks in the morning and evening for younger and older adults.

practice for older adults exceeded that of younger adults ($p < .001$ for both morning and evening comparisons).

Relative Variability

With mean RT statistically controlled, ANOVA revealed no main effect of time-of-day on RT variability, $F(1, 92) = .51$, $p > .05$. There was a main effect of block, $F(5, 460) = 9.69$, $p < .0001$, with relative variability decreasing with extended practice. There was a main effect of age group, $F(1, 92) = 20.58$, $p < .0001$, with older adults having a larger coefficient of variability than younger adults. However, this difference was accounted for largely by differences between younger and older adults tested in the evening; this was the nonoptimal testing time for older adults and the optimal testing time for younger adults. Specifically, there was an Age Group × Time-of-Day interaction effect, $F(1, 92) = 8.47$, $p < .005$–relative to their mean performance levels, younger and older adult's variability did not differ in the morning, $F(1, 92) = 2.30$, $p > .05$; on the other hand, when tested in the evening, older adults had greater relative variability when compared with younger adults, $F(1, 92) = 33.19$, $p < .001$ (Figure 3).

Because our study confounds age and time-of-day preference (see Discussion), a critical comparison in this context is whether or not

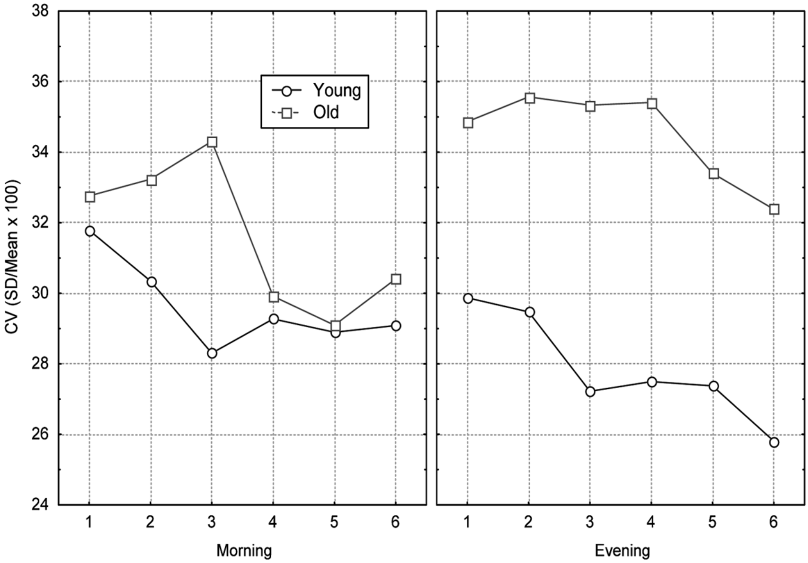

Figure 3. Digit-Symbol relative variability (RT *SD*/RT mean × 100) of younger and older adults in the morning and evening.

older, but not younger, adults demonstrate synchrony effects (i.e., a significant relationship between time-of-day and performance; cf. May and Hasher, 1998). Simple main effect analyses revealed significantly more variability in the evening when compared to the morning for older adults, $F(1, 92) = 6.71, p < .01$. Post hoc analyses comparing morning and evening performance block by block revealed that older adults were significantly less variable in the morning for blocks 4, $F(1, 92) = 11.77, p < .001$, and 5, $F(1, 92) = 9.19, p < .01$. Conversely, there was no main effect of time-of-day in the younger adult group, $F(1, 92) = 2.36, p > .05$. Also, gross comparison of earlier and later stages of practice (i.e., blocks 1 to 3 minus blocks 4 to 6) indicated that the overall reduction in variability in the older adult group was greater in the morning when compared to the evening ($F(1, 92) = 5.56, p = .02$); the same comparison in the younger adult group did not reach significance $F(1, 92) = .97, p > .05$).

ANOVA on z-Scores of Learning Curve Parameters

A 2 (age group) × 2 (morning/evening) × 3 (curve parameter) ANOVA was conducted with *z*-scores of the parameters a, b, c, from

Equation 1 (i.e., initial ability, total learning, and slope of learning) entered as a repeated-measures factor. Results confirmed age differences for all three learning curve components; older adults had slower initial performance, $F(1, 92) = 160.\ 90, p < .0001$, demonstrated greater overall learning, $F(1, 92) = 64.65, p < .0001$, and had steeper learning curves, $F(1, 92) = 26.15, p < .0001$. No other main or interaction effects were observed.

A second 2 (age group) × 2 (morning/evening) × 2 (curve parameter) ANOVA was conducted entering R^2 and relative R^2 indices as dependent variables. When applying a power function to each individual's learning over trials, the R^2 fit index provides an indication of the degree to which the observed data are well characterized by a power function of learning over trials. We predicted that older age and nonoptimal testing times would increase the observed variability during learning and thus reduce R^2 fit indices. Given the importance of initial ability level and total learning (b) on the shape of learning curves (cf. Logan, 1993, and regression above), we decided to compute a relative fit index:

$$\frac{R^2}{\mathrm{b}} \tag{3}$$

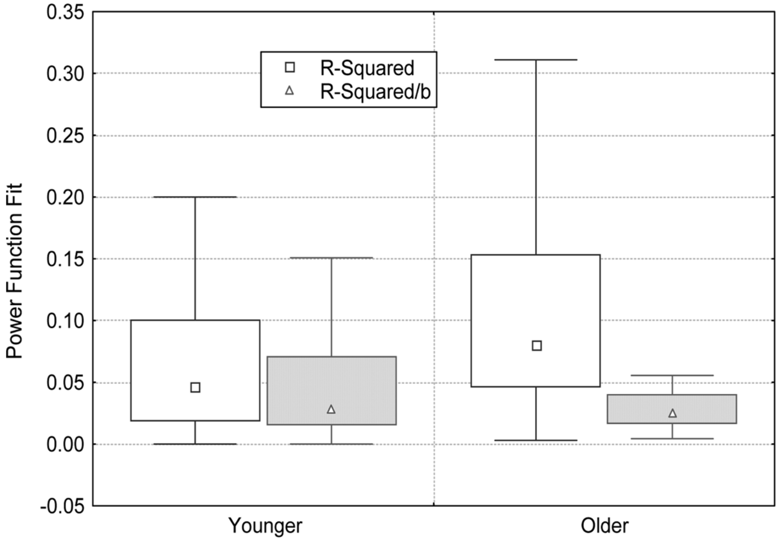

Figure 4. Power function fit and relative fit (i.e., R^2/total learning, b) for younger and older adults.

This allowed for an estimate of power function fit with individual differences in total learning statistically controlled.

ANOVA revealed a significant age x parameter interaction effect, $F(1, 92) = 56.85$, $p < .0001$—compared with younger adults, older adults had a larger R^2 fit, $F(1, 92) = 9.79$, but smaller relative R^2 fit ($F(1, 92) = 14.51$; Figure 4). No time-of-day effects were observed.

The Relationship between Relative Variability and Learning Slope

We were interested in examining the relationship between intraindividual variability and learning rate. Therefore, we used *relative variability* (see Equation 2) as an independent variable in a series of four forward stepwise regression analyses where learning slope was the critical outcome variable (c in Equation 1). First, using morning data, we entered initial performance levels (i.e., a in Equation 1), followed by relative variability (i.e., averaged across all six blocks) in the prediction of younger adults' learning slope (c). We then conducted a similar regression analysis using younger adults' evening data. Finally, we repeated this process using the morning and evening data of older adults.

In all four regression analyses, initial performance was selected first and was a significant predictor of learning rate ($p < .001$ in each case). Regardless or age or time-of-day, participants who were initially slower gained more benefit from practice than those who were initially faster. However, even after controlling for initial ability level, *relative variability* accounted for significant variance in the learning rate of younger adults tested in the morning (Table 1). Consistent with our prediction, greater relative variability was associated with slower learning.

Table 1. Relative variability as a predictor of learning slope (c) for younger and older adults in the morning and evening

	Young			Old		
	Beta	*t* value	*p* value	Beta	*t* value	*p* value
Slope						
Morning	0.512	3.448	0.001	−0.013	−0.128	0.899
Evening	0.132	0.972	0.337	−0.054	−0.506	0.615

Note. In each case, initial learning (a) has been statistically controlled. Gray cells indicate nonoptimal time-of-day.

DISCUSSION

The current study explored the relationship between intraindividual variability, time-of-day, and learning in younger and older adults. Even after controlling for the effects of age on mean RT, we found that older adults were more variable than were younger adults. We also found older, but not younger, adults were significantly more variable during their nonoptimal testing time (i.e., in the evening); younger adults relative variability did not differ from session to session. Also, the overall reduction in variability associated with practice in the older adult group, but not the younger adult group, was greater during optimal when compared to nonoptimal testing times. These results confirm previous research that suggests that synchrony effects are stronger in older adults (May and Hasher, 1998).

In addition to the synchrony effect observed for relative variability in the older adult group, we found that compared with younger adults, the memory performance of older adults was poorer in the evening (see also May et al., 1993; Petros et al., 1990). However, we found no direct effect of time-of-day on mean RT or learning rate in younger or older adults. Why is it that performance on the Wechsler Paired Associates Test and relative variability during digit-symbol learning both showed synchrony effects for older adults, but no such effect was observed for measures of mean RT during digit-symbol learning?

The Wechsler Paired Associates Test and the digit-symbol learning task differed in a number of important respects: The Wechsler Paired Associates Test involved encoding 10 word pairs presented orally; participants were asked to retrieve the second word in the pair after the first word was presented. The digit-symbol learning task involved the selection of an appropriate keyboard response when presented with a symbol on a computer screen; participants were given practice on the digit-symbol task and the digit-symbol rule was a relatively easy one to learn. Thus, the mnemonic/executive demands placed upon participants were likely higher in the Wechsler Memory Test; this may have made it more likely that memory, but not digit-symbol learning, was affected by time-of-day. Such a view is consistent with research suggesting that morning-evening differences are more likely to emerge when tasks place a burden on frontally mediated executive control functions (Hasher, Zacks, & May, 2000).

On the other hand, the effects of nonoptimal testing times on measures of relative variability in older adults does suggest that time-of-day was having some effect on the digit symbol performance of older adults. Although the digit-symbol rule was relatively easy to learn in this study, thus allowing for a level of average RT across blocks that did not differ across morning and evening test sessions, it may be that levels of random distraction were greater in the evening, particularly for older adults. Mathematical models of intraindividual variability have proposed that distraction is a likely mechanism for increased variability in processing (cf. Van Bruekelen, 1995). In Van Breukelen's (1995) model, response times consist of two components, mental processing time and distraction time. It is assumed that the tendency to switch from processing to distraction increases with lack of rest and in the presence of distracting stimuli. Therefore, in the context of Van Breukelen's model, we might propose that both mental processing time and distraction time are determined not only by rest, practice, stimulus, and response distraction and complexity, but also by other properties of tasks, such as the relationship between task demands and the requirement for endogenous arousal and sustained attention. One relevant hypothesis here is that during relatively simple RT tasks, there is a strong requirement for maintenance of endogenous arousal (i.e., participants are required to sustain attention while waiting for the presentation of a stimulus so that they can respond as fast as possible). Thus, the tendency to switch from processing to distraction may increase not only when presented with distracting stimuli in the task environment but also if a person has difficulty sustaining attention and suppressing task-irrelevant thoughts during less demanding, boring tasks. Research does suggest sustained attention decrements in healthy aging (see, e.g., Berardi, Parasuraman, & Haxby, 2001). Future research should attempt to clarify to what extent age-related increases in intraindividual variability can be observed as a consequence of distraction from task irrelevant thoughts during boring tasks or stimulus/response distraction during complex tasks. Other researchers have highlighted the more complex relationships between response distributions, task parameters, and individual differences (Balota & Spieler, 1999, Logan, 1992; Mewhort, Braun, & Heathcote, 1992), and there is ample scope for developing this line of research when analyzing age differences in performance.

Older adults in the current study demonstrated slower initial RTs, larger practice-related benefit, and greater total learning. Notably, this pattern of age differences in learning is not always observed. Age differences in learning are dependent on the learning task used, and our findings are consistent with those of Kramer et al. (1999), who reported (using a task-switching paradigm) that RTs reduced more quickly with practice for an older adult group compared to a younger adult group. Our data suggest that younger adults were operating closer to asymptote from the outset of learning. In other words, it is likely that younger adults found it relatively easy to perform quickly on the digit-symbol task, thus reducing the likelihood that additional practice would add substantially to their performance.

In the current study, RT variability did not affect the consolidation of digit-symbol learning in older adults; it did, however, account for variance in the learning rate of younger adults. Specifically, after controlling for initial RT performance—a variable that often affects the steepness of learning curves (Logan, 1992)—relative variability did not predict older adults' rate of learning. Conversely, and somewhat surprisingly, relative variability was a significant predictor of younger adults' learning rate in the morning (their nonpreferred time-of-day). As such, although older adults showed a more powerful effect of time-of-day on relative variability (thus supporting our second hypothesis), after controlling for initial ability level, relative variability was not an important predictor of learning rate. Although our data suggest that younger adults were operating closer to asymptote from the outset of learning, they did nonetheless demonstrate significant practice benefits in both morning and evening sessions. The fact that there was a relationship between the steepness of their learning curves and their levels of RT variability suggests, again, the possibility that nonoptimal testing times was having an effect on levels of distraction in the younger adult group, with greater levels of relative variability contributing to poorer overall learning in the morning. Conversely, because older adults gained so much more benefit from practice and because their initial digit-symbol response times were so much slower than younger adults, it may be that levels of intraindividual variability in RT were less critical as predictors of learning rate in the morning and the evening. Future research that controls for age differences in initial performance level—for example, by designing a task that is equally difficult for younger adults and older adults—might reveal a different pattern of results. The hypothesized relationship between intraindividual variability and learning rate needs to be explored in greater detail (see Nesselroade & Salthouse, 2004). The current study provided a first, and imperfect, test of the hypothesis.

The mismatch in initial ability levels between younger and older adults and the consequences of this mismatch for patterns of learning observed is not the only design problem in the current study. A relatively serious concern is that the results are confounded by the selection of the subjects. Older subjects were selected for morning type, whereas young subjects were selected for evening type. Thus, any group differences observed may be the results of morningness/eveningness as well as age. This is a problem with other studies that have used time-of-day as a contextual factor in the study of age differences (May & Hasher, 1998; May, Hasher, & Foong, 2005). It is difficult to carry out a study that avoids this confound. Only 2% of older adults have a strong evening preference, the majority (80%) show a strong morning preference (Yoon et al., 2006). Because morning preference older adults dominate the distribution, time-of-day is *always* going to be an important contextual factor when examining any kind of age difference in performance. Experimental strategies that examine how time-of-day mediates age differences in learning, although limited by the sampling constraints that result from the natural confound between age and preference, are an improvement on simpler cross-sectional strategies that ignore the potential time-of-day effects.

We used a *within-subject* design to examine if dominant time-of-day preferences (i.e., evening for younger and morning or older) had any effect on the performance of younger and older adults when they are tested both at their optimal and nonoptimal time-of-day. By counterbalancing the order of testing and using alternate versions of the same test, we could examine if the difference between optimal and nonoptimal testing times were larger in younger versus older adults. Interpretation of results obtained is a function of the design strategy chosen. For example, as both groups were tested twice, the issue of practice effects needs to be addressed. Importantly, when testing order was entered as an additional factor in our ANOVAs, it did not alter our interpretation of morning/evening differences observed.

Further, it could be argued that a *between-subject* design where both younger and older adults were randomly assigned to either morning or evening test sessions might have been better, as it would have removed practice from the design altogether. On the other hand, the advantage of a within-subject design is that those tested in the morning and evening are perfectly matched—comparisons don't run the risk of being confounded by any unknown differences between the two groups tested at different times.

Although the natural confound between age and time-of-day preference poses a significant problem, previous studies have demonstrated the importance of the dominant time-of-day preference of older adults on their behaviour throughout the day. For example, time-of-day effects can be observed for health behaviours. Leirer, Tanke, and Morrow (1994) found that prospective memory (remembering to do something in the future) involving older adults' medication and appointment adherence was significantly greater in the morning than in the afternoon or evening. Some cognitive functions seem to demonstrate a synchrony effect—that is, performance on these tasks is likely to be affected by the match between an individual's peak circadian arousal period and the time at which testing occurs—whereas others are invariant over the day. Importantly, if older adults but not younger adults are more disadvantaged by being tested at their nonoptimal time-of-day, then, on average, it will look like older adults are less competent than younger adults. This concern has been confirmed: younger adults don't show strong synchrony effects whereas older adults do, and this is particularly the case when younger and older adults are compared on tasks that tap the ability to inhibit (noise) in working memory (May, 1999; May, Hasher, & Bhatt, 1994; May & Hasher, 1998). We have to admit that, although confounded, the insights drawn from these studies has greatly advanced our understanding of the more complex, subtle, and variable effects of aging on performance.

Overall, this study is a useful stepping stone on the path to a fuller investigation of intraindividual variability, its relation to learning across the life span, and the role played by contextual factors in shaping the relationships observed. Time-of-day is but one among many potentially important exogenous variables that may act to influence intraindividual variability and learning. A fuller understanding of how endogenous and exogenous factors interact is needed. For example, efficient learning is dependent on the ability to sustain attention and optimal arousal, inhibit distraction, and maintain goal-oriented focus (Anderson & Craik, 2000; Hasher et al., 2000; Robertson & Murre, 1999), and, depending on the nature of the task and context, these building blocks of learning can influence how much intraindividual variability is observed when a person responds in a performance context (Van Breukelen et al., 1995). As such, understanding the relationship between intraindividual variability and learning will involve using a range of different learning tasks and a range of different testing conditions. A real challenge will be identifying the source of intraindividual variability observed in each unique context.

When it comes to modelling age- and disease-related brain changes that impact intraindividual variability, it is possible that electrophysiological measures may provide useful markers of 'neural noise.' Recent data collected in our laboratory points to a strong relationship between event-related potential (ERP) amplitude variability and RT variability—both markers also account for variance in memory performance (Hogan et al., 2006).

Understanding the intraindividual variability-performance relationship is important. In the field of gerontology, where knowledge of how endogenous and exogenous factors interact during learning is central to the design of successful training interventions, intraindividual variability needs to be considered. Although not examined in this study, it may be that imposing a training session upon an older adult at their nonoptimal time-of-day may cause unnecessary fatigue and distress as they attempts to keep a stable focus. Future research in this area should include self-reports of fatigue, distress, and task preferences when assessing time-of-day effects in younger and older adults. It may be that nonpreferred time-of-day can provide an ideal time for other, less strenuous cognitive tasks, or noncognitive tasks that facilitate learning in other ways. For example, when developing interventions that combine physical and cognitive activities (cf. Hogan, 2005), it may be that physical activities that facilitate arousal regulation and control can be better initiated at nonoptimal times. Similarly, cognitive exercises that naturally raise arousal through social facilitation—for example, exercises designed to enhance collaborative cognition—may be better placed at nonoptimal times, whereas cognitive tasks that involve a high level of executive control and are performed in isolation may be best performed at times when arousal is optimal. In the design of comprehensive activity programmes, it should be possible to develop a strategy whereby activities in the morning and in the evening complement one another.

Overall, consideration of intraindividual variability and time-of-day effects when examining the dynamics of age-related cognitive change and learning potential allow researchers a fresh perspective on the issue of optimization. The research ongoing in this field suggests that age differences are not static, are modifiable, and can be further enhanced if conditions of engagement and training are optimized.

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