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Age Deficits in Learning Sequences of Spoken Words

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Previous research has demonstrated age-related deficits in implicit learning of visual sequences characterized by subtle predictive relationships among the sequence elements. This study investigates whether this reflects modality-specific, or more general, sequence learning deficits by using an auditory sequence-learning task. Young and old adults responded with a key press to each of a series of unrelated spoken words. Unknown to the participants, every other word was presented in a fixed, repeating order with alternate words chosen at random. Both groups responded more quickly and accurately to the predictable than to unpredictable words, revealing sequence learning. However, elderly participants showed less learning than young participants on several measures. This suggests that age-related deficits in implicit sequence learning reflect a general impairment in learning subtle environmental covariations rather than a modality-specific visual impairment.

IMPLICIT learning involves acquiring information about a complex stimulus environment without awareness of either what was learned or that learning occurred (Seger, 1994). Because implicit learning is thought to be more basic than conscious, explicit learning, some have argued that it should be more resistant to the neurophysiological insults of aging (Reber, 1993). This possibility has been investigated using the serial reaction time (SRT) task in which people respond to each of a repeating series of stimuli by pressing a corresponding key (Nissen & Bullemer, 1987). Learning is demonstrated by slower response time (RT) when the repeating sequence is replaced by random trials. Learning is thought to be implicit since people are often unable to describe the sequence despite showing evidence for learning.

Age constancy has been observed for simple repeating sequences (Howard & Howard, 1989), but age deficits occur for higher-order sequences in which predictive relationships occur among nonadjacent items (Curran, 1997; Howard & Howard, 1997). For example, previous research showed age deficits when a four-element repeating sequence occurred on every other trial with alternate items chosen at random (Feeney, Howard, & Howard, 2002; Howard & Howard, 2001; Howard & Howard, 1997). In this alternating SRT task people must learn relationships that span at least two elements.

The finding of age-related deficits in higher-order sequence learning is important since many everyday tasks such as language processing and complex skill learning involve such complex relationships (Conway & Christiansen, 2001). Practically speaking, then, the age-related deficits in sequence learning may make it difficult for older people to acquire new skills or to adjust to subtle changes in their environment even after extended exposure. However, it remains unclear whether the implicit sequence learning deficits obtained are general or modality-specific since all previous aging studies have used visual stimuli. The present study addresses this issue by investigating sequence learning in the auditory modality.

There is reason to believe that modality may be important in sequence learning. For example, Goschke, Friederici, Kotz, and van Kampen (2001) reported a dissociation between phoneme and visual sequence learning in aphasics. Because elderly people show more pronounced deficits in spatial than verbal working memory (Myerson, Hale, Rhee, & Jenkins, 1999), and because brain areas implicated in visuospatial sequence learning (e.g., prefrontal cortex; Robertson, Tormos, Maeda, & Pascual-Leone, 2001) show atrophy with age (Raz, 2000), age deficits in sequence learning may also be modality specific. A recent study obtained age deficits with nonspatial visual letter sequences, demonstrating that age deficits occur with nonspatial stimuli (Negash, Howard, Japikse, & Howard, in press), but this does not rule out a potential modality-specific visual impairment. The present study examines this possibility.

Methods

Participants

We paid 12 young (M age = 19.8 years, SD = 1.6) and 12 elderly (M age = 73.6 years, SD = 4.4) experimentally naive volunteers to participate. Both groups were highly educated (young: M = 13.7 years of schooling, SD = 1.6; old: M = 17.9 years, SD = 2.5), and had similar Wechsler Adult Intelligence Scale–Revised (Weschler, 1981) vocabulary scores (young: M = 37.7, SD = 8.9; old: M = 37.2, SD = 6.7).

Stimuli and Apparatus

Stimuli were four spoken words, *romantic* (1), *chronological* (2), *popularity* (3), and *operation* (4), from the TIMIT digital corpus (Garofalo et al., 1993) played over headphones through the analog output of an iMac computer. Each was spoken by a different female voice at a comfortable listening level determined separately for each participant prior to testing. Although we did not measure presentation level, the stimuli were more intense for the old than the young people. The words averaged approximately 725 ms in duration and differed in their initial phoneme. Participants in the study performed the experimental task with a high level of overall accuracy (0.95 and 0.92, for elderly and young participants, respectively), indicating that both age groups were able to perceive the stimuli.

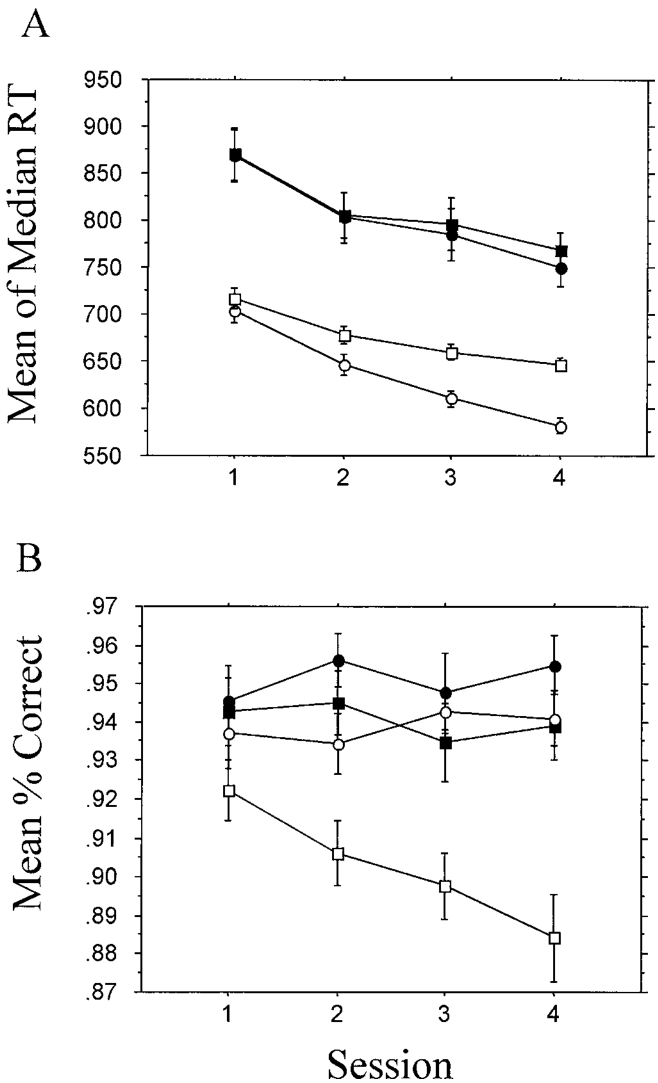

Figure 1. **A**, mean of median response time (RT) as a function of session and trial type for both the young and elderly groups and **B**, mean percentage correct as a function of session and trial type for both the young and elderly groups. ● = elderly, pattern; ■ = elderly, random; ○ = young, pattern; □ = young, random.

Procedure

The procedure followed our previous visual studies. Participants positioned the middle and index fingers of each hand on four response keys, corresponding to different words. Their task was to identify the single word occurring on each trial by pressing the appropriate key as quickly as possible while keeping errors to a minimum. Unbeknownst to the participants, word presentation order followed a continuously repeating eight-element sequence in which fixed (pattern trials) and randomly chosen (random trials) words alternated. For counterbalancing, we assigned two participants in each group to each of the six sequences that produced a unique repeating order (1r2r3r4r, 1r3r4r2r, 1r3r2r4r, 1r2r4r3r, 1r4r2r3r, and 1r4r3r2r, where 1 to 4 indicates a specific word and 'r' a randomly chosen one of the four words).

After 16 random practice trials, participants completed four, 70-min sessions. Each consisted of 21 90-trial blocks (10 random trials followed by 10 repetitions of the eight-element sequence). Trials began with word presentation and ended with a correct response, truncating the word if necessary. The next trial began after 120 ms. The computer measured RT from word onset to the correct response.

At the end of each block, the computer displayed the mean RT and accuracy for the previous two blocks and prompted participants to maintain an accuracy of about 92% to achieve comparable group error rates. After the fourth session, people completed four, 80-trial blocks of free generation, in which they were asked to "create a sequence like the one you heard." Each key press caused the corresponding word to be presented. After this, participants were asked a series of increasingly specific questions to probe their declarative knowledge.

Results and Discussion

Do the Postexperimental Interviews Reveal Evidence of Declarative Knowledge?

No one identified the alternating structure or length of the sequence. Most individuals expressed a feeling that some regularity was present, but they were unable to articulate it. Only one elderly and one young person described a sequence having more than chance overlap with what they heard (see Howard & Howard, 1997). Because an analysis excluding their data did not change the trend or significance of the results, we conclude that, as in the visual studies, learning was implicit.

Are There Age Differences in Learning Auditory Sequences?

We computed a median RT for correct trials separately for pattern and random trials across the repeating 80-trial sequence within each block, and took means across blocks within each session. Figure 1 shows the resulting RT (**A**) and accuracy (**B**) data. Increasingly faster and/or more accurate responding on pattern compared to random trials (referred to as the *trial-type effect*) reveals sequence learning. Previous work with visual stimuli demonstrated age deficits in the acquired sensitivity to sequence structure as revealed by significant trial type by age and trial type by session by age interactions (Howard & Howard, 1997).

We obtained an identical result here. Three-way repeated measures analyses of variance (ANOVAs; age group as between- and session and trial type as within-subject variables) revealed significant two- (Trial Type × Age) and three-way interactions for RT, $F(1,22) = 12.64$, $MSE = 958.503$ and $F(3,66) = 2.84$, $MSE = 213.517$, respectively, and accuracy, $F(1,22) = 26.32$, $MSE = 2.9\text{E-}4$ and $F(3,66) = 5.68$, $MSE = 9.1\text{E-}5$, respectively (we used a statistical criterion of .05 in these and all subsequent tests). Although the finding that random trials become less accurate with practice seems paradoxical, previous results have shown that with probabilistic sequences, people make more "anticipation-errors" as they learn (Schvaneveldt & Gomez, 1998). These reflect expectancies based on increasing knowledge of the sequence structure. Hence, as they learn more about the sequence, people make more errors on the unpredictable random trials.

In addition, we conducted individual Session × Trial Type ANOVAs separately for both age groups. Results indicate a significant interaction for RT, $F(1,3) = 14.29$, $MSE = 208.71$ for the young group, but not for the elderly group,$F(1,33) = 2.04$, $MSE = 218.32$, whereas accuracy revealed a significant interaction for both groups, $F(1,33) = 14.90$, $MSE = 1.38E\text{-}4$ (young) and $F(1,33) = 4.714$, $MSE = 4.37E\text{-}5$ (elderly). However, the effect was substantially larger for the young adults. These results indicate that both age groups demonstrate significant learning on at least one performance measure.

To summarize, both speed and accuracy reveal an age deficit in auditory sequence learning, consistent with previous results with visual stimuli. This points toward a general age-related se quence learning deficit rather than a modality-specific one.

What Do People Learn?

The previous visual study (Howard & Howard, 1997) has provided evidence that, without being aware of doing so, people learn the relative frequencies of three consecutive events or triplets. However, some triplets such as repetitions (e.g., 111 or 333) and trills (e.g., 121 or 434) only occur on random trials in the alternating task. Hence, they may contribute to the overall learning deficit reported earlier in this section.

A reanalysis of the data excluding repetitions and trills revealed a significant Trial Type $\times$ Age interaction for both speed and accuracy and a significant Trial Type $\times$ Session $\times$ Age interaction for accuracy. The three-way interaction did not reach significance for speed despite a clear trend toward an age deficit, likely reflecting the reduced statistical power caused by eliminating approximately 25% of the original data. However, because three of the four critical tests reveal a significant age-deficit, we conclude that the age deficit in sequence learning shown above cannot be explained by the influence of trills and repetitions alone. This is consistent with earlier work (Howard & Howard, 1997) and indicates that people in both age groups learn more subtle statistical properties of the sequence, and that there are age deficits in doing so.

Are There Age Differences in Expectancy-Based "Anticipation" Errors?

Previous studies (Howard & Howard, 1997) have shown that when people do make errors on random trials, the errors of young participants are more likely to be structure consistent than those of elderly participants. We define consistency in terms of the triplet structure of the sequence (see Howard & Howard, 1997). Hence, for the sequence 1r4r3r2r…, if the events 123 occur on successive trials and people respond incorrectly to the "3," then an incorrect response of "4" would be structure consistent, but an incorrect response of "2" would not.

Error consistency analysis in the present study revealed that the proportion of structure-consistent errors was higher for the young group, $M = .34$, $SE = .08$, than for the old group, $M = .28$, $SE = .07$, $F(1,22) = 8.36$, $MSE = .010$, consistent with the earlier visual findings (Howard & Howard, 1997). This provides additional support for an age deficit in auditory sequence learning.

Do the Free Generation Data Reveal Evidence of Learning?

Although in free generation people are encouraged to use their declarative knowledge, such responding is not "process pure," but rather reflects some combination of explicit and implicit (e.g., fluency) processes (Destrebecqz & Cleeremans, 2001).

We parsed the sequences people produced into structure-consistent and determined structure-inconsistent triplets and a mean generation rate for each triplet type (excluding repetitions and trills and normalized by the number of possible triplets of each type). An earlier visual study (Howard & Howard, 1997) revealed that younger people generated significantly more structure-consistent than structure-inconsistent triplets, but elderly people did not. A similar pattern occurred in the present study. Although an overall Consistency $\times$ Age Group ANOVA revealed only a significant main effect of Consistency, $F(1,22) = 6.69$, $MSE = .483$, the difference between generation rates for structure consistent and inconsistent triplets was substantially larger for the young group (6.12 vs. 5.18), $t(11) = 2.24$, $p < .05$, than for the elderly group (5.86 vs. 5.32), $t(11) = 1.39$, $p > .19$. This result is also consistent with a modality-independent age deficit.

Summary and Conclusions

The present findings support the view that age deficits in higher-order sequence learning reflect a modality-independent processing deficit in learning subtle environmental covariation. This is supported by the identical pattern of findings between the present auditory and previous visual studies. For both modalities, the young group shows greater learning than the old group as revealed by larger trial-type effects in speed and accuracy as well as in a greater proportion of expectancy-based or anticipation errors. Furthermore, as had been the case with the visual sequences, the postexperimental interview revealed that, despite demonstrating sequence learning in the auditory task, people were unable to describe the sequence structure they had learned.

Although it is clear that age deficits occur, the underlying mechanisms responsible for them are not. Two modality-independent possibilities include decreased overall working memory capacity or generic context processing deficits. According to the capacity view, because of cognitive slowing, elderly people have less information available simultaneously for processing than do young people (Salthouse, 1996). Thus, they have more difficulty in learning sequences based on statistical relationships among nonadjacent events (Curran, 1997; Howard & Howard, 1997). Our findings are consistent with this and suggest further that the deficit is not tied to a modality-specific working memory component.

Our results are also consistent with the context deficit theory that argues for an age-related impairment in the ability to encode and process contextual information (Braver et al., 2001). Because the alternating regularity requires learning the temporal context provided by the previous two items, the contextual deficit theory predicts the age deficit we observe. This is also consistent with recent evidence supporting an age-related associative deficit in recall and recognition tasks (Kahana, Howard, Zaromb, & Wingfield, 2002; Naveh-Benjamin, 2000). Furthermore, the context deficit theory relates age impairments to specific age-related neurobiological changes (Braver & Barch, 2002; Li & Sikstrom, 2002), increasing the likelihood that future work will be able to tie behavioral changes to their underlying biological mechanisms.

Finally, it is important to note that, despite the observed age-related implicit-learning deficits, both age groups were able to learn the higher-order vocal sequences. Thus, sensitivity to subtle sequential regularities, albeit impaired, does occur even in advanced old age.

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