Aging and Longitudinal Change in Perceptual-Motor Skill Acquisition in Healthy Adults

Karen M. Rodrigue, Kristen M. Kennedy, and Naftali Raz

Knowledge about aging of perceptual-motor skills is based almost exclusively on cross-sectional studies. We examined age-related changes in the retention of mirror-tracing skills in healthy adults who practiced for 3 separate days at baseline and retrained 5 years later at follow-up. Overall, the speed and accuracy of an acquired skill were partially retained after a 5-year interim, although the same asymptote was reached. Analyses with individual learning curves indicated that the effects of age on mirror-tracing speed were greater at longitudinal follow-up than at baseline, with older adults requiring more training to reach asymptote. Thus, although the long-term retention of acquired skills declines with age, older adults still retain the ability to learn the skill. Moreover, those who maintained a processing speed comparable with that of the younger participants evidenced no age-related performance decrements on the mirror-drawing task.

The ability to perform purposeful movements efficiently and precisely is an essential part of successful functioning in everyday activities. Advanced age, however, is associated with decrements in speed and accuracy of motor control (Spirduso & MacRae, 1990). The execution and planning of movement is affected by multiple factors, which may modify the acquisition, performance, and retention of novel perceptual-motor skills in older adults (Walker, Philbin, & Fisk, 1997). Previous research across a variety of perceptual-motor tasks reveals that the performance of older adults is slower and generally less accurate than that of their younger counterparts (Durkin, Prescott, Furchtgott, Cantor, & Powell 1995; Gutman, 1965; Kennedy & Raz, 2005; Raz, Williamson, Gunning-Dixon, Head, & Acker 2000; Ruch, 1934; Snoddy, 1926; Swanson & Lee, 1992; Thumin, 1962; Wishart & Lee, 1997; Wright & Payne, 1985). Although younger adults tend to perform better than their older peers on many perceptual-motor tasks, the effects of aging on the rate of skill acquisition remain unclear.

Age-related discrepancies in the shapes of acquisition curves vary across studies. In many samples, increasing divergence with practice is evident, and older adults do not improve across trials as much as their younger counterparts do (Gutman, 1965; Raz et al., 2000; Swanson & Lee, 1992; Thumin, 1962; Wishart & Lee, 1997; Wright & Payne, 1985). However, closing of the age gap after practice has been reported as well (Durkin et al., 1995; Kennedy & Raz, 2005). Although the differences across studies may be explained in part by variations in research design (e.g., failure to include multiple blocks of trials across sessions or days), there is some indication that the findings may be task specific. For example, in essentially the same sample, we found an age-diverging pattern on the pursuit rotor task (Raz et al.) and an age-converging one on mirror tracing (Kennedy & Raz). Thus, either the early or late learning stage (Karni & Bertini, 1997) may be affected by aging, depending on the task demands.

Although all tasks under consideration fall under the rubric of perceptual-motor or procedural skills, the variability among them is significant. Some tasks (e.g., the pursuit rotor) require repeated execution of a smooth and continuous motor response, whereas others (e.g., mirror tracing) may call for more complex cognitive involvement (inhibition of a prepotent visual-motor response and mental manipulation of the mirror image of the target stimulus). Previous research has illustrated the effects of task difficulty on slowing of reaction times (Fozard, Vercruysen, Reynolds, Hancock, & Quilter, 1994), and recent findings suggest that the differential effect of age on perceptual-motor skill performance is mediated by working memory (Kennedy, Partridge, & Raz, 2004). Therefore, task-specific differences in strategy and planning demands point to a possible role of cognitive resources in various phases of skill acquisition (Anderson, 1983). Reliance on these higher level processes may be essential in maintaining accurate and efficient performance in adults of all ages (Ackerman, 1986; Rogers, Fisk, & Hertzog, 1994).

Thus far, the research on the cognitive underpinnings of age-related differences in procedural skills focused on cognitive slowing, a continuous lifelong process affecting multiple functional domains (Birren, 1974; Fozard et al., 1994). Processing speed often explains a significant amount of age-related variance across a variety of cognitive domains (Salthouse, 1996), although a single-mechanism model is unlikely to fully account for age effects in skill retention (e.g., Fisk, Cooper, Hertzog, & Anderson-Garlach, 1995). Constraints imposed by age-related slowing on cognitive performance become increasingly evident with greater task difficulty (Liao, Jagacinski, & Greenberg, 1997; Walker et al., 1997). Therefore, reduced processing speed may explain some of the observed age-related differences in performance. Moreover, its contribution may be especially strong during the largely executive, early stages of skill acquisition (Anderson, 1983).

Given that healthy older adults can successfully acquire new skills (age differences notwithstanding) and improve their performance through practice on a variety of perceptual-motor tasks, a key question is whether older adults can retain newly acquired perceptual-motor skills, despite the known deleterious effects of aging on structural and functional brain integrity (Cabeza, 2001; Grady, 2000; Raz et al., 2004) and cognitive performance (Verhaeghen & Salthouse, 1997). Previous longitudinal studies of retention of skilled search have illustrated that
both younger and older adults can retain task-specific skilled memory search (Fisk et al., 1995), although older adults may retain less of the skill than do younger adults (Fisk, Hertzog, Lee, Rogers, & Anderson-Garlach, 1994). One study (Cooke, Durso, Schvaneveldt, 1994) reported retention of skilled search over 9 years in 3 participants of various ages. It remains unclear, however, whether the age-related differences in longitudinal change documented in specific skills such as visual memory search generalize to other procedural domains of learning.

To date, knowledge about aging and perceptual-motor skills in particular has been based exclusively on cross-sectional differences, and longitudinal cognitive aging studies have focused primarily on the declarative memory system, with few studies on procedural learning. Consequently, the effect of age-related change on perceptual-motor skill retention is unknown. Thus, our primary objective in the present study was to examine the effects of age on longitudinal retention of a previously learned perceptual motor skill, mirror tracing, in a sample of healthy adults covering a wide age range. We also sought to determine if aging has differential effects on changes in speed and accuracy of performance. Lastly, we inquired whether differences in perceptual processing speed predict perceptual-motor skill performance at follow-up.

**METHODS**

**Participants**

We collected the data for this study in a 5-year longitudinal investigation of age-related changes in brain and cognition conducted in a major metropolitan area in the United States. For the 5-year longitudinal follow-up, we arranged for participants from a previous cross-sectional study of procedural skills conducted in our laboratory (Kennedy & Raz, 2005; Raz et al., 2000) to be contacted by mail and telephone. Among the previous participants, 77 had complete cognitive and MRI data and were eligible for follow-up testing. Of the 57 (74%) who responded to our invitation, 32 (56% of the respondents or 42% of the total eligible pool) participated in the longitudinal study. All participants signed a consent form approved by the University Committee for Protection of Human Subjects in Research and were screened by means of a mail-in health questionnaire, supplemented by telephone and personal interviews.

We applied the same screening criteria used to determine eligibility for the original cross-sectional study to the follow-up sample. We excluded persons who reported history of cardiovascular, neurological, or psychiatric conditions, head trauma with loss of consciousness for more than 5 min, thyroid problems, diabetes, treatment for drug and alcohol problems, or a habit of taking three or more alcoholic drinks per day from the study. None of the participants used antiseizure medication, anxiolytics, or antidepressants and did not report arthritis. We screened all participants for dementia and depression by using the Blessed Information-Memory-Concentration Test (BIMC; Blessed, Tomlinson, & Roth, 1968) with a cutoff of 85% correct, the Mini-Mental Status Examination (MMSE; Folstein, Folstein, & McHugh, 1975) with a cutoff of 26 (87% correct), and the Geriatric Depression Questionnaire from the Center for Epidemiologic Studies–Depression scale (CES-D; Radloff, 1977), with a cutoff of 16. We administered the BIMC and CES-D on both testing occasions, whereas we gave the MMSE only at follow-up.

Of the 32 participants who completed the follow-up, we excluded 10 from data analyses because they failed to meet the health-screening criteria at follow-up. The excluded participants ranged in age from 50 to 74 years ($M = 61.8$), and the reasons for exclusion were angioplasty (1), cardiac surgery (1), stroke (2), diabetes mellitus (1), cancer (1), poor visual acuity (2), retinal damage (1), and loss of consciousness greater than 5 min (1). Thus, we analyzed complete cognitive data from 22 participants (13 women and 9 men).

The age of the participants at baseline ranged between 23 and 77 years ($M = 49.50 \pm 13.70$ years, 49.89 for men and 49.23 for women; $t = -.10, ns$). The average education was 15.55 ± 1.87 years, and no sex differences were observed (16.11 years for men vs. 15.15 years for women, $t = -1.27, ns$). Although we used an MMSE score of 26 as a cutoff to exclude participants with dementia, most MMSE scores at the time of second testing were higher than the cutoff (28.06 ± 1.41) and were unrelated to age ($t = -.04, ns$) or sex ($t = -.45, ns$). Participants returned for follow-up testing an average of 5.25 years ± 4.0 months after baseline testing.

The participants who returned for follow-up did not differ from the nonreturning cross-sectional participants in age (49.5 vs. 43.7 years, $t = -1.36$), education (15.55 vs. 16.02 years, $t < 1$), fluid IQ (Cattell Culture Fair Test, 101 vs. 104, $t < 1$), working memory, or perseveration (all $p > .10$). Returners and nonreturners marginally differed on a baseline measure of vocabulary word knowledge, with returnees = 26.84, nonreturnees = 23.34, $t(33) = -2.06, p = .05$. There was an equal number of men and women among the returnees (59% women and 41% men) and nonreturnees (53% women and 47% men), with $\chi^2 = .32, p = .85$.

We included 4 participants (three women) with medically controlled hypertension in the longitudinal sample (2 diagnosed at baseline and 2 more diagnosed by the time of follow-up). The hypertensive participants did not differ significantly in age from the remainder of the sample (mean age at baseline 46.25 ± 4.5 years, $t = .95, ns$), and they had the same number of years of education ($t = 1.45, ns$) as well as equivalent MMSE scores ($t = -.75, ns$).

**Mirror-Tracing Task**

The participants were seated in a quiet room in front of the Automatic Mirror Tracer (Model 58024, Lafayette Instruments Co., Lafayette, IN). They were instructed to trace a flat six-pointed star with a pencil-like metallic stylus, while only a mirror-inverted image of the star was visible. Participants were instructed to keep their eyes on the mirror at all times and to make as few errors as possible. We defined an error as an instance in which the stylus moved outside the pattern boundary, and the apparatus emitted a clicking sound every time an error was made. Number of errors (crossing target boundary) and total time spent inside the target area (to the nearest .01 s) were automatically recorded. Participants were instructed to start at the red dot (located at the top right corner of the star) and trace clockwise in the direction of the arrow. We tested all participants individually on three consecutive days, and they performed five blocks of five trials each, with a 10-s intertrial interval. Participants completed Block 1 on
Day 1, Blocks 2 and 3 on Day 2 with an approximately 45-min break between blocks, and Blocks 4 and 5 on Day 3 with an approximately 30-min break between blocks. At 5-year follow-up, we used the same apparatus and testing location, and participants followed identical instructions and procedures.

Perceptual Processing Speed

We administered the Digit Symbol Substitution subscale of the Wechsler Adult Intelligence Scale–Revised (WAIS-R; Wechsler, 1981) at follow-up to serve as a measure of perceptual processing speed. Throughout the duration of the test (90 s), we showed participants a template with nine digit-symbol pairings. Participants were then given a series of digits and were asked to pair each digit with its correct symbol according to the template, as quickly as possible.

RESULTS

We examined the longitudinal effects of age and sex on mirror-tracing performance in a mixed general linear model. In the model, the wave of measurement (baseline vs. follow-up) and day (25 trials nested within five blocks across 3 days) were within-subject factors; sex was a categorical independent predictor; and age at baseline (centered at its sample mean) was a continuous predictor variable. We analyzed the two indices of performance, error rate (errors in tracing) and speed (time to complete trial), separately. We dropped all nonsignificant interactions from the final models, and we adjusted the probabilities for interactions with the repeated measure factors by the Huynh–Feldt epsilon coefficient to correct for violation of sphericity assumption. We applied a natural logarithmic transformation [\( \text{error}_{\log} = \log(\text{error} + 1) \)] to alleviate skew in the distribution of errors.

Speed of Performance

The analysis revealed a significant main effect of age, \( F(1, 19) = 15.76, p < .001, \eta^2 = .29 \), with older participants showing longer completion times than younger adults. A trend for a sex effect on speed of performance (with women performing somewhat faster than men) was evident: \( F(1, 19) = 3.69, p < .07 \). We dropped a nonsignificant Age \( \times \) Sex interaction (\( F < 1 \)) from the model.

Error Rate

We observed a significant within-subject effect of wave of measurement (baseline vs follow-up), \( F(1, 19) = 9.18, p < .006, \eta^2 = .28 \), and a significant Wave \( \times \) Day interaction, \( F(2, 38) = 7.64, p < .01, \eta^2 = .27 \). Regardless of age or sex, participants performed significantly faster overall at the 5-year follow-up on Day 1, \( t(21) = 3.31, p < .003, \) and Day 2, \( t(21) = 2.13, p < .05 \), than at baseline on the same blocks, whereas no significant increases in speed were apparent in the later trials of Day 3 at Follow-up (\( t = 1, ns \)). Unadjusted means for speed at baseline and 5-year follow-up are displayed in Table 1.

Results also revealed a main effect of day of testing, \( F(4, 76) = 60.38, p < .001, \eta^2 = .79 \), indicating practice-related gains. A significant Age \( \times \) Day interaction, \( F(4, 76) = 9.71, p < .002, \eta^2 = .11 \), indicated that the slope of the regression of speed on age varied across days. A comparison of regression parameters across the 3 days of training indicated a stronger relationship between speed of tracing and age during the earlier stages of skill acquisition at both baseline and follow-up. At baseline, the regression of tracing time on age was significantly steeper on Day 1 (\( b = 1.65 \) s/year) than on Day 2 (\( b = .74 \) s/year) or Day 3 (\( b = .50 \) s/year), \( p < .05 \). At follow-up the pattern was repeated, with Day 1 slope (\( b = 1.78 \) s/year) being significantly steeper than those of Day 2 (\( b = .91 \)) or Day 3 (\( b = .63 \) s/year).

The observed age-related change in mirror-tracing speed, trial by trial, is illustrated in Figure 1, where for illustrative purposes we categorize age (a continuous factor) into young (follow-up age 28–36 years; \( n = 4 \)), middle-aged (45–56 years; \( n = 11 \)), and older adults (62–82 years; \( n = 7 \)). A comparison of the learning curves illustrates that younger and middle-aged participants reached asymptotic levels by the end of Day 2, whereas older adults did not reach asymptote until Day 3. On average, tracing speed on Day 1 at follow-up was 21% faster than that at the initial day of the baseline measurement. However, we noted a substantial variability in savings, with some participants starting reacquisition at more than 50% faster, whereas others showed tracing times that were slower by more than 70%. The variability in savings of tracing speed gains was not explained by age (Spearman \( r = .31, p > .15 \)). To explore the individual variability in retention and skill acquisition and to examine change in different components of learning and retention on an individual level, we fit each participant’s data at

---

Table 1. Descriptive Statistics for Speed and Error Rate in Mirror Tracing at Baseline (Time 1) and Follow Up (Time 2)

<table>
<thead>
<tr>
<th></th>
<th>Women</th>
<th>Men</th>
<th></th>
<th>Women</th>
<th>Men</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>M</td>
<td>SD</td>
<td>CV</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Day 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wave 1</td>
<td>70.79</td>
<td>35.12</td>
<td>.496</td>
<td>93.11</td>
<td>45.25</td>
</tr>
<tr>
<td>Wave 2</td>
<td>53.45</td>
<td>30.72</td>
<td>.575</td>
<td>68.98</td>
<td>43.32</td>
</tr>
<tr>
<td>Day 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wave 1</td>
<td>38.37</td>
<td>16.01</td>
<td>.417</td>
<td>52.57</td>
<td>22.06</td>
</tr>
<tr>
<td>Wave 2</td>
<td>32.10</td>
<td>15.51</td>
<td>.483</td>
<td>48.11</td>
<td>30.02</td>
</tr>
<tr>
<td>Day 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wave 1</td>
<td>29.23</td>
<td>14.46</td>
<td>.495</td>
<td>37.87</td>
<td>12.65</td>
</tr>
<tr>
<td>Wave 2</td>
<td>26.53</td>
<td>11.65</td>
<td>.439</td>
<td>35.34</td>
<td>20.18</td>
</tr>
</tbody>
</table>

Error Rate

<table>
<thead>
<tr>
<th></th>
<th>Women</th>
<th>Men</th>
<th></th>
<th>Women</th>
<th>Men</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>CV</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Day 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wave 1</td>
<td>1.74</td>
<td>1.02</td>
<td>0.587</td>
<td>1.75</td>
<td>1.20</td>
</tr>
<tr>
<td>Wave 2</td>
<td>1.01</td>
<td>0.754</td>
<td>0.700</td>
<td>1.13</td>
<td>0.862</td>
</tr>
<tr>
<td>Day 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wave 1</td>
<td>0.558</td>
<td>0.661</td>
<td>1.18</td>
<td>0.573</td>
<td>0.517</td>
</tr>
<tr>
<td>Wave 2</td>
<td>0.348</td>
<td>0.384</td>
<td>1.10</td>
<td>0.337</td>
<td>0.253</td>
</tr>
<tr>
<td>Day 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wave 1</td>
<td>0.245</td>
<td>0.266</td>
<td>1.09</td>
<td>0.299</td>
<td>0.306</td>
</tr>
<tr>
<td>Wave 2</td>
<td>0.236</td>
<td>0.269</td>
<td>1.14</td>
<td>0.230</td>
<td>0.195</td>
</tr>
</tbody>
</table>

Notes: CV is the coefficient of variation; CV = SD/M. Speed is expressed in seconds.
each wave of testing to an exponential learning curve. The model fitted to each participant’s data was as follows:

\[ T = T_0 + a \exp(-bt), \]  

(1)

where \( T \) is the tracing speed, \( T_0 \) is the asymptote (tracing speed at the trial number approaching infinity), \( a + T_0 \) is the intercept (tracing speed at trial number 0), and \( b \) is the time constant of the exponential decay of tracing speed from the intercept to the asymptote.

For most of the participants, the exponential model fit reasonably well to the trial-by-trial data: the median \( R^2 = .88 \) at baseline, and median \( R^2 = .73 \) at follow-up. The data for only 1 participant at baseline and 2 at follow-up failed to reach goodness of fit \( R^2 > .50 \). There was, however, a substantial variability in goodness of fit with the \( R^2 \) coefficient of variation (CV) = .25 at baseline and CV = .35 at follow-up. At neither occasion was the goodness of fit related to age (\( r = .06 \) at baseline, \( ns; r = .28 \) at follow-up, \( ns \)).

We conducted a repeated measures linear model analysis of the individual learning curve parameters, which were log-transformed to avoid the undue influence of outliers in a small sample. In that analysis, parameter type (intercept, asymptote, or time constant) and wave of measurement (baseline vs. follow-up) were repeated measure factors and age was a continuous predictor. The analysis revealed a significant Age \( \times \) Parameter type \( \times \) Wave interaction: \( F(2, 40) = 6.55, p < .007 \). In addition, a Wave \( \times \) Age interaction was significant, \( F(1, 20) = 4.51, p < .05 \), and the Wave \( \times \) Parameter type interaction was significant as well, \( F(2, 40) = 34.37, p < .001 \). Decomposition of the triple interaction revealed that, at baseline, only the intercept was associated with age, Spearman \( \rho = .54, p < .05, ns \), whereas the asymptote and the time constant showed no significant relation to age, \( \rho = .12 \) and \( \rho = .06, ns \). At follow-up, the associations with age strengthened, reaching \( \rho = .80, p < .001 \) for the intercept, \( \rho = .69, p < .01 \) for the asymptote, and \( \rho = .62, p < .01 \) for the time constant. We repeated the analysis after removing 3 participants for whom the exponential model did not fit the data well. This analysis showed an essentially unaltered pattern of results, although we observed some reduction in significance.

To investigate the role of processing speed in mirror-tracing performance, we used a mixed general linear model framework...
with Day 1 to 3 tracing times at follow-up as the dependent variable and age and WAIS-R digit symbol (DS, a speed of processing measure) at follow-up as continuous predictors. We recentered the DS scores and age at their sample means. In that model, as in the analyses already reported, we observed a significant main effect of age, $F(1, 18) = 20.12, p = .001, \eta^2 = .53$, and day, $F(1, 18) = 17.53, p < .001, \eta^2 = .33$, as well as Day $\times$ Age interaction, $F(2, 36) = 6.61, p < .001, \eta^2 = .27$. However, there was also a main effect of speed of processing, $F(1, 18) = 7.96, p = .01, \eta^2 = .31$, and an Age $\times$ DS interaction, $F(1, 18) = 15.43, p = .001, \eta^2 = .46$. There were no significant within-subject interactions with DS.

Decomposition of the Age $\times$ DS interaction revealed that DS predicted speed of mirror tracing only in older participants. When we split the age range at the median value of 55 years, the younger half of the sample evidenced no significant association between tracing time and number of DS items completed: unstandardized regression coefficient $b = -.16 (\pm .62)$ items/s and correlation of $r = -.09$, both $ns$. In contrast, among the older participants (aged 55 and older), the time of tracing was significantly related to DS score: $b = -2.34 (\pm .56)$ and $r = -.81, p < .01$. Furthermore, in comparison with their younger “fast-DS” counterparts, the older participants who did well on the DS task (above $Mdn = 55.54$) did not show any slowing in tracing across days at follow-up: time, $M = 34.90$ s versus $M = 35.45$ s. Notably, younger participants with slower DS performance showed no particular slowing on the mirror-tracing task (time of tracing, $M = 33.18$ s).

**Error Rates**

Repeated measures analyses of wave, day, age, and sex differences in error rates of mirror-tracing performance revealed a main effect for age, $F(1, 19) = 9.70, p < .005, \eta^2 = .34$. Older adults performed less accurately than younger adults across both waves of measurement, days of testing, and both sexes. We dropped a nonsignificant Age $\times$ Sex interaction from the model ($F < 1$), and no sex differences in error rate were apparent ($F < 1$). The participants, regardless of age, became

---

**Figure 2.** The learning curves for mirror-tracing errors across 25 trials at baseline and 5-year follow-up. Data are displayed by age category and illustrate retention of the skill during the early phases of learning. Regardless of age, all participants return after 5 years to perform more accurately than at the naïve baseline level.
more accurate across days, as indicated by a significant effect of day, $F(1, 19) = 54.72, p < .001, \eta^2 = .75$, and a nonsignificant Day \times Age interaction, $F(2, 38) = 2.84, p < .07$.

A significant effect of the wave of testing (baseline vs. follow-up) was apparent, $F(1, 19) = 10.78, p < .004, \eta^2 = .35$, but we found no reliable Wave \times Age interaction ($F < 1$). However, we did observe a significant Wave \times Day interaction, $F(2, 38) = 10.48, p < .001, \eta^2 = .32$. When we examined simple effects associated with that interaction, we found it apparent that participants performed more accurately on Day 1, $t(21) = 3.8, p < .001$, and Day 2, $t(21) = 2.59, p < .02$, but not on Day 3 ($t < 1$), of testing at 5-year follow-up than they did at baseline. Error rates by trial are illustrated in Figure 2. As with tracing speed, we observed substantial individual differences in retention of accuracy. Some participants started retraining at follow-up with 100% lower error rates, whereas others displayed about an 80% drop in accuracy. Notably, the accuracy savings on the first day only weakly depended on age ($\text{Spearman } \rho = -.36, p < .10$).

To test for measurement dependency between speed and error rate, we examined correlations among outcome variables (i.e., whether inferior accuracy was linked to slower speed). Across the blocks, speed and errors exhibited only sporadic positive correlations ($r = .01$–.41 at baseline and $r = .02$–.40 at follow-up), and regressions of speed on errors indicated that speed of mirror tracing did not significantly predict errors at baseline ($t = 1.58$) or at follow-up ($t = 1.41, \text{ns}$).

To investigate the possible role of processing speed in mirror-tracing error rates, we analyzed the same model for the mirror-tracing error scores as a dependent variable, with age, DS, and their interaction terms as independent predictors. Results again revealed main effects of age and day, but no effect of DS, nor any significant interactions with this variable (all $Fs < 1$). Because there was an insufficient variability in error rates at the later stages of learning, we checked if DS predicted error rates during the earlier phases of training and failed to find a reliable effect for Day 1 or Day 2 of practice ($Fs < 1$).

**Discussion**

To the best of our knowledge, this is the first longitudinal study of long-term retention of a novel perceptual-motor skill in healthy adults. The results indicated that an acquired perceptual-motor skill can be retained, to some degree, after a 5-year hiatus by healthy adults covering a wide age range. This finding is in accord with previous observations concerning other, non-perceptual-motor skills (e.g., Fisk et al., 1994; Gilbert, Rogers, & Samuelson, 2004). However, none of the participants retained their asymptotic level of performance achieved by the end of baseline training. Although most participants began follow-up practice at better-than-novice levels, the advantage of previous training was apparent only during the initial stage of retraining. By the end of retraining, the same asymptotes in both speed and accuracy of performance were reached as the ones that were established at the end of baseline training.

Within each measurement occasion, the participants across the age span improved their speed and accuracy of performance with practice, in accord with previous cross-sectional literature on a variety of tasks, such as rotor pursuit (Durkin et al., 1995; Raz et al., 2000; Wright & Payne, 1985), the Tower of Hanoi (Head, Raz, Gunning-Dixon, Williamson, & Acker, 2002), mirror reading (Durkin et al.), and mirror tracing (Gabrieli, Corkin, Mickel, & Growdon, 1993; Kennedy & Raz, 2005; Snoddy, 1926). However, we did observe differential effects of aging on speed and accuracy of performance. Whereas participants’ tracing speed across days of training was selectively dependent on age, we found no effect of age on change in error rates across practice within sessions.

Despite more favorable starting levels at follow-up, participants failed to exceed their previous levels of performance, confirming that the skill reached asymptotic levels during baseline training. An analysis of individual learning curves indicated that, for novices evaluated at baseline, the age-related differences were apparent only in the starting level of performance, with younger participants starting at faster levels than their older peers. In contrast, at follow-up, we observed age effects not only in initial starting level but also in the rate of learning and asymptotic level of performance as well. Thus, in this sample, the effects of aging were revealed and magnified by additional training. The pronounced age effects on asymptote and slope at follow-up compared with baseline may suggest age differences in the less automatized aspects of the mirror-drawing task specifically. If, indeed, the automatized component of the skill is unaffected by aging, then perhaps this age deficiency reflects older adults’ difficulty in the processing of more effortful components of the mirror-drawing task, such as inhibiting the prepotent response of the motor sequence to the visually reversed stimulus. Those functions rely on the age-sensitive brain regions (e.g., the prefrontal cortex and adjacent white matter); in fact, in the larger cross-sectional study, we found that older adults who had smaller prefrontal cortex volumes performed this task more poorly at later stages of learning (Kennedy & Raz, 2005).

It is unclear what accounts for age differences in the parameters of skill acquisition. We found that the speed of processing (as measured by the DS test) predicted the speed of mirror-tracing performance at follow-up, and this effect on performance depended on age. Specifically, whereas successful skill acquisition in young adults was independent of processing speed, older adults’ acquisition curves were constrained by their abilities: older participants who demonstrated efficient DS processing demonstrated superior mirror-tracing performance. In light of frequently reported age-related declines in speed of performance, it is important to emphasize that a small group of older participants with intact perceptual-motor abilities demonstrated performance that was on par with younger adults. Thus, even within a selected group of healthy older adults, there was a substantial variability in performance, with some older participants performing remarkably well. On the basis of the available data, we can say little about the sources of such preservation, and future studies are needed to identify potential predictors of preserved perceptual-motor speed.

In contrast to tracing speed, DS performance did not explain the accuracy with which the skill was executed. The lack of effect of perceptual speed on error rates may be the product of decreased variability, as all participants reached an asymptote of virtually no errors before training ended. Nonetheless, analyses confined to the early, more executive stage of skill acquisition, during which the error rate was not negligible, also failed to illustrate a role of perceptual speed in skill accuracy. Thus, it is possible that perceptual speed may play a specific role in
performance rather than exert a general effect on age-related differences in the retention of a perceptual-motor skill. Such lack of generalization reinforces the notion of importance of specific factors in cognitive aging and casts doubt on the applicability of the concept of generalized slowing to procedural learning.

We did not observe sex differences in mirror-tracing speed or accuracy. Although there was a trend for women to complete the task faster than men (see Table 1), it did not reach significance in this sample. Such sex differences were robust in the larger, cross-sectional sample tested at baseline (Kennedy & Raz, 2005). The trend for age-related slowing was especially evident among men, and it did not seem to reflect a speed–accuracy trade-off as they were not less accurate than women. Future longitudinal studies with larger samples should examine the possibility of sex effects in perceptual-motor skill performance.

This study has several limitations. First, it focuses on a specific skill and it is unclear how the observed pattern of results would generalize to other perceptual-motor skills. Another constraint on generalizability is our focus on healthy aging. The reported findings come from a highly selected, nonrepresentative sample of participants who were well-educated, highly motivated healthy volunteers who passed a stringent screening process. To avoid confounding the effects of aging with the effects of disease, we did not include individuals with common age-related illnesses in the analyses. Therefore, the observed effects of aging on skill retention likely reflect a best-case scenario of successful aging rather than a typical course of change. The findings reported here are additionally constrained by a small sample size, particularly in the life-span context.

In sum, the present study provides the first longitudinal evidence that healthy adults can retain a nontrivial portion of an acquired novel perceptual-motor skill, without additional practice over a long-term period. However, losses in both speed and accuracy occurred during that period and additional training was necessary for all participants, regardless of age, to reach their previous asymptotic levels of performance. Notably, greater amounts of practice resulted in a magnification of age effects in the rate of learning and the overall level of performance. Nevertheless, the results of this study indicate that older adults can successfully acquire new skills and improve their performance with practice. Further, they are able to retain a portion of their gains in accuracy, and to a lesser extent their gains in speed, over a period of 5 years; failure to do so may reflect age-related changes expressed in cognitive slowing. Moreover, some of the older adults who are characterized by lack of cognitive slowing are able to perform on par with their younger counterparts.

ACKNOWLEDGMENTS

This study was funded by the National Institute of Health under Grant AG11230. A portion of this paper was presented at the Cognitive Aging Conference in Atlanta, GA on April 2, 2004.

We thank Adrienne Williamson for management of the longitudinal data collection. We also thank the three anonymous reviewers for their helpful comments and suggestions.

Address correspondence to Naftali Raz, Institute of Gerontology, 226 Knapp Building, 87 E. Ferry St., Detroit MI 48202. E-mail: nraz@wayne.edu

REFERENCES


Received June 16, 2004
Accepted January 20, 2005
Decision Editor: Thomas M. Hess, PhD

Careers in Aging Resources

2 updated resources available from the Association for Gerontology in Higher Education which may answer many questions about careers in the field of aging and educational programs available to prepare for those careers:

Careers in Aging: Consider the Possibilities
A 16-page booklet primarily for high school and college students designed as an introduction to the field. Single copies, free; multiple copies, $0.20 each (members), $0.50 each (non-members).

Careers in Aging: Opportunities and Options
A 28-page booklet designed for upper-division undergraduates, graduate students, and adults considering a career change. Single copies, free; multiple copies, $1 each (members), $2 each (non-members).

Also available:

Careers in Aging: Old Friends, New Faces
A 10-minute videotape for those considering a career in aging, focusing on the personal rewards of aging-related careers and the great variety of employment opportunities. Purchase price, $10 (members), $15 (non-members).

Contact the AGHE office for the cost of postage and handling for multiple copies of the booklets, as well as for information about other AGHE publications, conferences, institutional memberships, subscriptions.

Association for Gerontology in Higher Education
1030 15th Street, NW, Suite 240, Washington, DC 20005-1503
Voice: 202-289-9806 Fax 202-289-9824