Age-Related Dissociations in Time-Accuracy Functions for Recognition Memory: Utilizing Semantic Support versus Building New Representations

By: Paul Verhaeghen, Tibor Palfai, John Cerella, Norbou Buchler, Michael P. Johnson, Michael D'Eredita, Dayna R. Green, William J. Hoyer & Maryann Makekau

Verhaeghen, P. Palfai, T., Cerella, J., Buchler, N., Johnson, M., D'Eredita, M., Touron-Green, D., Hoyer, W. J., & Makekau, M. (2000). Age-related dissociations in time-accuracy functions for recognition memory: Utilizing semantic support versus building new representations. *Aging, Neuropsychology, and Cognition*, 7:4, 260-272.

This is an Accepted Manuscript of an article published by Taylor & Francis in *Aging, Neuropsychology, and Cognition* in December 2000, available online: http://dx.doi.org/10.1076/anec.7.4.260.794.

Abstract:

Time-accuracy functions were derived for younger and older adults for recognition of line drawings of common objects, words of high imagery values, and figures (i.e., Chinese characters). We found that in the line drawing and word conditions, older adults were slower than younger adults, but were able to reach the same asymptotic level of performance. In the Chinese character condition, however, an age difference in asymptotic performance appeared. These results are incompatible with either general or process-specific theories of aging of episodic memory, and point at different aging trajectories for memory that utilizes the preexisting semantic network versus memory for representations that have to be built anew.

Keywords: Age difference | Aging | Time-accuracy functions | memory

Article:

Younger adults usually outperform older adults on episodic memory tasks. For instance, performance on tests for recall of word lists of the average 70-year-old is typically about one standard deviation below performance of the average 22- year-old (Verhaeghen, Marcoen, & Goossens, 1993). Across the adult life span, the average correlation between age and recall from episodic memory is about –.3 (Verhaeghen & Salthouse, 1997). Age differences have also been noted for recognition in episodic memory, but age differences in recognition tasks are generally smaller than are those for recall (LaVoie & Light, 1994). Many of the theories explaining age differences in episodic memory are tied to specific mnemonic processes (for an excellent and comprehensive overview, see Kausler, 1994; for a briefer review, see Smith, 1996). Recently, however, some theorists have argued that just a single mechanism may underlie the majority of age differences in memory functioning. This view of aging of episodic memory as a general phenomenon has been argued mainly from correlational data (for an overview, see Salthouse, 1996; for a meta-analysis of correlational data pertaining to age, episodic memory, and possible mediators, see Verhaeghen & Salthouse, 1997) and meta- analyses (Verhaeghen, 2000; Verhaeghen & Marcoen, 1993; Verhaeghen et al., 1993). The general mechanism involved is assumed to be behavioral slowing (Salthouse, 1996; Verhaeghen & Salthouse, 1997): As people grow older, basic speed of processing slows down, and this has deleterious consequences for any type of processing, including encoding in and retrieval from episodic memory.

Recent research using a time-accuracy methodology (i.e., a method in which presentation time is systematically varied and the functional relation between presentation time and number correct is mapped out explicitly) to examine age difference in episodic memory has shown that there indeed seems to be a general aging effect. For instance, in two experiments, Verhaeghen, Vandenbroucke, and Dierckx (1998) found that neither a levels-of-processing manipulation, introducing an inhibition requirement, nor having participants engage in articulatory suppression produced reliable age by condition interactions in any of the three parameters of the time-accuracy curve they estimated. (Note that all of these manipulations have been described in the literature as powerful moderators of aging effects in memory, and important theoretical consequences have been attached to these interactions when they have been found.) Likewise, Verhaeghen (2000) showed from meta-analytical results that within broad classes of episodic memory tasks (viz., list recall, paired-associate recall, and prose recall) the effects of aging on the parameters of the underlying time-accuracy functions appear to be quite general. Moreover, the effects are tied at least partially to speed of processing, because in these studies older adults are found to be consistently slower in reaching their asymptotic level of performance.

The present study explores the limits of Verhaeghen's conclusions regarding the in- variance of the age modulations in time-accuracy functions (2000; Verhaeghen & Marcoen, 1993; Verhaeghen et al., 1993; Verhaeghen et al., 1998). We tested whether theoretically meaningful age by condition interactions in episodic memory would emerge from the time-ac- curacy framework if more extreme manipulations are carried out. One of the obvious limitations of the analyses by Verhaeghen and his col- leagues is that they only pertain to verbal stimuli. In the present study, we broadened the stim- ulus set to include pictorial stimuli. We tried to position the level of difficulty of these stimuli on either side of the expected level of difficulty of the words we used, that is, words with a high concreteness value. On the one hand we used stimuli that were likely to be easier to remember than words, namely, line drawings of common objects (cf. the picture superiority effect; e.g., Paivio, 1971; Shepard, 1967; Standing, 1973). On the other hand, we used stimuli that were likely to be more difficult to remember than words, namely, a set of Chinese characters, which to the untrained observer appear as com- plex visual patterns that cannot be labeled verbally and are hard to integrate within any preexisting cognitive schema.

It is important to note that age by condition interactions involving both kinds of materials can be predicted from the literature. With regard to pictures of common objects, the compensation/cognitive support framework put forward by Bäckman (1989; see also Bäckman & Wahlin, 1995; and Hill, Wahlin, Winblad, & Bäckman, 1995) predicts that such concrete pictorial material would lead to smaller age differences than concrete words. That is because cognitive support is supposed to alleviate age differences. Line drawings offer the opportunity for dual encoding, which is typically found to enhance recognition (e.g., Paivio, 1971), and thus provide more cognitive support or more possibilities for compensation than words.

With regard to visual stimuli that carry no meaning, the cognitive support/compensation framework predicts that this condition yields larger age differences than both the word and line drawing condition, because internal support for building good memory traces is lacking in this material. Another framework, the levels-of- process dissociation framework (Kliegl, 1996), likewise predicts larger age differences for such nonsemantic stimuli. Among other propositions, the levels-of-process dissociation framework states that recognition from episodic memory can be situated at two different levels: a coordination/integration level, when new associations have to be formed, but with the stimuli them- selves having representations that are already present in the memory system (such as words and depictions of common objects); and a transformation/generation level, when a massive amount of interference is present or when completely new representations need to be built (such as for Chinese characters; see also Kliegl, Krampe, Mayr, & Liebscher, 1998). Age differences are assumed to be larger for the latter level. At least one study (Smith, Park, Cherry, & Berkovsky, 1990) has indeed found larger age differences in recognition for abstract pictures than for concrete pictures, and ascribes this difference to the absence of (preexisting) propositional content in the abstract stimuli.

We opted for recognition rather than recall as the test procedure in our study, for three rea- sons. First, recognition tests can be administered rapidly and require little subjective effort on the part of the research participant. Consequently, it is possible to obtain complete time-accuracy functions for the three projected conditions within a single session. Second, although it is easy to derive recognition scores for Chinese symbols, it is much harder to get good recall scores from such measures. Third, it is well- known that recognition performance is less susceptible to the negative effects of aging than recall performance. Thus, even if recall scores for very difficult meaningless material are virtually zero, we might indeed observe above- chance scores for recognition performance on the same material.

To summarize, the present study further explored the possibility of age by condition interactions in recognition from episodic memory using the time-accuracy methodology. Recognition memory was tested for line drawings of concrete objects, words, and Chinese characters. If the effect of aging on episodic memory is truly general, no age by condition interactions are expected. If memory is process-specific (as, for instance, is claimed in the compensation/cognitive support framework), we expect differential age effects for all three conditions. A third expectation is provided by Kliegl's (1996) dissociation framework, expecting differential aging for pictures/words and Chinese characters, but a general aging effect for pictures and words.

METHOD

Participants

Young adults were students at Syracuse University who participated in return for course credit. Older adults were recruited through newspaper advertisements and were paid $10 US for their efforts. In total, 45 younger and 50 older persons were tested. In order to avoid floor effects from distorting the findings, data from individual participants were discarded whenever the asymptote in one or more of the three conditions was below .55 (i.e., lower than 10% above chance). Five younger adults and 9 older adults failed to meet this criterion. In addition, one younger participant's data were discarded because of an extremely low asymptote in the line drawing condition (viz., .58, which was more than three interquartile ranges below the mean) and one older participant's data were discarded because of a very slow rate parameter in the word condition (viz., 3.59, which was more than three interquartile ranges above the mean). Consequently, the final sample consisted of 39 younger and 40 older adults. Young adults had a mean age of 21.9 (SD = 5.46) and older adults were on average 68.8 years old (SD = 5.45). Women comprised 56% of the sample of young and 57% of the sample of older adults. Mean number of years of education was 14.25 for the young (SD = 1.20; due to experimenter error, we have data on years of education only for 36 of our young participants) and 15.44 for the older adults (SD = 2.40; due to experimenter error, we have data on years of education completed for only 36 of our older participants); the difference is statistically significant, $t(70) = -2.67$. Older adults scored significantly higher than younger adults on a multiple choice vocabulary test (Shipley; young adults: M = 31.66, SD = 3.22; older adults: M = 35.33, SD = 3.27; $t(76) = -4.99$; data for 1 young participant were missing).

Materials and Procedure

For the line drawing condition, 400 line drawings of common objects and animals were used. This set of stimuli was originally compiled by Snodgrass and Vanderwart (1980); Berman, Friedman, Hamberger, and Snodgrass (1989); and Cycowicz, Friedman, Rothstein, and Snodgrass (1997) as a naming test. Twenty of the stimuli were used for a short list to familiarize participants with the task; the remaining 380 were randomly assigned to 10 lists. Each list consisted of 19 targets (presented at encoding) and 19 foils (each paired with a target at retrieval).

For the word condition, a list of 400 words was compiled from the Medical Research Council Psycholinguistic Database, using the Internet-based interface (http://www.psy.uwa.edu.au/MRC-Database/uwa_mzc.htm). Words were between 3 and 10 letters long and had a score of 500 or higher on both the concreteness and imagery scale as de vised by the MRC (these scales range from 100 to 700, and are a merging of the norms set by Gilhooly & Logie, 1980 and Toglia and Battig, 1978, and an unpublished expansion of the norms by Paivio, Yuille, and Madigan, 1968). Consequently, like the line drawings, they denoted highly concrete objects or living beings.

Average familiarity rating of the stimuli was 508 (*SD* = 67) on a 100-700 scale; these ratings are slightly higher than those for the set of line drawings (3.30 on a 1-5 scale, which amounts to 462 on a 100-700 scale). Twenty of the word stimuli were used for a short list to familiarize participants with the task; the remaining 380 were randomly assigned to 10 lists. Each list consisted of 19 targets (presented at encoding) and 19 foils (each paired with a target at retrieval).

For the Chinese character condition, 400 characters were selected from a Chinese font package (UnionWay AsianSuite). Early piloting showed that characters that were very complex (typically consisting of 20 or more different strokes, or consisting of more than two distinct parts) were very hard to recognize. Consequently, characters selected for the study were screened for relative simplicity as a visual stimulus. All characters consisted of at least four strokes. A sample of the stimuli is provided in Figure 1. Twenty of the stimuli were used for a short list to familiarize participants with the task; the remaining 380 were randomly assigned to 10 lists. Each list consisted of 19 targets (presented at encoding) and 19 foils (each paired with a target at retrieval).

Presentation of conditions was blocked, but the order at which conditions were presented was balanced across participants. Stimuli were projected one at a time at the center of a 13-inch monitor. Line drawings were presented such that their con- tours filled a 10 cm square viewport at the center of the screen. Chinese characters filled a 5 cm square viewport at the center of the screen. (The difference in size was related to the difference in resolution of the original line drawing files. Shrinking the line drawing stimuli would have been at the cost of perceptual detail; enlarging the Chinese characters resulted in pixelization that we found distracting.) Words were presented in lowercase letters, about 17 mm high, of a bold Times-like font (48 points). Participants were allowed to adopt a viewing distance from the screen that they considered most comfortable; hence the difference in size of the different stimulus sets should not be of much consequence.

The 19 study items of a list were presented sequentially at a fixed rate. Presentation times were equal for all conditions and their order was fixed: 750 ms, 350 ms, 2000 ms, 175 ms, 250 ms, 3000 ms, 500 ms, 6000 ms, 1000 ms, and 100 ms. Simi- lar presentation times had previously yielded good estimates for time-accuracy functions in studies by Verhaeghen et al., 1998, Expt. 2, and Verhaeghen, 1999.

Immediately after presentation of each list, recognition trials began. Two stimuli, one target and one foil, were presented simultaneously on the screen, side by side, and participants responded by pressing a key that corresponded to the location of the stimulus they recognized as having been presented during encoding. Accuracy rather than speed of responding was encouraged.

Participants were tested individually in a quiet, comfortable, light-sealed room with controlled ambient lighting. All assessments were taken in a single session, typically lasting about 60 minutes. Participants were encouraged to take breaks when- ever they felt tired; few people, however, chose to take breaks.

All statistical tests were one-tailed, and alpha level was set at .05.

Fig. 1. Sample stimuli from the Chinese character condition.

RESULTS

Time-Accuracy Analysis

For each individual, a three parameter time-accuracy function was estimated with proportion correct as the dependent variable and presentation time (in seconds) as the independent variable, using the SPSS nonlinear regression module. The equation used for fitting was:

$$p(\mathrm{Re}) = .5 + (c - .5)\ (1 - \exp\ [(a - t)/b]) \text{ for } t > a; \text{ and } p(\mathrm{Re}) = .5 \text{ for } t \leq a. \qquad (1)$$

This equation describes a delayed exponential function, and has been applied successfully to episodic memory performance by Kliegl et al. (1998), Verhaeghen and

Kliegl (1998), Verhaeghen et al. (1998), and Verhaeghen (1999). The value of two terms in the equation are fixed: *t* is the time each individual word has been projected on the screen, expressed in seconds; and *p*(Re) is the proportion of items recognized correctly. The three parameters (*a*, *b*, and *c*) are estimated by the nonlinear regression algorithm. Parameter *a* represents the onset time, that is, the time needed for performance to rise above the measurement floor; *b* represents the rate of approach, that is, how fast the curve goes from onset time to asymptotic performance (higher *b* values implying slower processing); and *c* represents asymptotic performance, that is, performance when presentation time is unlimited. The *.5* terms in the equation represent guessing probability; their role is to rescale the vertical axis so that the curve is estimated in the .5-to-1 accuracy interval rather than in the 0-to-1 interval.

In a preliminary inspection of the data, we found that across conditions, the first list presented (i.e., the list presented at 0.75 s) consistently yielded a higher probability of recognition than could be expected from the curve described by the other data points. We assume that this position effect is due to lack of proactive interference on the first trial of a new task. In order not to induce a systematical distortion in the estimation of the individual time-accuracy curves, we decided to drop this first data point from sub- sequent analyses. Also, the individual data showed a considerable drop in the number of items recognized correctly from the presentation time of 350 ms to 500 ms in the Chinese character condition (i.e., at a portion of the presentation time continuum where the curve is rapidly rising). On average, performance dropped from 11.9 to 10.6 in younger adults and from 10.6 to 10.1 in older adults. Particular characteristics of the list presented at the 500 ms presentation time might have made it less memorable than the other lists, and we decided to drop data for this presentation time in this condition from the analysis. As a consequence, the estimate of the individual curves was based on 26 rather than 30 data points.

The three curves (one for each condition) for each participant were estimated simultaneously. Fit of the time-accuracy functions proved satisfactory for both age groups (after removing outliers, younger adults: average pseudo-R^2 =.76, *SD* = 0.08; and older adults: average pseudo-R^2 = .77, *SD* = 0.10). Pseudo-R^2 in non- linear regression equals 1– (residual sum of squares/total sum of squares corrected for the mean); it is analogous to R^2 in linear regression in that values close to 1 denote perfect fit; unlike R^2, however, the value of the nonlinear pseudo- R^2 can become negative.

Age Differences and Interactions in Parameters of the Time-Accuracy Functions

Means and standard deviations for the parameters of the three time-accuracy functions, along with results of t tests for age differences, are presented in Table 1. The average performance of the participants in each age group for each usable presentation time in each of the conditions is depicted in Figure 2, along with the average time-accuracy curve for these participants. (It should be noted that with nonlinear functions, the average of the individual curves is not necessarily of the same form as the best fitting curve for the group data. Hence, deviations of the averaged curve from the averaged data points do not necessarily represent misspecification of the model.)

Table 1. Parameters of Time-Accuracy Functions for Recognition from Episodic Memory as a Function of Age, along with Results of t Test for the Effect of Age.

	Younger adults		Older adults		
	M	(*SD*)	*M*	(*SD*)	$t(77)$
			Line drawings		
Onset time (ms) (*a*)	26	(42)	46	(70)	–1.56
Rate of approach (*b*)	0.17	(0.11)	0.24	(0.20)	–2.29*
Asymptote (*c*)	0.97	(0.03)	0.96	(.03)	1.07
			Words		
Onset time (ms) (*a*)	89	(252)	70	(117)	0.45
Rate of approach (*b*)	0.19	(0.15)	0.36	(0.21)	–4.05*
Asymptote (*c*)	0.92	(0.07)	0.91	(0.05)	0.42
			Chinese characters		
Onset time (ms) (*a*)	206	(292)	340	(406)	–1.69*
Rate of approach (*b*)	0.38	(0.43)	0.35	(0.43)	0.32
Asymptote (*c*)	0.75	(0.12)	0.69	(0.08)	2.32*

* $p < .05$ (one-tailed).

As can be seen in Table 1 and Figure 2, age differences were present in the rate of approach for both the line drawing and word conditions. In the Chinese character condition, a significant age difference was found for both onset time and asymptotic level of performance.

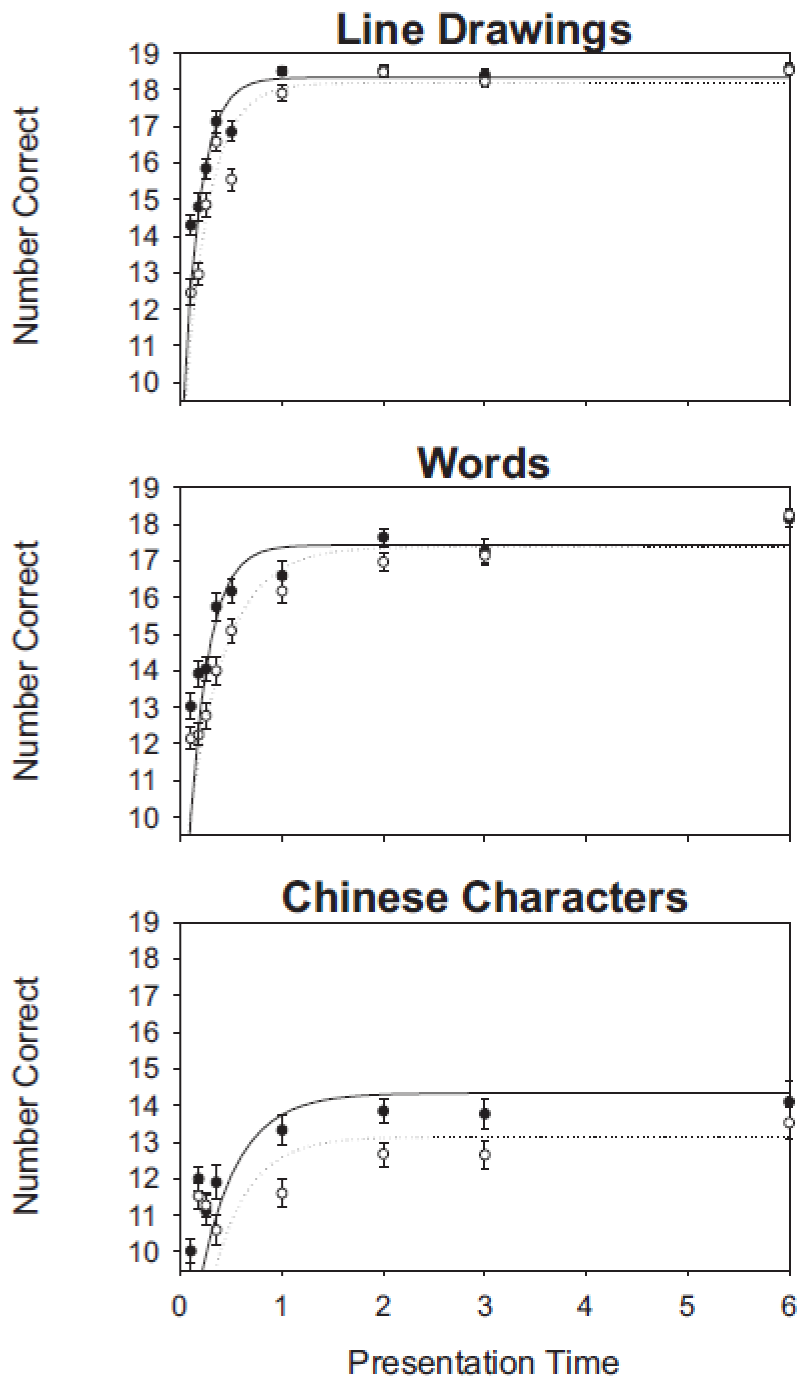

Fig. 2. Performance in the three recognition conditions as a function of age and presentation times (filled circles: younger adults; open circles: older adults; error brackets denote standard errors), along with the average time-accuracy curve.

An analysis of variance for age, condition, and age by condition interactions for each of the parameters was conducted. For the onset parameter (parameter *a*), only the main effect of condition was significant, $F(2, 154) = 23.76$; the main effect of age, $F(1, 77) = 1.95$, and the interaction effect, $F(2, 154) = 1.98$, failed to reach significance. As can be seen in Table 1, onset times rose monotonically with difficulty of the condition.

It can be argued (see also Verhaeghen, Kliegl, & Mayr, 1997) that a logarithmic transformation of the dynamic parameters (i.e., onset time and rate of approach) is in order for a correct test of interaction effects. This is because age differences in processing rate fit a proportional model (i.e., a model that predicts that older adults are slower than younger adults by a fixed percent- age or a fixed ratio) much better than an additive model (i.e., a model that predicts that older adults are slower than younger adults by a fixed amount, e.g., Cerella, 1990; Cerella, Poon, & Williams, 1980). Logarithmic transformation reverts the parameters to proportional measurement space. For the onset parameter, the age by condition interaction failed to reach significance after logarithmic transformation, $F(2, 154) = 0.58$, *ns*.

For the rate of approach parameter (parameter *b*), only the main effect of condition was significant, $F(2, 154) = 8.12$ (rate of approach, as can be seen in Table 1, covaried monotonically with task difficulty); neither the main effect of age, $F(1, 77) = 2.76$, nor the interaction effect, $F(2, 154) = 2.89$, was statistically significant. After logarithmic transformation, however, the inter- action effect (which had a p value of .059 when raw units were used) became significant, $F(2, 154) = 4.32$. Follow-up analysis of two-way interactions showed no significant interaction be- tween age and condition for line drawings versus words, $F(1,77) = 0.54$, *ns.* The interaction between age and condition for words versus Chinese characters was indeed significant, $F(1, 77) = 5.51$, and the interaction for line drawings versus Chinese characters, though not significant, $F(1, 77) = 3.01$, *ns*, had a rather low p value associated with it ($p = 0.087$).

For the asymptotic level of performance (parameter *c*), the main effect of condition proved significant, $F(2, 154) = 383.25$, as did the age by condition interaction, $F(2, 154) = 4.32$; the age effect, however, did not reach significance, $F(1, 77) = 3.37$. Table 1 shows that asymptotic performance went down monotonically with increasing task difficulty, and that asymptotic performance of the young was better than that of the older adults only in the Chinese character condition. Follow-up analysis of two-way inter- actions confirmed the presence of significantly larger age differences in the asymptote for the Chinese character condition when compared with both the line drawing condition, $F(1, 77) = 4.52$, and the word condition $F(1, 77) = 5.69$; and they confirmed the absence of an age by condition interaction for line drawings versus words, $F(1, 77) = 0.03$, *ns.*

DISCUSSION

The present research attempted to expose differential effects of aging on different types of recognition tasks. Three tasks were used: recognition for line drawings of common objects, recognition for words denoting common objects, and recognition for Chinese characters. We found a dissociation between memory for line drawings and words on the one hand, and memory for Chinese characters on the other hand. The locus of the interaction, in terms of the time-accuracy parameters affected, depended on whether or not the stimulus content received semantic support. For semantically supported memory (memory for material that can be as- signed a meaning and linked to specific elements in semantic memory), the effects of age were restricted to speed of processing, because older adults simply needed more time to reach the same level of performance as younger adults. In other words, in the present sample and with semantically supported tasks, only a limited-time mechanism of aging (Salthouse, 1996) was found to be operating.

Chinese characters, on the other hand, led to an age difference in final accuracy in the absence of an age difference in speed of elaboration. With this type of material, even with an unlimited amount of processing time, older adults would be unable to reach the same level of performance as younger adults – an effect that a limited-time slowing mechanism cannot explain.

The interactions found indicate differential effects of aging across conditions, and are thus incompatible with a view of episodic memory aging as a general phenomenon. The details also seem to be at odds with specific theories, such as the compensation/cognitive support theory (e.g., Bäckman, 1989), which predict that age differences will covary with conditions, that is, age differences will be smaller in conditions offering less support or less opportunity for compensation. This theory would predict differential aging effects for line drawings and words, because line drawings offer an opportunity for dual encoding which is less likely to occur with words.

Our results are, however, in line with Kliegl's (1995) levels-of-process framework. This theory predicts a dissociation between age effects found in semantically supported memory (Kliegl's coordination/integration level) and those found in memory for meaningless stimuli (Kliegl's transformation/generation level), and predicts that no dissociations will occur within either type of material. These predictions, and our conforming results, are in agreement with previous findings from the literature. For the nondissociation between words and pictures, see Park, Puglisi, and Sovacool (1983); for the dissociation between concrete and abstract materials, see Smith et al. (1990). Our time-accuracy analysis designates asymptotic performance as the locus of this effect. An important caveat, however, must be made. Asymptotic age differences in memory performance have been found in other studies under conditions that would appear to be at the level of coordination/integration (Verhaeghen, 1999; Verhaeghen et al., 1998). Consequently, we interpret the current findings cautiously as pointing to an increase in asymptotic age differences from semantically supported to semantically unsupported memory, rather than as demonstrating the complete absence of asymptotic age differences in semantically supported memory.

There is, of course, the prosaic possibility that the absence of an age by condition interaction in the asymptote is due to a ceiling effect in the line drawing and word conditions which may have masked a true age difference. (Given the nature of the tasks, it was difficult to avoid both ceiling effects in the semantically supported conditions and floor effects in the semantically unsupported conditions.) Actually, very few of the estimated asymptote parameters equaled unity, and those were distributed almost equally across age groups: 9 younger and 7 older adults had an asymptote of 1.0 in the line drawing condition, and only 1 younger and 2 older adults had an asymptote of 1.0 in the words condition. We also note that both Verhaeghen, Vandenbroucke, and Dierckx (1998, Expt. 2) and Verhaeghen (1999) found asymptotic age differences in recognition memory with asymptotic levels in the young comparable to those obtained here. Thus the scores of our young participants appear to be sufficiently below unity to allow age interactions to occur.

Why does the semantic system support equal levels of encoding effectiveness when external time limits are removed, whereas encoding new, meaningless stimuli leads to relatively large age differences in encoding effectiveness? One way to explain the findings is to point to the intactness of the mechanism of semantic activation in old age (for a review, see Kemper, 1992). Inasmuch as recognition depends heavily on familiarity (Atkinson & Juola, 1974; Jacoby, 1991; Mandler, 1980), that is, on the absolute level of activation of a node in a semantic network (e.g., Anderson, 1983), small or nonexisting age deficits are expected in recognition for elements that can indeed be related to the preexisting semantic network. Elements for which new representations have to be built on-line, however, might be subject to possible age-related differences in the ultimate effectiveness of building such representations in memory. This simple and straightforward explanation, however, remains internal to the specific memory task used here, namely recognition memory. This model cannot be generalized to recall, because familiarity plays a much lesser role in recall.

An alternative and broader mechanism to explain the present results is the working-with-memory model advanced by Moscovitch (e.g. Moscovitch, 1992, 1994; see also Anderson, Craik, & Naveh-Benjamin, 1998, for an application of this model to the attentional demands on encoding and retrieval in old age). The working- with-memory model posits that elements to be retained in episodic memory are processed through two neural systems, the hippocampal system and the frontal system (see Petrides, 1998, for a similar model based on a distinction between *automatic* retrieval, driven by posterior cortical association regions, and active retrieval, controlled by the ventrolateral frontal cortex). According to this theory, information in consciousness is channeled automatically to the hippocampus, which integrates the stimulus with perceptual and semantic records so as to form a memory trace. Effective use of the hippocampal system, however, assumes controlled, strategic processes, which necessarily involve the frontal lobe system. Damage to the frontal lobes ‘‘typically does not lead to memory loss if the cues are sufficient to specify the target event,’’ but does lead to ‘‘impairment on tests in which extra-cue organizational factors are important, [and] in which complex search strategies must be initiated and executed’’ (Moscovitch & Winocur, 1995, p. 324). It is well-known that aging especially affects the frontal lobes (for an overview, see Raz, 2000; West, 1996). The finding that age differences are larger in recall than in recognition is in accordance with this model (Petrides, 1998). In a recognition study, Parkin and Walter (1992) found that older adults rely more on familiarity (as opposed to explicit recollection) for recognition of lists of words than younger adults and that within the older age group there was a correlation between the extent to which recognition is familiarity based and scores on a test of frontal lobe dysfunction. Thus, the frontal lobe dysfunction associated with normal aging leads older participants away from controlled, strategic processing. Likewise, Rybash and Hoyer (1996) found that in older adults, the influence of unconscious influences in recognition memory for objects is relatively larger than in younger adults. The present study suggests that regardless of the speed of deployment of strategic processing (i.e., regardless of the rate of elaboration as captured in the rate of approach parameter), frontal lobe damage (or a dysfunction in the interaction between the frontal and hippocampal systems) may lead to a de- crease in asymptotic performance for tasks that rely heavily on controlled, strategic processing.

Although the results pertaining to asymptotic performance seem explainable, one aspect of the findings is puzzling at first sight, namely the absence of age differences in the rate parameter in the Chinese character condition. For both the line drawing and word conditions, older adults were found to be slower in their encoding processes than younger adults, and the slowing factors (i.e., the old/young ratios of the rate parameters, which were 1.4 and 1.9, respectively) are not out of line with what would be expected from meta-analyses of behavioral slowing in latency data (e.g., Cerella, 1990). For the Chinese character condition, however, no age-related slowing was evident at all (the old/young ratio of the rate parameters was .9), indicating that the elaboration process for these stimuli was as fast for older adults as for young adults.

There is reason to be slightly distrustful about this slope equivalence. This result may simply be an artifact due to the relative coarseness of the measurement space with the asymptote only 50% above chance. That is, we may have obtained inadequate estimates of the rise in the curve in the Chinese character condition. As can be seen in the lower panel of Figure 2, the data in this condition are quite noisy at the short presentation times needed for a correct estimate of the slope of the time-accuracy function. Consequently, until this finding is replicated, we should not attach too much weight to it.

If we do take the finding at face value, one possible explanation for the combination of an age difference in asymptotic performance in the absence of an age difference in rate of approach may be found in neural network theory. When age differences in cognition are modeled in such networks, the general assumption made (e.g., Cerella, 1990; Hannon & Hoyer, 1994; Li, Lindenberger, & Frensch, 1996; MacKay & Burke, 1990; Salthouse, 1988) is that networks simulating performance of older people are identical in structure and function to networks simulating performance of younger people; however, older networks are functioning less well because nodes are eliminated, connections disappear, or the level of noise increases. In other words, networks simulating behavior of older adults can be considered damaged or degraded versions of younger adult networks. The degradation of the network occurs over the adult life span, which implies that the network will certainly have learned concepts such as the ones contained in the word and picture stimuli in our experiment before it gets damaged. Under such circum- stances (at least when the damage is not too extensive), networks have been shown to exhibit behavior known as graceful degradation (e.g., Rolls & Treves, 1998). For instance, auto-associator networks trained to respond to certain stimuli and damaged after the learning episodes may well be able to recover the original stimulus, as long as the damage is not in the final layer. In other words, the level of activation for stimuli previously learned may be as high in a damaged as in an undamaged network. If we interpret the asymptote as reflecting the strength of activation of the items in episodic memory (McClelland, 1979), then asymptotic performance in recognition memory in degraded net- works may be as accurate as asymptotic performance in intact networks for stimuli that were in the repertoire before the damage occurred. How- ever, information will be propagated at a slower rate through damaged networks (e.g., Cerella, 1990), and hence we might expect such net- works to be slower in reaching the asymptotic level of activation. In sum, results from neural network studies suggest that older adults will be slower than younger adults in recognition performance for familiar, overlearned stimuli such as words and concrete pictures, but they might well be equally effective at asymptote as younger adults. For stimuli acquired after degradation of the network has occurred, however, the situation appears to be different. For instance, Li et al. (1996) have shown that degrading an auto-associator network by adding noise between the connections leads to a lowered asymptote, but has only slight effects on the speed of reaching the asymptote. (Note that the Li et al. network was designed to simulate accumulation of learning over trials; we are assuming here that such learning behavior of networks is analogous to accumulation of information in a single trial.) In other words, for tasks such as learning to recognize Chinese characters (a novel task for both younger and older adults), older adults will be expected to perform at a lower asymptotic level, but they should not necessarily reach this asymptote at a slower rate.

To summarize, in this study we found evidence for the existence of differential aging effects on recognition memory for stimuli that can be encoded in a preexisting semantic network and stimuli that require the generation of new representations. Behavioral slowing governed age differences in recognition memory for semantically supported material, whereas the age difference in recognition for material that is not supported by semantic memory was situated in the asymptote. We advanced some possible, not mutually exclusive mechanisms (viz., familiarity, working with memory, and graceful degradation in neural networks) to elucidate this dissociation within recognition memory.

REFERENCES

Anderson, J.R. (1983). *The architecture of cognition.* Cambridge, MA: Harvard University Press.

Anderson, N.D., Craik, F.I.M., & Naveh-Benjamin, M. (1998). The attentional demands of encoding and retrieval in younger and older adults: 1. Evidence from divided attention costs. *Psychology and Aging, 13,* 405-423.

Atkinson, R.C., & Juola, J. (1974). Search and decision processes in recognition memory. In D.H. Krantz, R.C. Atkinson, R.D. Luce, & P. Suppes (Eds.), *Contemporary developments in mathematical psychology* (Vol. 1, pp. 242-293). San Fran- cisco, CA: Freeman.

Bäckman, L. (1989). Varieties of memory compensation by older adults in episodic remembering. In L.W. Poon, D.C. Rubin, & B.A. Wilson (Eds.), *Everyday cognition in adulthood and late life* (pp. 509-544). Cambridge: Cambridge University Press.

Bäckman, L., & Wahlin, A. (1995). Influences of item organizability and semantic retrieval cues on word recall in very old age. *Aging and Cognition, 2*, 312-325.

Berman, S., Friedman, D., Hamberger, M., & Snodgrass, J.G. (1989). Developmental picture norms: Relationships between name agreement, familiarity, and visual complexity for child and adult ratings of two sets of line drawings. *Behavior Research Methods, Instruments & Computers, 21*, 371-382.

Cerella, J. (1990). Aging and information-processing rate. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (3rd ed., pp. 201- 221). New York: Academic Press.

Cerella, J., Poon, L.W., & Williams, D.M. (1980). Age and the complexity hypothesis. In L.W. Poon (Ed.), *Aging in the 1980's* (pp. 332-340). Washington: American Psychological Association.

Cycowicz, Y.M., Friedman, D., Rothstein, M., & Snodgrass, J.G. (1997). Picture naming by young children: Norms for name agreement, familiarity, and visual complexity. *Journal of Experimental Child Psychology, 65*, 171-237.

Gilhooly, K.J., & Logie, R.H. (1980). Age of acquisition, imagery, concreteness, familiarity and ambiguity measures for 1944 words. *Behaviour Research Methods and Instrumentation, 12,* 395-427.

Hannon, D.J., & Hoyer, W.J. (1994). Mechanisms of visual-cognitive aging: A neural network account. *Aging and Cognition, 1*, 105-119.

Hill, R.D., Wahlin, A., Winblad, B., & Bäckman, L. (1995). The role of demographic and life style variables in utilizing cognitive support for episodic remembering among very old adults. *Journals of Gerontology: Psychological Sciences, 50*, P219- P227.

Jacoby, L.L. (1991). A process dissociation frame- work: Separating automatic from intentional uses of memory. *Journal of Memory and Language*, *30*, 513-541.

Kausler, D.H. (1994). *Learning and memory in normal aging.* San Diego, CA: Academic Press.

Kemper, S. (1992). Language and aging. In F.I.M. Craik & T.A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 213-270). Hillsdale, NJ: Erlbaum.

Kliegl, R. (1995). From presentation time to processing time: A psychophysics approach to episodic memory. In W. Schneider & F.E. Weinert (Eds.), *Memory performance and competencies: Issues in growth and development* (pp. 89-110). Mahwah, NJ: Erlbaum.

Kliegl, R. (1996, July). *Cognitive development and cognitive complexity: A psychophysics approach.* Paper presented at the Max Planck Institute for Psychological Research, Munich, Germany.

Kliegl, R., Krampe, R., Mayr, U., & Liebscher, T. (1998). *Testing the limits and multinomial modeling of age differences in proactive interference: Evidence for a context encoding deficit.* Manu- script submitted for publication.

LaVoie, D., & Light, L.L. (1994). Adult age differences in repetition priming: A meta-analysis. *Psychology and Aging*, *2*, 539-553.

Li, S.-C., Lindenberger, U., & Frensch, P. (1996, April). *Interference, reduced processing resources, and cortex: In search of a general computational framework for theories of cognitive aging.* Paper presented at the Cognitive Aging Conference, Atlanta, GA.

MacKay, D.G., & Burke, D.M. (1990). Cognition and aging: A theory of new learning and the use of old connections. In T. Hess (Ed.), *Aging and cognition: Knowledge organization and utilization* (pp. 281-300). Amsterdam: North-Holland.

Mandler, G. (1980). Recognizing: The judgement of previous occurrence. *Psychological Review*, *87*, 252-271.

McClelland, J.L. (1979). On the time relations of mental processes: A framework for analysing processes in cascade. *Psychological Review, 86*, 287- 330.

Moscovitch, M. (1992). Memory and working-with- memory: A component process model based on modules and central systems. *Journal of Cognitive Neuroscience, 4*, 257-267.

Moscovitch, M. (1994). Memory and working with memory: Evaluation of a component process model and comparison with other models. In D.L. Schacter & E. Tulving (Eds.), *Memory systems 1994* (pp. 269-310). Cambridge, MA: MIT Press.

Moscovitch, M., & Winocur, G. (1995). Frontal lobes, memory, and aging. In J. Grafman, K.J. Holyoak, & F. Boller (Eds.), *Structure and functions of the human prefrontal cortex* (pp. 119-150). New York: New York Academy of Sciences.

Paivio, A. (1971). *Imagery and verbal processes.* New York: Holt.

Paivio, A., Yuille, J.C., & Madigan, S.A. (1968). Concreteness, imagery, and meaningfulness values for 925 nouns. *Journal of Experimental Psychology Monograph, 76,* 509-514.

Park, D.C., Puglisi, J.T., & Sovacool, M. (1983). Memory for pictures, words, and spatial location in older adults: Evidence for pictorial superiority. *Journal of Gerontology, 38,* 582-588.

Parkin, A.J., & Walter, B.M. (1992). Recollective experience, normal aging, and frontal dysfunction. *Psychology and Aging, 7*, 290-298.

Petrides, M. (1998). Specialized systems for the processing of mnemonic information within the primate frontal cortex. In A.C. Roberts, T.W. Rob- bins, & L. Weiskrantz (Eds.), *The prefrontal cortex: Executive and cognitive functions* (pp. 103- 116). Oxford: Oxford University Press.

Raz, N. (2000). Aging of the brain and its impact on cognitive performance: Integration of structural and functional findings. In F.I.M. Craik & T.A. Salthouse (Eds.), *The handbook of aging and cognition* (2nd ed., pp. 1-90). Mahwah, NJ: Erlbaum.

Rolls, E.T., & Treves, A. (1998). *Neural networks and brain function.* Oxford: Oxford University Press.

Rybash, J.M., & Hoyer, W.J. (1996). Process dissociation procedure reveals age differences in unconscious influences on memory for possible and impossible objects. *Aging, Neuropsychology, and Cognition, 3,* 251-263.

Salthouse, T.A. (1988). Initiating the formalization of theories of cognitive aging. *Psychology and Aging, 3,* 3-16.

Salthouse, T.A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review, 103,* 403-428.

Shepard, R.N. (1967). Recognition memory for words, sentences, and pictures. *Journal of Verbal Learning and Verbal Behavior, 6,* 156-163.

Smith, A.D. (1996). Memory. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (4th ed., pp. 236-250). San Diego, CA: Academic Press.

Smith, A.D., Park, D.C., Cherry, K., & Berkovsky, K. (1990). Age differences in memory for concrete and abstract pictures. *Journal of Gerontology: Psychological Sciences, 45,* P205-P209.

Snodgrass, J.G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *6*, 174- 215.

Standing, L. (1973). Learning 10,000 pictures. *Quarterly Journal of Experimental Psychology, 25*, 207- 222.

Toglia, M.P., & Battig, W.R. (1978). *Handbook of semantic word norms.* New York: Erlbaum.

Verhaeghen, P. (1999). The effects of age-related slowing and working memory on asymptotic recognition performance. *Aging, Neuropsychology, and Cognition, 6,* 201-213.

Verhaeghen, P. (2000). The parallels in Beauty's brow: Time-accuracy functions and their implications for cognitive aging theories. In T. Perfect & E. Maylor (Eds.), *Models of cognitive aging* (pp. 50-86). Oxford: Oxford University Press.

Verhaeghen, P., & Kliegl, R. (1998). *The effects of learning a new algorithm on asymptotic accuracy and execution speed in old age: A reanalysis of Baltes & Kliegl (1992).* Manuscript submitted for publication.

Verhaeghen, P., Kliegl, R., & Mayr, U. (1997). Sequential and coordinative complexity in time-accuracy functions for mental arithmetic. *Psychology and Aging, 12,* 555-564.

Verhaeghen, P., & Marcoen, A. (1993). Memory aging as a general phenomenon: Episodic recall of older adults is a function of episodic recall of the young. *Psychology and Aging, 8,* 380-388.

Verhaeghen, P., Marcoen, A., & Goossens, L. (1993). Facts and fiction about memory aging: A quantitative integration of research findings. *Journal of Gerontology: Psychological Sciences, 48*, P157- P171.

Verhaeghen, P., & Salthouse, T.A. (1997). Meta-analyses of age-cognition relations in adulthood: Estimates of linear and non-linear age effects and structural models. *Psychological Bulletin, 122,* 231-249.

Verhaeghen, P., Vandenbroucke, A., & Dierckx, V. (1998). Growing slower and less accurate: The effects of age on time-accuracy functions for recall from episodic memory. *Experimental Aging Research, 24,* 3-19.

West, R.L. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychological Bulletin, 120,* 272-292.