The Effects of Learning a New Algorithm on Asymptotic Accuracy and Execution Speed in Old Age: A Reanalysis

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Time-accuracy curves were derived for 16 younger and 19 older persons who participated in a study on training in the method of loci (Bates & Kliegl, 1992). The effects of instruction were to immediately and permanently boost asymptotic performance and initially slow down the rate of approach to the asymptote. After extensive practice, rate of approach returned to the initial fast level. Age differences were found in both asymptotic performance and rate of approach. The effects of instruction and practice, however, were similar in younger and older adults, but older adults needed 1 session of instruction more than younger adults did before the intervention showed its full effect.

One of the most replicated findings in the field of cognitive aging is the age-related decline in recall from episodic memory (for a meta-analytic overview, see Verhaeghen, Marcoen, & Goossens, 1993; Verhaeghen & Salthouse, 1997). It is well known that measures assumed to indicate basic speed of processing are important mediators between age and episodic memory (for an overview, see Salthouse, 1996, and Verhaeghen & Salthouse, 1997). Research leading to this conclusion has mostly used correlational analysis. Recently, however, the influence of basic speed on higher order cognition has also been examined with an experimental method. In these studies (Kliegl, Krampe, Mayr, & Liebscher, 1998; Kliegl, Mayr, & Krampe, 1994; Mayr, Kliegl, & Krampe, 1996; Verhaeghen, 1999; Verhaeghen, Kliegl, & Mayr, 1997; Verhaeghen, Vandenbroucke, & Dierckx, 1998), processing time is indirectly manipulated through the availability of the external resource "presentation time," and accuracy is mapped out as a function of time. A mathematical function relating time to accuracy (a time-accuracy function) is then fitted to the data, and the parameters describing this function are used for subsequent analysis.

Researchers studying the relation between presentation or processing time and cognitive performance in young adults have demonstrated that this relation is typically nonlinear and well described by a delayed exponential equation (e.g., Dosher, 1976; Lohman, 1989; McClelland, 1979; McIntyre & Griffith, 1995; Wickelgren, 1977). This equation is governed by three parameters. Performance remains at chance level until a certain point in time (the onset time). From the onset time on, performance rises in a negatively accelerating curve, that is, the performance curve rises rather steeply from chance level and then gradually becomes less and less steep, flattening toward a horizontal asymptote. The third parameter describing the function is the rate of approach, that is, the rate at which performance goes from chance level to the asymptote from the onset time on. More formally, the equation used to fit the data in the studies described above (assuming that chance level is zero) is

\[ p = c \left(1 - \exp\left(\frac{(a - t)/b}{c}ight)\right) \quad \text{for } t > a; \]  

\[ p = 0 \quad \text{for } t \leq a; \]  

where \( a \) is the onset time, \( b \) is the rate of approach, and \( c \) represents the asymptote. Note that the \( b \) parameter as included in this equation is scaled such that higher \( b \) values indicate slower rates of approach, or, in other words, curves that are less steep.

One important advantage of using the time-accuracy methodology is that it allows for a distinction between dynamic effects (i.e., effects on rate and onset) and asymptotic effects of aging on cognitive performance. One obvious consequence of age-related slowing might be that aging effects the dynamics only of the curve. In this case, older adults would simply need more time for performance to rise above chance level; or they might need more time to reach their asymptotic level, which would then be equal to that of young adults; or both onset time and rate differences would be present. If only dynamic differences are present, then age differences can be remediated by allowing for more processing time. Salthouse (1996) called this the limited-time mechanism for cognitive slowing. Aging, however, might also affect the level of performance ultimately reachable, or even the quality of the final outcome. Salthouse (1996), for instance, has argued for a simultaneity mechanism of cognitive slowing, that is, one consequence of slowing could be that products of earlier information processing may be lost by the time that later processing is completed. If earlier products are needed for accurate performance, then such a mech-
anism might affect the ultimate, asymptotic performance of the system.

Another advantage of the time-accuracy methodology is that performance of an individual is now captured in three distinct parameters that each can be assigned meaning, depending on the task. Take the onset parameter. For episodic memory, it makes sense to posit that a word stimulus must be read before it can be in any way remembered and, conversely, that it will stand a minimal chance of being remembered as soon as it has been accessed in the lexicon. Consequently, the onset parameter can be interpreted as the time needed to recognize the word and access the lexicon. For the rate of approach parameter, Kliegl (1995) offered an explanation in terms of elaboration rate. The assumption is that participants studying a list of words generate elaborations (i.e., particular associations) for each of the stimuli and that the probability of recall is directly proportional to the number of elaborations that can be generated (e.g., Craik & Tulving, 1975; James, 1890; Kausler, 1991, p. 351; note that sheer repetition does not necessarily lead to better recall [e.g., Glenberg, Smith, & Green, 1977], therefore this component of elaboration seems a necessary ingredient of effective encoding for free recall). Elaborations are assumed to be sampled out of a finite store of associations. Hence, increased processing time will allow for sampling of more elaborations and consequently to better recall. Kliegl (1995) assumed that after usage, the elaborations are put back into the store. This increases the likelihood of sampling elaborations already retrieved as time increases and will lead to diminishing returns with increased processing time, or in other words, to a time-accuracy curve flattening to an asymptote. The negative exponential is compatible with such a stochastic replacement model of learning (Restle & Greeno, 1970). The asymptote is generally taken to reflect the maximum strength of activation (McClelland, 1979), or the carrying capacity of the system (van Geert, 1993), under the particular circumstances of the task.

Previous time-accuracy research has demonstrated that in rather simple tasks, such as figural scanning, word scanning, figural reasoning, and cued recognition (Kliegl et al., 1994; Mayr et al., 1996), older adults are merely slower in getting performance off the measurement floor or in reaching the asymptote than young adults. This suggests that a simple limited-time slowing mechanism is sufficient to explain aging effects in such tasks. However, for recall, age differences in asymptotic performance have been found, as well as age differences in the rate of approach parameter (Kliegl et al., 1998; Verhaeghen and Marcoen, 1996). This suggests that the elaboration processes slow down with age and that the carrying capacity of the system for episodic memory decreases.

There is, however, a possible confound here, in the sense that strategic processes at encoding and retrieval are possibly important determinants of episodic recall, and people do differ in the strategies they bring to such tasks (e.g., Verhaeghen & Marcoen, 1996). Behavioral slowing and loss of ultimate accuracy can only rightfully be traced to mental slowing and to a loss of carrying capacity when the correspondence axiom (Cerella, 1990) holds, that is, when we can be certain that young and older adults apply the same processes (in the same sequence) to a task. If strategy differences exist, then behavioral slowing and age-related accuracy differences might be the result of usage of less-than-optimal strategies by older adults and not of mental slowing or loss of carrying capacity per se. Consequently, more conclusive evidence for the existence of age-related differences in speed of encoding processes and in final accuracy should come from research where strategy differences between younger and older adults have been minimized.

A line of research that seems particularly promising for our goal of strategy equalization is the intervention research aimed at eliciting cognitive and memory plasticity by teaching older adults effective cognitive and mnemonic strategies (e.g., Baltes & Labouvie, 1973, Baltes & Schaeie, 1976; Baltes & Willis, 1982; Denney, 1979; Kliegl & Baltes, 1987; Labouvie-Vief, 1976). It has been demonstrated that the performance of older adults on memory tasks can indeed be boosted considerably by simple instruction and some practice with an efficient mnemonic, such as the method of loci. In a meta-analysis, Verhaeghen, Marcoen, and Goossens (1992) found the effect to be about three quarters of a standard deviation. This demonstration of memory plasticity, in turn, implies that older adults are typically applying suboptimal strategies to the kind of memory tasks psychologists subject them to in their laboratories, but so, apparently, are younger adults. In a follow-up meta-analysis, Verhaeghen and Marcoen (1996) noted that in all memory-training studies (with only one exception) in which both a group of younger and older adults were trained, the effects of training in the older adults were found to be smaller than those in younger adults. Consequently, younger adults actually benefit more from memory training than older adults. Thus, it seems that when younger and older adults are performing identical (and highly effective) strategies, age differences do not disappear; on the contrary, they are exacerbated. This observation still leaves us in the dark as to the locus of the effect: Older adults might be disproportionately slower than younger adults when using effective mnemonics (and this could be due to increased onset times, slower rates of approach, or both), their level of asymptotic performance might increase less after training, or both. Another possibility is that older adults need more practice with the strategy than younger adults and that true equalization of strategy use will only occur after extended practice.

In this article, we apply the time-accuracy methodology to a long-term data set that examined plasticity in episodic memory functioning (Baltes & Kliegl, 1992; Kliegl, Smith, & Baltes, Kliegl, Smith, & Baltes, 1989, 1990). In this study, a group of 16 younger and 19 older adults were trained in the method of loci and practiced the method during fifteen 1-hr sessions. The method of loci is an imagery-based mnemonic that is particularly suited for serial recall of words. Briefly, in this mnemonic, participants are instructed to associate each of the words to be remembered with a particular location (a "locus") in an ordered sequence of locations, using interactive imagery for the association (see, e.g., Bellezza, 1987, for more details). At retrieval, the user mentally revisits each location in the correct order and uses the location as a retrieval cue for the image from which the original word is decoded. In this study, a series of 30 Berlin landmarks provided the loci. A total of 38 pretest, instruction, practice, and assessment sessions were administered over a period of 1 year and 4 months. Given the extremely long duration of this program, we assume that the technique will be highly overlearned, and younger and older adults will be thoroughly equated on strategy use at the end of training and practice. Data are available for one pretest occasion and nine posttest occasions. At each of these points during training, serial
recall of a list of 30 words was measured at 6 (pretest to sixth posttest) or 12 (seventh posttest to final posttest) presentation times per word, ranging between 0.84 s and 20.00 s. In previous articles reporting on results from this study, data were averaged across these presentation times. In this article, we reexamined the data from these different presentation times to derive time-accuracy functions for each individual at each of the testing occasions. Previous analysis on this data set revealed sizable treatment gain for both young and older adults. The age differences present at pretest were magnified over the course of training and practice sessions, especially at the longer presentation times, suggesting asymptotic age differences.

The first goal, then, of this article is to assess the effects of training and practice in the method of loci on the parameters of the time-accuracy functions. More specifically, we were interested in capturing the differences between the effects of instruction versus continued practice on dynamic and asymptotic effects on the time-accuracy function for serial recall. One interesting aspect of the previous findings, as seen in Figure 2 in Kliegl et al. (1990) and Figure 1 in Baltes and Kliegl (1992), is that the curves describing performance as a function of testing occasions are quite smooth, rising steeply at first but then gradually flattening toward a horizontal asymptote. At first sight, this seems to suggest that the transition from an untrained to a trained and then a well-practiced state is quite undramatic, and it closely follows the general rule of the power law of practice (Newell & Rosenbloom, 1981). A closer investigation of the correlation matrix, however, revealed that the correlation between pretest and the first posttest was quite small, but correlations were high between the different posttest occasions (Kliegl et al., 1990). This then suggests no smooth transition, but indicates that different mechanisms are indeed at play in pretest and posttest, making for a drastic reordering of participants on the performance continuum. No such dramatic change occurs between posttest occasions, suggesting that settling into a well-practiced state is indeed a smooth transition. We hoped to see this qualitative shift from learning to continued practice reflected in the parameters of the underlying time-accuracy functions.

Given that the method of loci prescribes a specific strategy, the meaning of the parameters of the time-accuracy function changes after posttest. As stated above, the onset time reflects the time needed for minimal recall of the stimulus. When people are applying the method of loci correctly, encoding of a word entails retrieval of the appropriate locus, reading the word, and forming a combined mental image of the locus and the word. Thus, the onset time at and after posttest should not only reflect perceptual processes needed for word reading, but also the time needed for retrieval of the locus during the encoding phase of the experiment. We remain agnostic as to whether these processes occur in parallel; we assume, however, that an increase in the onset parameter after training would signify that either the locus retrieval and word reading processes are executed in a serial fashion, or else that cueing is occurring somewhere in the parallel stream of processing (Liu, 1996). A decrease in onset time over the course of practice can mean at least two things: either retrieval of the locus and word reading become increasingly parallel in their execution, or the retrieval process is executed in an increasingly faster fashion. The rate-of-approach parameter would still reflect the time needed for elaboration, which, in this case, means forming and elaborating on an interactive image. Forming interactive images is not a strategy that most adults spontaneously apply to serial recall (Verhaeghen & Marcoen, 1994). Consequently, we expect that, after posttest, the rate parameter will decrease with continued practice, because the process of generating an interactive image will become more efficient. For the transition from pretest to posttest, we might expect the rate of approach to go up, because this transition entails a change from strategies that are spontaneously applied to the task and are presumably partially automatized to a new, deliberately controlled way of doing the task. Given that the method provides an excellent cueing structure for both encoding and retrieval, we would expect asymptotic accuracy to go up considerably after training. If the sequence of locations is well learned at the first posttest, then we should expect little change in asymptote after the first posttest.

The second goal of our reanalysis was to examine age differences in the parameters and how they change across training sessions. On the basis of previous research on adult age differences in time-accuracy functions for recall from episodic memory (Kliegl et al., 1998; Verhaeghen et al., 1998), we expect initial age differences in rate of approach and asymptotic performance but not onset time. One question of particular interest concerns potential age differences in the nature of the transitions and the possibility of interactions between age and testing occasions. It is our assumption that comparison of the final sessions of practice, when the mnemonic is highly overlearned in both age groups, should give us a good estimate of age differences in memory functioning when both groups are using an identical highly effective strategy. Although some literature on aging and skill acquisition exists (for overviews, see Baron & Cerella, 1993, and Salthouse, 1991), our article is the first to investigate age differences at the level of the parameters of an underlying performance model, rather than at the level of observed latencies or observed accuracy.

Method

Detailed information on participants, procedure, and testing materials can be found in the original articles describing this study (Baltes & Kliegl, 1992; Kliegl et al., 1989, 1990). Here, we briefly reiterate the main points concerning the method.

Participants

Participants were 16 young adults, ranging in age between 20 and 30 years, and 19 older adults, ranging in age between 66 and 88 years old. All participants scored above average on the Hamburg-Wechsler-Intelligenztest für Erwachsene test (i.e., German version of the WAIS; Hardesty & Lauber, 1956; young IQ, \( M = 118, SD = 6 \); old IQ, \( M = 125, SD = 8 \)). All were in good self-reported health. Younger and older adults did not differ significantly on intelligence and self-reported health measures.

Design

The entire experimental schedule consisted of thirty-eight 1-hr sessions, distributed over a period of 1 year and 4 months. After initial assessment, two phases can be distinguished: a training phase (Sessions 5 and 6) and a practice phase (Sessions 7 to 37). The last session was a debriefing session.

Materials. Lists of 30 words were used for the assessment of serial recall. All words were nouns denoting concrete objects. Words used for the assessment lists appeared only once in the experiment.
Training conditions. In each of the training and practice sessions, scheduled at approximately two sessions per week, 4 lists of 30 words were administered. Across all sessions of training and practice, each participant performed 4,380 trials of interactive imagery, linking a word to a location. During the training phase (Sessions 5 and 6), the method of loci was explained. Words were presented at time intervals comfortable to each individual, that is, without time pressure. During the 15 sessions of practice (Sessions 8, 9, 11, 12, 14, 15, 21, 22, 23, 28, 29, 30, 33, 34, and 35), presentation of words was experimenter paced. Different presentation times between 0.84 s and 20.00 s per word were used (6 different times up until Session 25; 12 after Session 25; see next paragraph for precise values). Participants were moved to shorter presentation times when they passed a criterion (50% or 80%) correct. When performance was below criterion on two successive occasions, longer presentation times were used again.

Performance Assessment

Assessment of serial recall occurred in Sessions 3 (pretest), 7 (immediate posttest), 10, 13, 16, 17, 25, 26/27, 31/32, and 36/37 (practice). There were two assessment formats reflective of the change in rates of presentation times after Session 23. At the first seven occasions, 6 lists of 30 words were administered with presentation times of 20.00 s, 15.00 s, 10.00 s, 5.00 s, 3.00 s, and 1.00 s. At the final three occasions, assessment extended over two sessions. In the first of these sessions, four lists were administered at 20 s, 15 s, 11.84 s, and 8.44 s; in the second occasion, eight lists were administered with presentation times of 6.33 s, 4.75 s, 3.56 s, 2.67 s, 2.00 s, 1.50 s, 1.14 s, and 0.84 s. We decided to drop the shortest presentation times from the analysis, because it is unlikely that the method of loci can be applied at very fast presentation rates. (This is an assumption that seems inherent in research using this mnemonic. Studies using the method of loci with college-age adults have used presentation times of 5.00 s and longer; Bellezza & Reddy, 1978; Carlson, Kincaid, Lance & Hodgson, 1976; De Bendi & Cornoldi, 1985, 1988; Kemp & van der Krogt, 1985; Lee & Edwards, 1981; Roediger, 1980; Ross & Lawrence, 1968. At shorter times, it may become difficult to both retrieve the locus and start forming an image.) Therefore, only scores based on the five presentation times of 5.00 s, 3.00 s, and 1.00 s were used for the time-accuracy analysis. Starting with assessment 26 and 27, mean scores for 11.84 s and 8.44 s were used as an approximation for the 10-s score. Likewise, a score for the 5.00-s rate was based on the mean of scores of the 6.33-s and 4.74-s rate and for the 3.00-s rate on the mean of scores for lists presented at 3.56 s and 2.67 s per word.

Results

For each individual, the three parameters of the time-accuracy function for each testing occasion were estimated by fitting Equation 1 to the data, with proportion recalled as the dependent variable and presentation time (in seconds) as the independent variable. The 10 time-accuracy functions for each participant (one for each occasion based on five lists with different presentation times) were fitted simultaneously, using the Statistical Package for the Social Sciences nonlinear regression module. The parameter estimates of these individual time-accuracy curves were then averaged across individuals within each age group to yield average estimates for younger and older adults for each of the occasions. These estimates are depicted in Figure 1. The models fit the data quite well; the average pseudo-\(R^2\) value for the fit of the individual curves was .83 for the young (\(SD = 0.07\)) and .89 for the old (\(SD = 0.05\)).

An analysis of variance (ANOVA) was conducted to determine the effects of age, testing occasion, and the Age \(\times\) Testing Occasion interaction on the parameters. As explained in the introductory section, we were interested in capturing the differences between the effects of instruction versus continued practice on dynamic and asymptotic effects on the time-accuracy function for serial recall. Therefore, two series of ANOVAs were conducted, one on the contrast between the pretest and immediate posttest, and one on the immediate posttest to final test portion of the learning curves.

Effects of Age and Training–Practice on Onset Time

For parameter \(a\), the onset time, neither the main effects nor the interaction effect reached significance (all \(F < 1\), indicating that the effects are very small) in the pretest-to-immediate-posttest contrast. In the analysis of the nine testing occasions between immediate posttest and final test, a main effect was found for testing occasion, \(F(8, 264) = 3.67, MSE = 0.20, p < .001\), but not for age, \(F(1, 33) = 0.58, MSE = 0.59, ns\). As can be seen in Figure 1, the onset parameter tended to decrease over testing occasions. The main effect of testing occasion, however, was qualified by an Age \(\times\) Testing Occasion interaction, \(F(8, 264) = 2.80, MSE = 0.20, p < .01\). (Note that this interaction was a cross-over interaction. Hence, no transformation is necessary to
account for the effects of general slowing in the onset parameter.) Regression analysis shows that the decrease in onset time over testing occasions was entirely due to changes within the older sample. When we regressed the average onset time on testing occasion number within each age group, linear regression did not fit the data of the young group ($R^2 = .00$; regression coefficient $- .00$); for the old group, however, there was a reliable decrease of the onset parameter across testing occasions ($R^2 = .58$; regression coefficient $- .02$). This implies that retrieving the locus and identifying the stimulus took a constant amount of time in younger adults, regardless of the stage in practice. For older adults, these processes speed up with about 20 ms for each additional 1-hr session of practice.

**Effects of Age and Training–Practice on Rate of Approach**

In accordance with the principles outlined in Verhaeghen et al. (1997), analyses on parameter $b$, which is the rate of approach, were conducted on log-transformed scores. After logarithmic transformation, testing for an Age $\times$ Condition interaction becomes a test for deviations from a multiplicative model of aging. That is, we tested whether the young over old ratio of rates remained constant across testing occasions. This model is in accordance with extant models of age-related slowing (e.g., Cerella, 1990), which state that central processing in older adults is slowed by a constant proportion as compared to processing in younger adults. Given our assumption that perceptual factors would impact the onset time parameter and not the rate parameter, and given that no motor response is executed during the encoding stage of this memory task, we assume that peripheral input–output processes play no role in the rate parameter. Hence, this parameter should thus conform to a strictly proportional model.

For the pretest to immediate posttest contrast, only the effect of testing occasion was significant, $F(1, 33) = 6.78, MSE = 18.86, p < .05$. Neither the age main effect, $F(1, 33) < 1, MSE = 13.80$, nor the Age $\times$ Testing Occasion interaction, $F(1, 33) = 1.39, MSE = 18.86, ns$, reached significance. Consequently, one effect of instruction in the method of loci appeared in the form of slowing. This slowing is equivalent across age groups, and younger and older adults do not differ in the rate of approach before and immediately after training.

For the posttest to final test sessions, a reliable main effect was found for age, $F(1, 33) = 12.79, MSE = 3.52, p < .01$. The Age $\times$ Testing Occasion interaction, $F(8, 264) = 4.13, MSE = 1.84, p < .001$, was also reliable, but not the testing-occasion main effect, $F(8, 264) = 1.33, MSE = 1.84, ns$. However, as can be seen in Figure 1, the slowing effect of instruction was not complete in older adults at the first posttest. Rather, older adults continued to slow down in the second posttest session. Therefore, we reanalyzed the data, conducting an ANOVA on the segment of the curve representing the second posttest to the final posttest. In this analysis, reliable effects were found for age, $F(1, 33) = 35.06, MSE = 2.19, p < .001$, and testing occasion, $F(7, 231) = 3.16, MSE = 0.75, p < .01$, but not for the Age $\times$ Testing Occasion interaction, $F(7, 231) = 1.40, MSE = 0.75, ns$. Thus, as slowing down at the first and (for older adults) second posttest, elaboration speed increased again, apparently at the same rate in both age groups. The age difference in the posttest to final test segment was highly reliable, with older participants being much slower to reach asymptote than younger adults.

**Effects of Age and Training–Practice on Asymptotic Level of Performance**

A problem arose with the analysis of parameter $c$. Verhaeghen et al. (1997) suggested to analyze the effects of the asymptotic parameter ($c$) by investigating the effect of $c$ on time demand needed to reach a given level of performance. In other words, not the parameter $c$ itself is being analyzed, but its impact on the time needed to reach a given criterion level of recall. This criterion level necessarily needs to be smaller than the lowest asymptote reached by any participant in any session—otherwise the time needed would be indeterminate for participants with an asymptote lower than the criterion level. As the lowest level was very low indeed (several people had asymptotes lower than .1 at one or more of the early sessions), the Verhaeghen et al. (1997) technique was not applicable to the present data set. Likewise, an alternative technique suggested by Verhaeghen et al. (1998; i.e., analyzing the asymptote after logit transformation) could not be applied because many participants attained perfect asymptotes in the later sessions, therefore logit ($c$) would be indeterminate. Also, no matter how the data are transformed, this ceiling effect in later sessions makes conclusions from any type of ANOVA tentative at best.

Because none of the more sophisticated approaches could be applied, we decided to conduct a standard ANOVA on untransformed $c$ parameters. For the pretest-to-immediate-posttest contrast, a reliable main effect was found for testing occasion, $F(1, 33) = 71.25, MSE = 0.08, p < .001$, and age, $F(1, 33) = 7.06, MSE = 0.06, p < .05$, but not for the Age $\times$ Testing Occasion interaction, $F(1, 33) = 2.16, MSE = 0.08, ns$. This signifies that older adults had lower asymptotes than younger adults and that there was a marked positive effect of training on asymptotic accuracy.

For the posttest-to-final-test portion of the learning curve, only the age main effect was found to be significant, $F(1, 33) = 12.48, MSE = 0.18, p < .001$. Neither the testing occasion, $F(8, 264) < 1, MSE = 0.04, ns$, nor the Age $\times$ Testing Occasion interaction, $F(8, 264) = 1.05, MSE = 0.04, ns$, reached signifi-
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Figure 2. Rate of approach as a function of asymptotic performance and training session for younger and older adults. The two points in the left-hand portion of the graph represent performance in Session 3 (pretest); the arrow indicates the direction of time; successive sessions are connected with lines.

Graphical Analysis

Figures 2 and 3 depict alternative ways of looking at the data concerning some of the parameters. Both of these figures reprise the data contained in Figure 1, but they represent them in different ways, emphasizing different aspects of our data. Figure 2 depicts two phase portraits, one for each age group. A phase portrait is a graph depicting change in a system over time; the system is depicted in an n-dimensional space (called state space) and is defined by n descriptive variables. Here, we show a two-dimensional plot relating the rate of approach parameter to asymptotic performance. As can be seen in the graph, the two phase portraits are remarkably similar. At first, a sizeable increase occurs in the asymptotic parameter because of instruction in the method of loci, while at the same time the rate of approach goes up (meaning that the research participants are getting slower at executing encoding operations). When the peak of slowing and of the rise in asymptotic performance is reached, the curve drops almost vertically, meaning that the asymptote stays constant while the rate of approach goes down. The lines are almost parallel for the two age groups, showing a high qualitative resemblance of the effects of instruction and continued practice. At the same time, the diagram also illustrates two important differences between the age groups, namely, first, that the starting point of the curves (i.e., the point depicting performance at pretest) is different; and second, that older adults need one session more to reach their peak of asymptotic performance. The similarity in shape combined with a different starting point leads to the nonconvergence of age differences in the course of memory training.

Figure 3 depicts the change over testing occasions of the young-old difference in the rate parameter in a Brinley plot. In such a plot (Brinley, 1965), average data of older adults are depicted as a function of average data of young adults. The difference between a traditional Brinley plot and Figure 3 is that Figure 3 contains an ordered sequence of points obtained on the same participants. The curve describing the change over time of the rate parameter seems to curl back onto itself. This suggests that, after the initial shock of applying the new mnemonic, participants return to their initial speed of encoding processes (and thus to the same initial age difference). This in turn suggests that the speed at which encoding processes are executed may well be a given within the cognitive system, that is independent of the algorithm used, at least after a sufficient amount of practice with the algorithm has been provided.

In that sense, the basic speed of processing of the system works as a point attractor (e.g., Kelso, 1995), that is, after destabilization, the system returns to its initial settings, much as a spring that is...
Discussion

In this study, older and younger adults were trained in the method of loci, and they received extensive practice with the method over a period of many months. The results were analyzed at the level of parameters of the time-accuracy function, that is, the function relating proportion of recall to the time each item has been presented.

Our first goal was to assess the effects of training and practice in the method of loci on the parameters of the time-accuracy function. Training in an effective mnemonic, such as the method of loci, entails learning a new algorithm for encoding the to-be-remembered materials. As such, this intervention initially destabilizes the system. This can be seen in the effects of training on the parameters of the function: It slowed the participants down after posttest (viz., the rate parameter is larger after training, and for the older adults, the onset time increases as well), while at the same time asymptotic performance is boosted. After this initial shock, the main effect of continued practice is to speed up processing (viz., the rate of approach goes down, and for the older adults, the onset time decreases), while the asymptotic level of performance remains relatively stable. Thus, two distinct mechanisms seem to be at work in instruction and practice, which have their impact on different aspects of time-related performance. The method of loci provides participants with a framework that allows both for efficient encoding of the individual words and for correct serial order recall. This effectively increases the maximum capacity of the system for serial recall. However, this increase comes at the cost of slowing down the encoding processes, as evidenced by an increased rate of approach. Maybe the reason for this initial slowing is that the assemblage of the components of a newly learned algorithm is typically an effortful process, occurring under deliberate control (Duncan, 1986; Norman & Shallice, 1986). In the method of loci, some compilation of various components is indeed required: retrieving the locus, forming an image of the locus, forming an image of the word, and combining these in an interactive fashion. After initial destabilization, the system speeds up again. Likely candidates for this speed-up include faster execution of the compilation process itself, increased automaticity in the execution of one or more of the components, maybe allowing for parallel processing, or the acquisition of a library of stock images (or of stock solutions for finding an interactive image) that can be applied at particular loci. Note that this double effect of increased asymptotic performance and first elevated and then decreasing rate of approach makes for a deceptively smooth learning curve at the level of mean performance, in that the abrupt change in asymptotic performance is masked by the abrupt task-related slowing that occurs.

An interesting finding is that the onset time increases for older adults (but not for younger adults) immediately after training (i.e., during the first and second posttest) and then decreases quite steadily (at a rate of about 20 ms per session). Estimates of the onset parameter should be interpreted cautiously, however. For instance, we found that in the last few sessions, onset times were effectively lower for older than for younger adults. This might indicate a failure in precision of estimating the parameter, maybe due to the fact that no data points were sampled close to the onset time (minimum presentation time used for estimating the curves was 3 s). Nevertheless, the pattern is compatible with the hypothesis that after instruction in the method of loci participants not only read the word but also retrieved the locus, which they need to generate the mental image. The decrease of the onset time over the course of practice, up to the initial pretest level, suggests that over practice, retrieval of the locus becomes more and more automatic. For young adults, this transition may have occurred during the instruction sessions, which were sufficient to establish the skill at a very high level. The reader should note that the finding that the onset times for young and older adults do not differ at pretest is consistent with all previous time-accuracy research on recall and recognition of words from episodic memory (Verhaeghen, 1999; Verhaeghen et al., 1998). This result suggests that the lexical access process has an identical time course for younger and older adults—a result consistent with lexical access time-course estimates from spread-of-activation studies (for an overview, see Duchek & Balota, 1993) and at least some of the data on reading times (Wingfield & Stine-Morrow, 2000).

Our finding of a dramatic shift from an untrained to a trained state, followed by a gradual relaxation of the system into a more efficient way of executing the algorithm is in accordance with the correlational analysis on the same data set reported in Baltes and Kliegl (1992). This analysis showed that instruction disrupts the rank order of participants, which then stayed quite consistent during continued practice in both age groups. We suspect that the maximum capacity of the system may well be a function of both the learner and the task, therefore the transition from the individual’s preferred strategy at pretest to the imposed strategy at posttest may boost performance of certain individuals more than that of others. This is convergent with some evidence gathered by Verhaeghen and Marcoen (1996). In that study, older adults who at pretest indicated that they linked words in a list using some associative technique had more trouble with applying the method of loci correctly. Likewise, in that study, the ability to recall paired associates, as measured with an independent test at pretest, had a larger effect on posttest than on pretest performance. Thus, the method of loci might be better suited to certain individuals than to others, and this reorders participants. Once the method has been learned, however, practice mostly has the effect of honing the component skills, and there is no reason why this should disturb the rank order of participants.

For the rate-of-approach parameter, significant age differences were found in the practice portion of the learning curve. Consequently, older adults are slower than young adults (at least during the period of extended practice with the mnemonic). This is in accordance with the bulk of the literature on aging and slowing (e.g., Cerella, 1990; Salthouse, 1991, 1996) and with previous time-accuracy research that examined age differences in recall from episodic memory (Kliegl et al., 1998; Verhaeghen et al., 1998). This result points at the existence of a limited-time mechanism (Salthouse, 1996) for encoding of information both when individuals apply their usual encoding strategies and when the method of loci is applied.

There was an age main effect in asymptotic performance, both in the pretest-to-posttest contrast and in the practice portion of the learning curve. Older adults are ultimately less accurate than younger adults. Kliegl et al. (1998) and Verhaeghen et al. (1998)
have previously demonstrated such asymptotic age differences in recall from episodic memory, and the current research extends this finding to recall when both age groups are equated in their use of a highly efficient strategy. Thus, this is strong evidence for the robustness of an asymptotic age difference in recall from episodic memory. This is not an obvious result. It signifies that even when given an unlimited amount of time, and even after months of practice, older adults do not reach the same level of recall as younger adults when applying a mnemonic device that provides an excellent and consistent cueing device at both encoding and retrieval. Stated in Salhouse’s (1996) terms, this implies that a simple limited-time mechanism of slowing is insufficient to explain adult age differences in recall from episodic memory. Of course, in the present experiment no special instructions occurred after the initial instruction sessions. New practice regimes or special coaching directed at increasing asymptotic levels late in the experiment may lead to further shifts of the asymptote.

With regard to the change in age differences over training and practice, no Age \times Testing Occasion interaction was found for either the rate of approach or the asymptote. Thus, within the limits of the statistical power of this analysis, the effects of instruction and practice on these parameters were identical for younger and older adults. The phase portrait depicted in Figure 2 offers a vivid description of this similarity: The change over time of the system described by the rate of approach and the asymptote is remarkably similar in younger and older adults, as illustrated by the parallelism of the traces. This suggests a strong qualitative resemblance in the processes underlying performance changes as a function of instruction and practice in younger and older adults. (But note that older adults reach the peak in the graph only at the second testing occasion, showing that although the system described by the rate and asymptotic parameters is indeed similar in older and younger adults, the older system moves slower through state space.)

There is a third, and quite exciting, illustration of the young–old parallelism. The trace of the rate parameter in Brinley space as depicted in Figure 3 reveals that, at least at the group level, the original age difference acts as an attractor state. In other words, over the course of training and practice, the rate of approach returns to its original setting (and hence to its original age difference), much as a spring returns to its original shape after contraction or expansion. This finding suggests that the speed of elaboration of encoding into episodic memory, after a strategy has become automatic, might well be a constant that is intrinsically stable.

Summarized, it appears that the instruction in the method of loci has its primary effect in a lasting increase of the asymptotic level of recall and in temporary slowing of elaboration processes. In older adults, we observed the additional effect of increasing the minimum time needed for minimal recall. Older adults were found to be slower than younger adults and to have a lower level of asymptotic recall. These differences were largely preserved over training and practice after an initial warming-up period for older adults.

References


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