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Professional Expertise Does Not Eliminate Age Differences in Imagery-Based Memory Performance During Adulthood

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Using a testing-the-limits paradigm, the authors investigated the modulation (attenuation) of negative adult age differences in imagery-based memory performance as a function of professional expertise. Six older graphic designers, 6 normal older adults, 6 younger graphic design students, and 6 normal younger students participated in a 19-session program with a cued-recall variant of the Method of Loci. Older graphic designers attained higher levels of mnemonic performance than normal older adults but were not able to reach younger adults' level of performance; a perfect separation of age groups was achieved. Spatial visualization was a good predictor of mnemonic performance. Results suggest that negative adult age differences in imagery-based memory are attenuated but not eliminated by the advantages associated with criterion-relevant ability (talent) and experience.

The purpose of this study was to examine the effect of imagery-related professional expertise on the magnitude of age differences in memory functioning with the Method of Loci, a mnemonic strategy for the serial encoding and recall of word lists (Bower, 1970; McDaniel & Pressley, 1987; Paivio, 1971). Recent research using a testing-the-limits paradigm (Baltes, 1987; Kliegl & Baltes, 1987) has reported the existence of large and robust age differences favoring the young in recall performance with the Method of Loci during adulthood (Baltes & Kliegl, 1992; Kliegl, Smith, & Baltes, 1989). The present study investigates whether age differences would also be observed in a group of older adults with large amounts of criterion-relevant preexperimental practice and high levels of criterion-relevant ability.

Evidence from different lines of research suggests that visual imagery plays an important role in memory functioning with the Method of Loci. First, it has been shown that the reported use of imagery in cued word recall tasks is positively related to recall level (Janssen, 1976; Richardson, 1985). Second, several studies have reported a positive relation between marker tests of spatial visualization ability and recall performance (Christiansen & Stone, 1968; DiVesta & Sunshine, 1974; Ernest, 1977, 1987; Kliegl, Smith, & Baltes, 1990). Third, memory functioning with the Method of Loci has been linked to the visuospatial subcomponent of working memory. Using a secondary-task paradigm, Baddeley and Lieberman (1980) and Logie (1986) found that a secondary task aimed at disrupting visuospatial processing interfered with the use of the Method of Loci. The authors concluded that spatial or visual components of working memory are critically involved in memory functioning with the Method of Loci. Thus, based on the available evidence, visual imagery seems to be an important, if not critical, component in memory functioning with the Method of Loci.

In our own work, we have trained younger and older adults in the Method of Loci to investigate age-related differences in upper limits of plasticity (developmental reserve capacity) in the domain of memory functioning. Adding to earlier results of age differences in word recall with imagery instructions (Hulicka & Grossman, 1967; Mason & Smith, 1977; for a review, see Bäckman, Mäntylä, & Herlitz, 1990), it was found that the magnitude of age differences favoring the young is increased, rather than reduced, through training (Baltes & Kliegl, 1992; Kliegl et al., 1989, 1990; Rose & Yesavage, 1983; Thompson & Kliegl, 1991). Experiment 2 of Kliegl et al. (1989) may serve as a typical example. In this experiment, younger and older adults participated in a 20-session training program with the Method of Loci. Substantial gains in recall performance as a function of mnemonic training were observed in both age groups. However, younger adults profited significantly more from training than older adults. Compared with pretest performance, age differences at posttest were magnified to such a degree that there was almost no overlap between the two groups. Because of this magnification of age differences, Kliegl et al. (1989) concluded

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that the effects of cognitive aging may be more clearly identifiable at performance conditions near the upper limits of reserve capacity, or cognitive plasticity, than at baseline performance conditions.

In a follow-up study (Baltes & Kliegl, 1992), it was shown that age differences persisted through an additional 18 sessions of training and assessment, thus involving a total of 38 training and assessment sessions. In other words, there was no major change in the magnitude of the age difference between Sessions 21 and 38. In light of the ineffectiveness of extensive training in reducing the magnitude of age differences favoring the young, it was concluded that the observed age differences are not easily explained by assuming an experiential deficit on the part of older adults. Rather, it was suggested that age differences in the use of the Method of Loci are more likely the consequence of an aging-associated loss in neurophysiological efficacy.

In a continuation of this line of research, our study investigates whether the pattern of age-related decline in memory functioning with the Method of Loci also applies to older adults with a high amount of task-relevant preexperimental practice, knowledge, and ability (talent). Combining these factors was assumed to offer a strong test of the possibility that there are exceptions to the robust and sizable age difference favoring the young reported in Baltes and Kliegl (1992) and Kliegl et al. (1989). Given that visual imagery seems to be an important, if not critical, component in memory functioning with the Method of Loci, we searched for a profession that places a high emphasis on the generation of visual images in the context of verbal material. The profession of graphic design seemed to fulfill this criterion. Graphic designers working as freelance artists create posters, art catalogues, advertisements in newspapers and news magazines, as well as other kinds of pictorial representations. They are informed about the intended pictorial representation both verbally and visually. This information is then integrated into the development of the pictorial representation. Frequently, this process requires the creation of pictorial symbols that tie concepts and emotional states to the target product. It appeared plausible to assume that the kind of creative visual imagery that is needed to achieve expert levels of performance in this type of professional activity would also facilitate the use of the Method of Loci.

In principle, a possible superiority of expert graphic designers over "control" individuals may be because of experience, ability, or a combination of both. On the one hand, a superiority of experts over nonexperts may reflect the effects of task-relevant experiences and their coordination into a specific body of factual and procedural knowledge. On the other hand, this superiority may also be a consequence of initial differences in talent or task-relevant abilities. By selecting a group of older professionals with a high level of task-relevant experience or talent, we maximized the chances of qualifying our central hypothesis based on earlier research (Baltes & Kliegl, 1992; Kliegl et al., 1989)—that the age differences in memory functioning with the Method of Loci found so far are, because of their robustness and seeming irreversibility, the result of an aging-associated loss in mental efficacy. It should be noted at the outset that this extreme-group design does not allow for the effective estimation of the relative importance of experience and talent at different ages, a question better addressed by the use of longitudinal research designs or by cross-sectional studies with a more continuous distribution of the age variable (e.g., Salthouse, Babcock, Skovronek, Mitchell, & Palmon, 1990). Rather, the important question was whether a group of older experts with lifelong experience in the production of visual images on the basis of verbal material would be able to reach the level of performance of younger adults with or without similar task-relevant experience. To investigate this question, age and expertise were examined at two levels (i.e., younger adults versus older adults and experts versus normal "control" individuals).

In summary, the goal of this study was to investigate whether a group of older adults with a criterion-related expertise would show no or substantially reduced negative age differences when compared with younger adults. Such a finding would stand in contrast with earlier research, where we have demonstrated a very robust and sizable age difference favoring the young (Baltes & Kliegl, 1992; Kliegl et al., 1989). In addition to memory functioning with the Method of Loci, analyses concerning expertise-related objective tests of spatial visualization and visual creativity were conducted to support the legitimacy of the contrast between experts and controls.

Method

Participants

Six older graphic designers (ages 64–81, $M = 69.9$ years), 6 normal older control adults (ages 64–80, $M = 70.5$ years), 6 younger graphic design students (ages 22–24, $M = 23.0$ years), and 6 normal younger control students (ages 21–24, $M = 22.6$ years) participated in the experiment. There were an equal number of men and women in each of the four groups. Except for 2 older graphic designers and 2 older normal participants with 9 years of schooling, all research participants had completed approximately 13 years of schooling. At the time of testing, all younger participants were undergraduates at Berlin universities. Those not specializing in graphic design were studying at other departments of the Free University of Berlin.

Recruitment process. Older normal adults were recruited by an advertisement in a local newspaper. Graphic design students were recruited by announcements in Berlin art schools. The normal younger participants were recruited by personal contact. With respect to older graphic designers, the recruitment process was more complex. First, the dean of the graphic design department at the Berlin School of Arts (Hochschule der Künste Berlin) was informed of the study and was asked to help in locating older graphic designers. He provided a list of all graphic designers who were members of the Berlin section of the German Graphic Design Association (Bund Deutscher Grafik-Designer eV.) and marked the names of those members who, according to his knowledge, were beyond 65 years of age. On the basis of this information, 18 letters were sent out asking for participation in the study. Four individuals chose to participate in the study as a consequence of this letter. The remaining 14 older graphic designers did not partake in the recruitment process for one of the following reasons: no interest (4 people), too young (2 people), ill health or death (4 people), change of address (i.e., no contact established; 3 people), poor knowledge of German (1 person). The four positive respondents provided the names of other older graphic designers who had not been included in the first round of letters. The first two of these individuals were willing to participate in the study.

To convince older graphic designers to participate, they had to be told about the relevance of visual imagery for this study. For this rea-

son, all research participants were provided with a description of the Method of Loci during the recruitment process. Given that knowledge about the Method of Loci, albeit preliminary, can result in effective use of the method and given that no control for preexperimental practice could be implemented, it was not possible to obtain an unbiased estimate of serial word recall prior to mnemonic (e.g., imagery) instructions in this experiment.

Description of older graphic designers.[1] All 6 older graphic designers were experts in the sense that they had been successful professionals. At the time of testing, 5 designers were still active in their field of specialization. The 1st was the president of the Berlin section of the German Graphic Design Association. At the time of testing, he was one of the leading graphic designers in West Berlin and a member on the board of prestigious juries and committees. Since 1967, he has won 21 prizes for outstanding work in graphic design. In addition, his artwork has been presented in several exhibitions in Germany, Japan, and the United States. The 2nd expert graphic designer was an emeritus faculty member of the graphic design department of the Berlin School of Arts. At the time of testing, this person was 75 years of age and was still giving private drawing lessons. The 3rd individual worked as a cartoonist for numerous European journals and newspapers. Similar to the 1st individual, the 4th expert specialized in posters for art exhibitions. She won prizes for outstanding work, both alone and with her husband, a former president of the Berlin section of the German Graphic Design Association. The 5th individual had had an increasing number of exhibitions in the past 20 years. Starting her career as an ordinary graphic designer, she specialized in patchwork and reached high levels of expertise in this particular technique. The 6th individual specialized in the decoration of shop windows; she also worked as a teacher at a Berlin graphic design school.

Description of younger graphic designers. Of the 6 younger graphic designers, 5 designers were at the end of their 2nd year at the graphic design department of the Berlin School of Arts (Fachbereich Visuelle Kommunikation der Hochschule der Künste Berlin). This school is a highly competitive college. Individuals applying for the graphic design department have to pass oral and written exams, including tests of spatial reasoning, visualization, and creativity, and have to present a folder with their own artwork. The admission rate, varying somewhat from year to year, is about 10% of all applicants. The 6th participant had just completed her degree as a graphic designer at another Berlin graphic design school (Berufsfachschule für Fotografie, Grafik und Mode). In contrast with the university department, her school has a more applied orientation, and the average admission rate is somewhat higher (around 25%).

Apparatus

Apple IIe personal computers were used for stimulus presentation, timing, and response collection. Stimuli were presented in standard 40-column Apple font on a monitor using a green display on a black background.

Materials

The Method of Loci is a memory strategy involving the use of a highly familiar ordered sequence of locations (i.e., a mental map) as a cognitive structure for encoding and retrieving new information (cf. Bower, 1970; Kliegl et al., 1989). To-be-encoded items are successively linked with locations from the mental map through the use of visual imagery. At recall, the ordered locations are mentally revisited, and the visualized items are retrieved and decoded if necessary.

List of Berlin landmarks. All participants received the same set of 20 well-known Berlin landmarks as memory pegs. The sequence of locations was geographically meaningful and corresponded to a fictitious sightseeing tour. A city map and photographs of the landmarks were used in training.

Stimuli. A total of nine different nonoverlapping 20-item noun lists were used. Five lists were administered in Block 1 (Sessions 3–9; see also Table 1). The nouns in these lists had an imagery rating above 6.00 on a 7-point scale according to the norms provided by Baschek, Bredenkamp, Öhrle, and Wippich (1977; cf. Paivio, Yuille, & Madigan, 1968). To avoid effects related to cohort, care was taken that the nouns were neither dated nor modern. The remaining four lists were used in Block 2 (Sessions 10–21).[2]

Procedure

Overview. Participants were scheduled to participate in 21 sessions lasting from 60 to 90 min each. Sessions were administered on different days with a minimum of 1 day between sessions and a maximum generally not exceeding 4 days. Participants were tested individually by Ulman Lindenberger or by a research assistant. For each session, participants received DM 20 (i.e., approximately $12).

Psychometric assessment. Psychometric assessment served three purposes. The first was to test the expectation that graphic designers would perform above the level of normal control adults on measures of criterion-relevant intellectual abilities (visual creativity and spatial visualization), the second was to check whether graphic designers and controls were comparable in general (i.e., not directly expertise related) aspects of intelligence, and the third was to examine whether measures of criterion-relevant intellectual abilities would in fact predict cued serial recall with the Method of Loci.

In the first session, a test of visual creativity, the Parallel Lines subtest of the Torrance Tests of Creative Thinking: Thinking Creatively With Pictures, Form A (Torrance, 1966b), was administered. The second session started with tests from the Hamburg-Wechsler Intelligence Test for Adults in the following order: Forward Digit Span, Backward Digit Span, Vocabulary, and Digit Symbol Substitution (Wechsler, 1964). Thereafter, two tests of spatial visualization, Card Rotation and Surface Development, were given (Ekstrom, French, & Harman, 1976).

Instruction in the Method of Loci (Session 3). At the beginning of Session 3, participants were introduced in detail to the Method of Loci. First, they were told about the historical origins of the method. Then, the functioning of the method was explained to them using concrete examples. The generation of interactive visual images between landmark cues and to-be-learned words was highlighted as the critical feature of the method. Graphic designers were asked to recollect aspects of their work performance that involved different forms of interactive visual imagery, and it was suggested to them that they consider the acquisition of the Method of Loci as a task that is related to their professional expertise. Other participants were asked to think of situations in which they used interactive visual imagery. They were told that they were expected to engage in this kind of activity in the following sessions. Next, all participants were given a form with the 20 Berlin landmarks in experimental sequence and were told about their function in the Method of Loci. A city map of Berlin was provided by the experimenter, and participants were asked to locate the landmarks on the map in correct order.

Assessment of memory skill. At encoding, the landmark and the target item appeared almost simultaneously on the screen with the

[1] Personal information is revealed with the consent of the participants.

[2] Within blocks, data were collapsed across lists. For a more detailed description of the lists as well as a description of additional transfer-of-training assessments, see Lindenberger (1990).

Table 1
Overview of Experiment

Session	Name	Purpose
1–2	Psychometric assessment	Validation of expertise
3–9	Block 1	Method of Loci: Training
10–21	Block 2	Method of Loci: Post-training assessment

landmark preceding the noun by 0.1 s. Interpair intervals (i.e., time intervals with no item presented) were fixed at 0.4 s.

After the last landmark–noun combination of a given trial had been presented, participants initiated the recall phase by pressing the return key. In contrast with most other studies with the Method of Loci, recall was cued by presenting the landmarks in the same serial order as at encoding. It was assumed that graphic designers had large amounts of professional experience in generating visual images on the basis of verbal material but not in retrieving these images without the help of external cues. Therefore, the provision of such cues was expected to maximize the beneficial effects of graphic design expertise on serial word recall with the Method of Loci. Participants verbalized their responses, and the experimenter entered digit codes to each of the to-be-learned items on a numeric keyboard. Null responses ("don't know") were allowed. The response time limit was set at 30 s, and latencies for individual responses were collected.

Within groups, half of the participants received the sequence of Berlin landmarks in reverse order. For the entire duration of the experiment, it was ensured that a given landmark–noun combination was never presented more than once to a participant to avoid repetition effects.

Block 1 (Sessions 3–9): Training. Five different lists of high-imagery nouns were administered in each session, amounting to a total of 35 trials (i.e., administrations of a list). Within sessions, each of the five lists appeared only once. To allow for the examination of training gains, lists were presented with equal presentation times (i.e., 4.5 s per word) in Sessions 3 and 9. During the remaining training sessions, presentation times were increased from self-paced (Sessions 4 and 5) to 7.5 s per word (Sessions 6 and 7) to 4.5 s per word (Session 8). After the recall phase, the tutor commented on the participant's performance and made suggestions for further improvement. For instance, the tutor stressed the importance of creating interactive visual images that combined landmark and noun information and encouraged the participant to concentrate ("zoom in") on those aspects or details of a location that the participant considered to be most imageable.

Block 2 (Sessions 10–21): Posttraining assessment. Four different 20-item noun lists were presented at times of 7.5, 4.5, or 1.5 s per word. Each combination of lists and presentation times was administered four times, resulting in 12 trials per list, or a total of 48 trials. These 48 trials were equally distributed over the 12 sessions. A different trial order was generated for each of the 6 subjects within a group. The following constraints were met in the generation of trial orders: (a) Within sessions, each of the four lists appeared exactly once; (b) within sessions, one of the three presentation times was administered twice and the other two were administered once; and (c) across all sessions, each combination of list and presentation times appeared once in the first, second, third, and fourth measurement occasion within a session.

In summary, nine different 20-item noun lists, five in Sessions 3 to 9 and four in Sessions 10 to 21, were administered after two sessions of psychometric testing. Twenty Berlin locations served as memory loci. Recall was cued by presenting the Berlin locations in the same order as during encoding. A given noun list was not administered more than once within one session. Across all sessions, a given noun did not appear more than once at the same location.

Results

Results are provided in four sections. First, group differences in psychometric tests are reported. Second, data from Block 1 are examined to check whether participants in all groups profited from training and were able to use the mnemonic technique under easy task conditions. Third, posttraining group differences in Block 2 are analyzed to investigate whether old graphic designers were able to reach the performance level of young participants. Finally, group differences in cued serial word recall are examined as a function of psychometric test performance at pretest.

Psychometric Assessment

Table 2 displays means, standard deviations, and the outcome of relevant statistical tests for all psychometric measures broken down by group. Separate 2 × 2 (Age Group × Expertise) analyses of variance (ANOVAs) were computed for each of the measures.

Graphic designers scored significantly higher on the two tests of spatial visualization and the Torrance Visual Creativity test than control participants. With the exception of Card Rotation in young participants, $t(10) = .63$, $p > .1$, the difference between graphic designers and control participants was also significant when tested within age groups (all $ts > 3.59$, all $ps < .01$). No significant effects of expertise were found on the Wechsler tests. The presence of differences between experts and control participants on the criterion-relevant ability markers together with the absence of such differences on other measures of intellectual ability was consistent with our expectations.

In regards to age differences, younger adults had higher scores than older adults in Digit Symbol Substitution, Forward Digit Span, and the two tests of spatial visualization; for Backward Digit Span, the difference was marginally significant. The lack of significant age differences in Vocabulary and the negative age differences in Digit Symbol Substitution are consistent with findings from large-scale normative studies of cognitive aging (cf. Salthouse, 1982). The negative age difference obtained for the Forward Digit Span test is somewhat discrepant with past work as negative age differences are normally more pronounced for Backward than for Forward Digit Span. The absence of significant age differences on the Torrance Visual Creativity test stands in contrast with earlier studies reporting adult age differences in creative performance favoring the young (Alpaugh & Birren, 1977; Ruth & Birren, 1985). One possible explanation for the discrepancy is that Alpaugh and Birren as well as Ruth and Birren used other measures of creative performance. Possibly their measures put a stronger emphasis on the fluency as compared with the flexibility, originality, and elaboration subdimensions of creative performance than the measure used in our study.

Table 2
Means, Standard Deviations, and F Values for Psychometric Tests

	Younger adults				Older adults						
	Normal		Designers		Normal		Designers		*F* values		
Tests	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	Age	Expertise	Age × Expertise
Criterion-relevant tests											
Torrance Visual Creativity	43.7	5.0	55.6	8.2	42.4	4.4	58.3	10.5	0.06	**20.93**	0.45
Surface Development	18.2	4.5	26.7	3.0	3.4	2.1	13.8	6.5	**59.24**	**27.63**	0.22
Card Rotation	64.5	13.6	68.8	9.9	25.2	8.2	50.2	13.4	**38.14**	**9.76**	**4.84**
Wechsler tests											
Digit Symbol Substitution	60.0	3.1	60.6	8.4	47.7	9.4	45.4	6.6	**21.51**	0.08	0.23
Vocabulary	70.3	2.1	67.7	7.0	70.3	8.0	63.3	7.8	0.63	3.13	0.44
Forward Digit Span	7.5	0.8	7.8	1.2	6.3	1.0	6.5	0.8	**9.78**	0.39	0.04
Backward Digit Span	6.2	0.8	6.7	1.4	6.5	0.8	6.3	1.0	3.62	0.58	0.14

Note. In all four groups, $N = 6$; for all F values, dfs = 1, 20. Values significant at the .05 level are boldfaced. Raw scores are reported for all measures except for the Torrance Visual Creativity test. Scores on the latter measure represent the T-transformed (i.e., $M = 50$, $SD = 10$) unweighted composite of the scoring dimensions of fluency, flexibility, originality, and elaboration (cf. Torrance, 1966a, 1966b).

Acquisition of Mnemonic Skill

A 2 × 2 × 2 (Age Group × Expertise × Session) ANOVA with session as a repeated factor was computed to examine whether cued serial word recall increased from Session 3 (first session of Block 1) to Session 9 (last session of Block 1). It was found that participants in all groups improved their performance, $F(1, 20) = 37.14$, $MS_e = 1.03$, $p < .01$. Time did not interact with age group or expertise, indicating that gains in recall performance did not differ across groups, Time × Expertise, $F(1, 20) = 0.16$; Time × Age Group, $F(1, 20) = 1.87$; Time × Expertise × Age Group, $F(1, 20) = 0.12$; all ps > .1.

Performance in Session 5 was used to examine whether participants in all four groups reached high levels of cued serial word recall under easy (i.e., self-paced) encoding conditions, thereby providing evidence that they were able to use the mnemonic strategy in principle. The performance level of younger control participants ($M = 18.6$, $SD = 1.1$), younger graphic designers ($M = 19.7$, $SD = 0.3$), and older graphic designers ($M = 16.4$, $SD = 1.2$) was clearly above the range of performance in cued serial word recall generally found in adults without instruction and training in a memory skill, suggesting that subjects in these groups were using the Method of Loci. The situation is somewhat less clear in the case of the older control participants who recalled on average 9.2 words ($SD = 4.0$) in correct serial position. However, this level of performance is still higher than normally observed in older samples under similar task conditions but without imagery instructions (cf. Kliegl et al., 1989; Treat & Reese, 1976). For instance, Kliegl et al. (1989) found that a comparable sample of older adults recalled about 4 out of 30 words prior to mnemonic instructions under very similar task conditions.

Even if one was to conclude that older control participants did not use the Method of Loci with sufficient facility, this conclusion would not jeopardize the scientific merit of our study. It is still possible to examine the primary goal of this study, namely, whether a criterion-referenced group of older adults (i.e., older graphic designers) approximates the performance level shown by younger adults not selected for criterion-related skills.

Modulation of Age Differences in Recall Performance Through Expertise

We now turn to the crucial question of whether older graphic designers were able to reach the level of recall performance of younger adults. Data from Block 2 were used to address this question. Figure 1 shows the average performance in Block 2 for each of the 24 research participants. Cronbach's alpha for this score, which was based on 48 trials, was .99 in the total sample, .95 in younger control participants, .93 in younger graphic designers, .98 in older control participants, and .87 in older graphic designers.

A 2 × 2 (Age Group × Expertise) ANOVA was computed with average performance in Block 2 as the dependent variable. Younger participants recalled more words in correct serial posi-

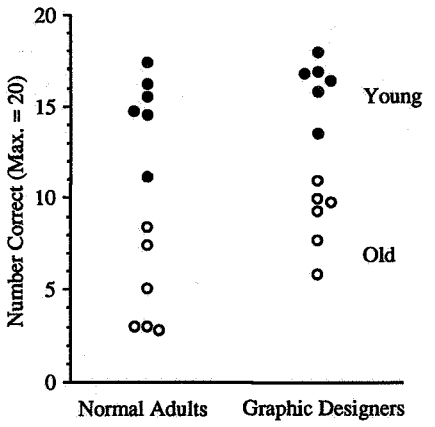

Figure 1. Cued serial word recall in Block 2 (i.e., averaged over Sessions 10–21). (Open dots represent older subjects, and filled dots represent younger subjects.)

tion than older participants, $F(1, 20) = 110.11$, $MS_e = 4.05$, $p < .01$, and graphic designers recalled more words correctly than control subjects, $F(1, 20) = 10.53$, $p < .01$. The interaction was not significant, $F(1, 20) = 2.68$, $p > .1$. In follow-up t tests, it was found that older graphic designers performed above the level of older control participants, $t(10) = 3.19$, $p < .01$, but below the level of younger control participants, $t(10) = -5.19$, $p < .01$. The difference between younger graphic designers and younger control participants was not significant, $t(10) = 1.25$, $p > .1$.

An inspection of the data shown in Figure 1 reveals that none of the older graphic designers were able to reach the level of performance of younger adults. On the basis of chance, this perfect separation is highly unlikely, that is, $p = (1/18!) * (12! * 6!) = 5.39^{-5}$. The highest scoring older graphic designer remembered, on average, 11.08 words in correct serial position, whereas the lowest scoring younger subject remembered 11.25 words. Thus, although older graphic designers performed above the level of the older normal group, none of them were able to reach the level of the younger participants.

Age differences as a function of presentation time. One may wonder whether the superiority of younger participants over older graphic designers and of older graphic designers over older control participants was confined to one or two of the three different presentation times that were used in Block 2. A series of follow-up t tests was computed to examine this issue. The relevant data and analyses are shown in Table 3. The difference between older graphic designers and younger control participants was significant at all three presentation times. Similarly, the difference between older graphic designers and older normal adults was significant with 7.5 s and 4.5 s per word; at 1.5 s per word, the difference was marginally significant. Thus, the results found in the main analysis were not restricted to a particular presentation time.

Given that older and younger subjects differed in Digit Symbol Substitution performance, one may argue that the observed age differences were due to the fact that speeded encoding conditions were used throughout Block 2. In this case, one would expect larger age differences with faster presentation times. However, an inspection of the data shows that age differences were largest with the 4.5-s presentation time (age difference in cued serial word recall was 9.6 words), followed by the 7.5-s presentation time (8.45 words) and the 1.5-s presentation time (7.7 words). The corresponding 2×3 (Age $\times$ Presentation Time) interaction was significant, $F(2, 40) = 6.08$, $MS_e = 0.91$, $p < .01$; quadratic trend, $F(1, 20) = 15.83$, $MS_e = 0.58$, $p < .01$. On the basis of this evidence, it does not seem likely that the observed age differences were an artifact of speeded encoding conditions. This finding is also consistent with earlier research (Kliegl et al., 1989) where, using the same paradigm, age differences favoring the young of similar magnitude continued to exist with slow presentation times (i.e., with 10 s, 15 s, and 20 s per word).

Stability of group differences. A $12 \times 2 \times 2$ (Session $\times$ Age Group $\times$ Expertise) repeated measures ANOVA was computed to check whether the pattern of group differences changed in the course of Block 2. A main effect of session was found, $F(11, 220) = 3.26$, $MS_e = 2.26$, $p < .01$, reflecting a slight decrease in performance from an average of 11.98 words in Sessions 10–12 to an average of 10.78 words in Sessions 19–21; linear trend, $F(1, 20) = 6.99$, $MS_e = 7.12$, $p < .05$. Age group and expertise did not interact with session—overall effect, all three Fs$(11, 220) < 1$; for linear trends, all three Fs$(1, 20) < 1.70$—indicating that the observed pattern of group differences was stable throughout Block 2. Together with the absence of group differences in training gains observed in Block 1, the stability of individual differences within and across groups (indexed by the high internal consistencies reported earlier) as well as the absence of Group $\times$ Session interactions in Block 2 speak against the possibility that additional exposure to the Method of Loci would allow older graphic designers, or older adults in general, to reach the level of cued serial word recall displayed by younger adults.[3]

Correlates of Mnemonic Performance

Criterion-relevant versus Wechsler tests. Table 4 displays the relationship between mnemonic performance (i.e., cued serial recall in Block 2) and four psychometric measures: Spatial visualization (i.e., an unweighted composite of Card Rotation and Surface Development), the Torrance Visual Creativity test, Digit Symbol Substitution, and Forward Digit Span. Spatial visualization was significantly related to mnemonic performance, at both the level of simple correlations and after partialing out one or both design variables. This is consistent with experimental studies (Baddeley & Lieberman, 1980; Logie, 1986) documenting the importance of visuospatial processing in memory functioning with the Method of Loci. The significant first-order correlations between the two Wechsler tests and mnemonic performance were no longer significant after controlling for age group, whereas the reverse was true for the Torrance Visual Creativity test.

Older graphic designers versus older control adults. We expected that the difference in cued serial recall between older graphic designers and older control adults would be explainable in terms of individual differences on the criterion-relevant tests of visual creativity and spatial visualization. To test this prediction, an analysis of covariance was computed with age group as a between-subjects factor and the score on the Torrance Visual Creativity test as a covariate. Again cued serial word recall in Block 2 averaged over presentation times served as the dependent variable. The covariate explained a significant amount of variance, $F(1, 9) = 11.42$, $MS_e = 4.42$, $p < .01$. The remaining difference in cued serial word recall between the two groups was not significant, $F(1, 9) = 1.22$, $p > .1$. The same result was obtained with spatial visualization as a covariate. Given that older graphic designers performed above the level of older con-

[3] Given that the same four lists were used throughout Block 2, one may wonder about the existence of confusion errors and group differences therein (cf. Kliegl & Lindenberger, in press). A $2 \times 2 \times 12$ (Age Group $\times$ Expertise $\times$ Session) ANOVA was computed to examine this issue. Confusion errors were more frequent in older than in younger subjects, $F(1, 20) = 13.69$, $MS_e = 16.63$, $p < .01$; the main effect of expertise, $F(1, 20) = 1.07$, and the Age $\times$ Expertise interaction, $F(1, 20) = 1.98$, were not significant. Confusion errors did not vary significantly as a function of session, $F(11, 220) = 1.80$, $MS_e = 1.06$, $p > .05$, and session did not interact with expertise or age group (Fs < 1.40, ps $> .20$).

Table 3
Means, Standard Deviations, and Post hoc t Tests for Cued Serial Recall of 20-Item Noun Lists During the Test Phase

	Younger adults				Older adults				*t* values	
	Normal		Designers		Normal		Designers			
Rate	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	Older designers vs. younger normal	Older designers vs. older normal
7.5 s/word	17.3	1.8	18.6	1.1	6.6	3.0	12.4	2.3	−4.13***	3.73***
4.5 s/word	16.9	2.5	18.3	1.0	5.7	3.0	10.3	2.2	−4.86***	3.14**
1.5 s/word	10.7	2.4	12.0	2.5	2.9	1.4	4.4	1.3	−5.71***	1.88*

* $p < .10$. ** $p < .05$. *** $p < .01$.

trols on both the dependent variable and the covariates, these results are not surprising. Nevertheless, the complete elimination of group differences in cued serial recall between the two groups after statistically controlling for differences in visual creativity or spatial visualization gives further support to the hypothesis that the recall advantage of older graphic designers over older normal adults was due to the visual image generation component of the Method of Loci.

Discussion

The major aim of this study was to explore whether a select group of older individuals would be able to reach the performance level of younger adults after being exposed to a memory training program that has been found to produce a close-to-perfect separation of adult age distributions (Baltes & Kliegl, 1992; Kliegl et al., 1989; Thompson & Kliegl, 1991). Our results seem to allow for a clear answer to this question. Although older graphic designers recalled more words in correct serial position than older control participants, none of them were able to reach the level of performance displayed by younger control participants.

In our view, this result lends further support to the robustness and generality of age differences favoring the young reported in earlier studies involving the application of a testing-the-limits paradigm in the study of plasticity (developmental reserve capacity) associated with the Method of Loci (Baltes & Kliegl, 1992; Kliegl et al., 1989, 1990). It is also consistent with the finding reported by Salthouse and his colleagues (Salthouse et al., 1990) that professional expertise in architecture does not eliminate negative age trends in measures of spatial visualization. In our study, the older graphic designers represent a group that presumably combines two factors of advantage: criterion-related experience and preexperimental task-relevant abilities, or talent. Their excellence in such abilities was demonstrated by their clear superiority over older control participants in the Torrance Visual Creativity test and in the two tests of spatial visualization. Therefore, we submit that our results are not easily accountable in terms of experience-based practice deficits associated with old age. Rather, we conclude that it is more likely that neurophysiological losses associated with aging are involved.

Table 4
Correlations Between Cued Serial Word Recall in Block 2 and Psychometric Measures

		Partialing out		
Tests	First order	Age group	Expertise	Both
Criterion-relevant tests				
Torrance Visual Creativity	.25	**.58**	.08	.31
Spatial visualization composite	**.87**	**.66**	**.88**	**.44**
Wechsler tests				
Digit Symbol Substitution	**.69**	.19	**.73**	.27
Forward Digit Span	**.53**	.08	**.52**	.00

Note. Boldfaced coefficients are significant at the .05 level. The spatial visualization composite represents the unweighted mean of Card Rotation and Surface Development.

There are, however, at least two limitations in this study that challenge a neurophysiology-based interpretation of the negative age differences obtained. First, there is the possibility that another group of older experts from a different field of specialization would reach higher levels of mnemonic skill and would perhaps outperform a group of comparable younger individuals. For example, selecting an older group of professional mnemonists using the Method of Loci or related mnemonic techniques may represent a stricter evaluation of the cumulative role of expertise-related experiential benefit. The decision to choose graphic designers as the expert group in our study was guided by the assumption that interactive visual imagery is an important factor in memory functioning with the Method of Loci (Baddeley & Lieberman, 1980; DiVesta & Sunshine, 1974; Logie, 1986; Richardson, 1985). The performance profile of graphic designers observed in our study supported this view. Nevertheless, other choices could be made with equal plausibility, and it remains an empirical question whether other professions would be more effective in reducing the age difference.

The second limitation is related to the brevity of the kind of training used in this study. Although the lack of power because of small sample size does not allow strong claims on this issue, the absence of age differences in recall gains during the training phase and the stability of group differences during the test phase suggests that subjects in all groups profited about equally from mnemonic training. Nevertheless, it is true that a relatively short training phase (7 sessions) was followed by an extensive test phase (12 sessions). One does not know whether older graphic designers might be able to overcome the age difference if provided with a more extensive training program. Given the

high degree of stability in age differences over a period of 38 sessions reported by Baltes and Kliegl (1992), this possibility does not appear to be a likely one. Similarly, one does not know whether a different type of training program, such as a longer exposure to self-paced encoding conditions or individually adjusted presentation times, would have resulted in a significant reduction of age differences. It should be noted, however, that recent studies using such procedures also reported very large age differences favoring the young (Kliegl et al., 1989; Thompson & Kliegl, 1991).

Given that the age differences reflect an aging-related loss in the mechanics of memory, one may wonder about the precise nature of this loss. In our study, no attempt was made to identify subcomponents of serial word recall with the Method of Loci (cf. Lea, 1975). Therefore, we can only offer correlational evidence regarding this issue. It appears that age differences with the Method of Loci are due to both imagery-specific (i.e., spatial visualization) and more general factors (i.e., Digit Symbol Substitution, Forward Digit Span). One possibility would be that spatial visualization ability determines the probability of creating a visual image and that mental speed determines the rate with which this visual image is being elaborated, rehearsed, and connected with other factors involved in the processing ensemble associated with the Method of Loci. Clearly, more process-oriented age-comparative work with the Method of Loci is needed to examine this hypothesis (cf. Kliegl & Lindenberger, in press; Thompson & Kliegl, 1991). Recent research on cue utilization with mnemonic devices (Battig & Bellezza, 1979; Bellezza, 1987; Bjork, 1978; Bower, 1970; Lea, 1975; Roediger, 1980), on the role of visual imagery in the Method of Loci (Baddeley & Lieberman, 1980; Cornoldi, Calore, & Pra Baldi, 1979; DeBeni & Cornoldi, 1988; Logie, 1986), and on subsystems of working memory (Baddeley, 1986) may prove to be relevant in this regard (for a discussion of these issues, see Lindenberger, 1990).

It needs to be emphasized that cross-sectional studies, such as this one, offer only preliminary evidence on the issue of age-related changes in the relative importance of ability and experience as determinants of individual differences in performance. In the long run, longitudinal studies are necessary to disentangle critical factors such as talent, experience, and aging. Such a longitudinal approach would also permit the examination of the nature of experience and its possible interaction with increasing age-related limitations of the mechanics of the mind (Baltes, Dittmann-Kohli, & Dixon, 1984). For example, the modulation of age differences in limits of cognitive functioning through professional expertise may follow different paths. Specialized professional knowledge and the provision of continuous practice may prevent age-related decrements in cognitive functioning that would occur under normal circumstances. In addition, aging experts may develop specific types of professional knowledge as a compensatory reaction to decrements in expertise-related cognitive operations. Some of these compensatory reactions may depend on the expert's prior awareness of the impending aging loss, whereas others may take the form of adaptive regulations without awareness (cf. Bäckman & Dixon, 1992; Baltes & Baltes, 1990; Charness, 1989; Salthouse, 1984; Uttal & Perlmutter, 1989).

In conclusion, our study, with its focus on the search for limits of plasticity (Baltes, 1987; Kliegl & Baltes, 1987), has shown that a group of older persons selected for criterion-relevant advantageous factors (professional experience with imagery, criterion-relevant talent or abilities) was not able to reach the level of memory skill displayed by younger adults without such positive selection characteristics. This finding gives further substance to the hypothesis of a robust negative age difference in some basic components of the mind associated with the mechanics of memory. Further research is needed to better understand the nature of these components and their relationship to other cognitive processes undergoing negative age changes during adulthood. Our results suggest that the use of visual imagination in the production of memory traces is among the critical components involved.

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