

Aging and Implicit Learning of an Invariant Association

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We investigated whether there is an age-related decline in implicit learning of an invariant association. Participants memorized letter strings in which a given letter always occurred in the second position (see Frick & Lee, 1995). Experiments 1 and 2 showed that young and older adults learned this regularity implicitly, with no significant age differences, even when a perceptual feature of the stimuli changed between encoding and test. Experiment 3 confirmed that learning had occurred during encoding, in that learning increased with the number of encoding presentations. We conclude that implicit learning of this invariant association is largely preserved in healthy aging, revealing another avenue by which older people continue to adapt efficiently to environmental regularities.

Key Words: Implicit learning—Invariant association—Nondeclarative learning.

WE OFTEN learn about environmental structure without awareness or intent, by means of implicit or nondeclarative learning (Forkstam & Petersson, 2005; Reber, 1993; Squire, 2004). For example, we learn the location of light switches and steps in a new home by navigating through it, and we become sensitive to how people are likely to react by interacting with them. Even though implicit learning is essential for adapting to environmental change throughout life, the effect of aging on implicit learning has been studied relatively little. There are many forms of implicit learning. These forms differ in their cognitive demands, in their underlying brain systems (Squire), and in the extent to which they reveal age-related differences (for reviews see Forkstam & Petersson; Prull, Gabrieli, & Bunge, 2000). For example, the same older people who are impaired at implicit learning of complex event sequences are as good as college students at implicit learning of spatial contexts (Howard, Howard, Dennis, Yankovich, & Vaidya, 2004).

In the present study we focus on a form of implicit learning not previously studied in aging. We adopted one of a class of “invariant feature” tasks introduced by Burton and colleagues (Bright & Burton, 1994; Kelly & Wilkin, 2006; McGeorge & Burton, 1990). The version used here was developed by Frick and Lee (1995); they gave college students a test of immediate memory in which the participants saw, and then attempted to report, 24 letter strings, each of which contained 6 or 7 consonants. Every string had a “critical” letter (e.g., “H”) in the second position. Surprisingly, most people did not become aware of this regularity and yet, on a subsequent test, they reliably discriminated new letter strings conforming to the rule from those that did not.

Unlike most invariant feature tasks in which the relative frequency of individual items could be learned (i.e., that the

numeral 3 occurs frequently), the Frick and Lee task requires learning an association (i.e., that a certain letter always occurs in a given position). The associative nature of this task makes it particularly useful for the study of aging, because studies of implicit associative learning have yielded mixed results.

Some previous research suggests that implicit learning of associations is intact in older people. For example, age constancy has been reported for learning repeated supraspan sequences in a verbal version of Hebb’s task (Turcotte, Gagnon, & Poirier, 2005, Experiment 1), for artificial grammar learning (McGeorge, Crawford, & Kelly, 1997), and for the perceptual-motor learning of deterministic first-order event sequences, in which some pairs of items occur more frequently than others (Curran, 1997; Howard & Howard, 1992). However, this evidence does not isolate implicit learning, because awareness cannot be ruled out.

In contrast, other research has reported persistent age-related deficits in implicit learning when awareness is avoided by presenting complex second-order probabilistic sequences in which the lowest level of regularity to be learned spans three events (Bennett, Howard, & Howard, 2007; Curran, 1997; Howard & Howard, 1992; Howard et al., 2004; Howard & Howard, 1997). These age differences could be due to an age-related deficit in learning associations, but they could also be due, all or in part, to capacity deficits. For events to be associated by means of implicit learning, they must be activated simultaneously, so that their co-occurrence can be detected. When age-related decreases occur in the speed of processing, older people are able to keep fewer items activated in memory simultaneously (Salthouse, 1996).

Frick and Lee’s invariant feature task used here offers a means of assessing the learning of an invariant association while avoiding awareness. Experiment 1 aims to replicate Frick and

Table 1. Participant Characteristics: Means With Standard Deviations in Parentheses

Characteristic	Experiment 1		Experiment 2	
	Young	Old	Young	Old
Age	20.92 (1.68)	73.25 (4.43)***	19.87 (1.62)	71.50 (5.27)***
Education years	14.67 (1.56)	17.83 (2.62)**	13.08 (1.88)	15.75 (2.18)**
Health	4.50 (0.52)	4.25 (0.62)	4.58 (0.52)	4.33 (0.78)
Test score				
MMSE	29.33 (0.99)	28.50 (2.32)	29.67 (.65)	29.08 (1.73)
WAIS Vocabulary	34.17 (8.50)	37.17 (6.12)	29.42 (7.48)	39.83 (11.61)*
WAIS Digit Span	21.58 (3.94)	20.00 (4.07)	19.83 (3.54)	18.42 (3.00)
Computation Span	27.30 (27.76)	19.50 (33.71)	49.58 (50.36)	10.83 (15.14)*

Notes: For health, 1 = poor to 5 = excellent; MMSE = Mini-Mental Status Exam; WAIS = Wechsler Adult Intelligence Scale, third edition.

* $p < .05$; ** $p < .01$; *** $p < .001$.

Lee's findings in young people and to compare them with older adults. If, as we hypothesize, the ability to form this invariant association implicitly does not decline with healthy aging, then the groups will show equivalent discrimination between category exemplars and nonexemplars, even though the older people will recall less during the immediate memory phase.

EXPERIMENT 1

METHODS

Participants

We tested 12 young and 12 older adults. The young adults were Catholic University of America students, and the older adults were community-dwelling residents. The older group was more educated than the young, but they did not differ in self-rated health or on the neuropsychological measures shown in Table 1.

Stimuli

For the encoding phase, we created 24 consonant strings. Each contained 7 different consonants, with the second "critical" letter always the same. Following Frick and Lee (1995), we used six critical letters (D, F, H, K, M, W), each assigned to two people in each age group. We randomly selected the remaining letters in each string from the 20 consonants.

For the discrimination phase, we created 20 pairs of seven-item strings, none presented during encoding. Within a pair, both parts contained the same letters, but in a different random order, and in one of the strings, the critical letter occurred in the second position. A sample pair for the critical letter H was as follows:

QHBVCNX CNQVXHB

On half of the discrimination trials, the correct string was on the left. Strings were presented on a computer in an uppercase Times Roman font, 88 point during encoding and 48 point during discrimination.

Procedure

After informed consent was completed, the encoding phase followed. Each of 24 trials contained a fixation cross, followed by the letter string for 3.6 seconds. After each string, participants were to "recall the letters in the exact order they

were presented" by saying them aloud. No mention was made of the regularity. The discrimination phase followed immediately. On each of 20 trials, the two letter strings were shown side by side. Participants chose the letter string "which looks more familiar." No feedback on correctness was given.

Following the discrimination phase, participants were asked two questions. The first was this: "Can you describe any particular reason for choosing one of the letter strings over the other? If so, please explain that reason. Even if you are unsure, please make a guess." The second was as follows: "You may have noticed that there was a pattern among all of the string sets that you were asked to recall. Do you have any idea what that pattern was? Even if you are unsure, please make a guess." Finally, participants completed health and biographical questionnaires and the tests shown in Table 1.

RESULTS AND DISCUSSION

Verbal Reports

No participants mentioned a regularity involving the second letter position or their critical letter, even though we did elicit some response to the questions from 23 of 24 participants. In response to Question 1, 50% of the participants referred to choosing the most familiar string. Five people reported that the regularity was that no vowels had appeared: as a result of this apparent lack of awareness, we included all 24 participants in the following analyses.

Immediate String Recall During Encoding

As the left panel of Figure 1 suggests, the age groups did not differ in the mean number of the 24 strings they repeated back perfectly during encoding, $t(22) = 0.68$, $p = .51$. This lack of an age deficit, though unexpected, is consistent with the fact that the age groups did not differ on the WAIS Digit Span Test (where WAIS stands for the Wechsler Adult Intelligence Scale, third edition; see Wechsler, 1997), which is a measure of short-term memory capacity (Table 1).

Sensitivity to the Regularity During Discrimination

The left panel of Figure 2 shows the mean percentage correct discrimination. Both age groups discriminated significantly above chance (50%), young $t(11) = 4.29$, $p < .01$, and older $t(11) = 4.73$, $p < .01$, and the groups did not differ significantly, $t(22) = 0.34$, $p = .73$. The percentage correct discrimination

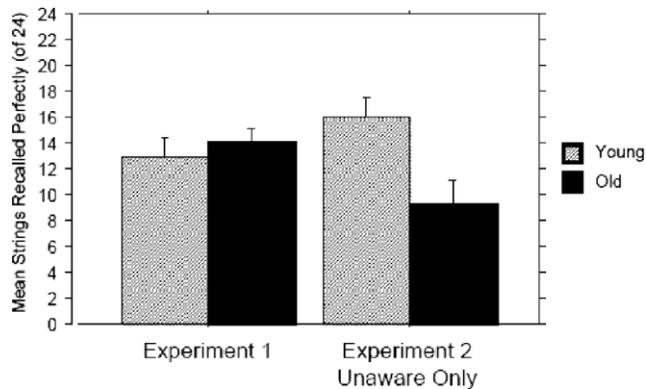


Figure 1. Mean number of strings (of 24) repeated back perfectly in immediate serial recall by young and older adults during the encoding phase in Experiments 1 and 2, with standard error bars. For Experiment 2, data are reported only for participants who were unaware of the regularity as measured by their response to a hint question at the end of the experiment.

for young (64.6%) and older (66.2%) groups is similar to the 63% observed in Experiment 1 by Frick and Lee (1995).

At the individual subject level, 83% of the young participants and 92% of the older participants got 55% or more of the items correct.

EXPERIMENT 2

Experiment 1 replicated and extended the findings of Frick and Lee (1995), in finding that both young and older people could discriminate between category exemplars and nonexemplars but couldn't report how they did so. Further, we detected no age deficit in discrimination accuracy, suggesting that this form of implicit learning might be age constant. Nonetheless, the fact that there were no age deficits on string recall or on other tests, such as Computation Span, which usually reveal age deficits, could mean that we happened to test atypical groups.

Experiment 2 had three goals. First, we wanted to replicate Experiment 1 with different samples. Second, because of our focus on implicit learning, we wanted to rule out the possibility that people knew more than they reported during the interview. Therefore, we added the following hint question at the end (similar to Kelly & Wilkin, 2006; Wright & Burton, 1995): "In fact, the pattern consisted of one letter always occurring in a certain position in the list. Can you make a guess as to what the letter was and in what position?" Third, we wanted to determine whether the learning was hyperspecific in being tied to the visual stimuli the participant saw. Some studies of invariant feature learning have yielded hyperspecificity with discrimination reduced to chance when surface features of the stimuli were changed between encoding and test (Stadler, Warren, & Lesch, 2000), but others have not (Huddy & Burton, 2002; Newell & Bright, 2002). To address this question here we switched the letter case between encoding and discrimination.

METHODS

Participants

We tested 24 paid volunteers, 12 young and 12 older adults, from the same sources as used in Experiment 1, although no

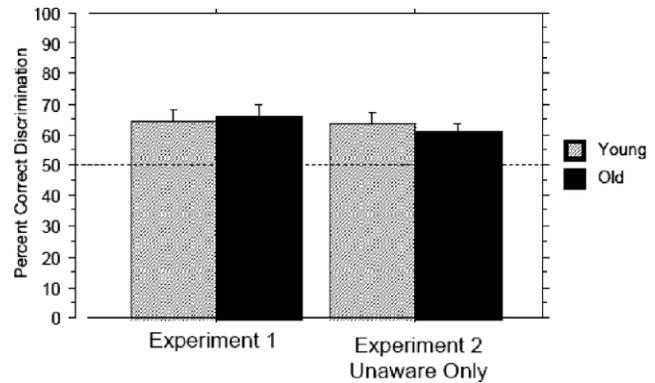


Figure 2. Mean percentage correct discrimination of category exemplars by young and older adults in Experiments 1 and 2, with standard error bars. For Experiment 2, data are reported only for participants who were unaware of the regularity as measured by their response to a hint question at the end of the experiment. The dashed horizontal line indicates chance performance.

person participated in both experiments. Table 1 shows that, as in Experiment 1, the older group was more educated than the younger, and the groups did not differ on self-reported health, Mini-Mental State Examination score (Folstein, Robins, & Helzer, 1983), or Digit Span Test score. As is typical, the older group outperformed the young on the vocabulary test. In this experiment, unlike the first, the older group was significantly poorer than the young at the Computation Span Test (Salthouse, Mitchell, Skovronek, & Babcock, 1989, using the Total Span score from Raz, Gunning-Dixon, Head, Dupuis, & Acker, 1998), a measure of working memory capacity. The substantially higher Computation Span score average for the young group in Experiment 2 is due primarily to one participant who scored 80 points higher than the next highest person. When that outlier is removed, the young mean Computation Span score in Experiment 2 is 37.82. Overall, then, the samples differ across experiments in that the young people in Experiment 2 tend to score higher than those in Experiment 1, whereas the reverse holds for the older groups.

Stimuli

The stimuli were identical to Experiment 1, except that during encoding the stimuli were presented in lowercase, rather than in uppercase, font.

Procedure

The procedure was identical to Experiment 1, except that we added the third "hint" question to the questionnaire.

RESULTS AND DISCUSSION

Verbal Reports

Answers to Questions 1 and 2 regarding strategies used and the ability to report the regularity without any hint led to responses similar to those in Experiment 1. However, in response to the hint probe in Question 3, we found that 2 of 12 young people (17%) and 4 of 12 older people (33%) reported both the correct position (second) and the correct letter (e.g., H), and one additional older person reported the correct letter

only. According to Fisher's exact test, this group difference in number aware was not significant, $p = .37$. The probability of reporting both correctly by chance is very low (.01).

To provide a conservative test of learning in the absence of awareness, unless otherwise stated, the following analyses include only the "unaware" participants (i.e., those who were unable to report either the position or the letter correctly). We did not include awareness as an independent variable because there were so few aware participants, but we do report t tests with and without the aware participants to show that their presence does not change the results.

Immediate String Recall During Encoding

The right panel of Figure 1 shows that the older group recalled the strings less accurately than did the young during encoding, $t(15) = 2.78$, $p = .02$. This is also the case when aware participants are included, $t(22) = 4.31$, $p = .01$. Thus, this experiment, unlike Experiment 1, yielded the expected age deficit in string recall.

Sensitivity to the Regularity During Discrimination

As shown in the right panel of Figure 2, and consistent with Experiment 1, unaware participants in both age groups discriminated significantly above chance, young $t(9) = 3.55$, $p < .01$, and older $t(6) = 3.60$, $p < .02$. [When aware participants are included, young $t(11) = 4.38$, $p < .01$, and older $t(11) = 3.68$, $p < .01$.] What is also consistent with Experiment 1 is that we did not detect an age difference in discrimination accuracy, $t(15) = 0.54$, $p = .60$. [When aware participants are included, $t(22) = 0.08$, $p = .94$.]

At the individual subject level, of the unaware participants, 70% of the young adults and 82% of the older adults got 55% or more of the items correct.

Experiment 2 gives more convincing evidence than Experiment 1 that this invariant learning can be implicit in that the participant cannot verbalize the regularity. In Experiment 2, the unaware participants were unable to guess either the critical letter or its location, despite having been told this detailed information about the nature of the regularity.

There is evidence that those participants we classified as aware did not gain this awareness until the hint question itself. If the aware participants had become aware during encoding, they should have been perfect, or nearly so, on discrimination. However, only one aware participant (and no unaware participant) was 100% correct on discrimination, and for the remaining people, the range of discrimination scores across the unaware participants (45%–80%) and aware participants (50%–80%) was very similar, suggesting neither group was aware during encoding. It is also unlikely that the aware group became aware during the discrimination phase, because had they done so, then discrimination accuracy should have improved during testing, especially for the aware group. However, this was not the case. Across all participants, percentage correct discrimination was 64.2 ($SE = 3.2$) for the first half of testing (i.e., first 10 trials) and 65.4 ($SE = 3.7$) for the second half. Of the 24 participants, 9 were in the direction of having discrimination accuracy decrease from the first to the second half, 8 were in the opposite direction, and 7 had the same percentage correct on both halves. This pattern held for both aware and unaware people.

This latter finding suggests both that participants' above-chance discrimination was due to learning during encoding rather than learning during the discrimination test and also that participants who became aware did not likely do so during discrimination testing.

Combining Experiments 1 and 2

We also subjected the discrimination scores from Experiments 1 and 2 to an age (young vs older) \times Experiment (1 vs 2) factorial analysis of variance. No main effects or interactions approached significance, either for all the participants from Experiment 2 or only those who were unaware. This lack of age effects on discrimination even when the two experiments are combined provides stronger evidence that older people are as good as young people at learning the regularity. In addition, the above-chance discrimination by both age groups in Experiment 2, where the case of the stimuli changed between encoding and discrimination, suggests that what is being learned about category membership here is not tied to the visual form of the stimuli.

EXPERIMENT 3

The goal of Experiment 3 was to provide direct evidence that the learning being tapped on the discrimination test occurs, at least in part, during the encoding phase. In the first two experiments, discrimination accuracy did not vary under any condition, being near to the 63% for the unaware participants in the original study by Frick and Lee (1995) in all conditions. This lack of variation raised the possibility that the discrimination measure might be tapping not category learning during encoding, as we would like to argue, but rather learning resulting from the discrimination testing itself. The fact that, in Experiment 2, discrimination did not improve from the first to the second half of testing argues against this concern, but Experiment 3 provides a more direct test by varying the number of encoding trials. If discrimination accuracy is indeed tapping implicit learning that occurs during encoding, then accuracy should increase with the number of encoding trials for unaware participants.

METHODS

Participants

We randomly assigned 30 paid Georgetown University undergraduates between the ages of 18 and 23 years to each of three conditions (10, 20, or 30 encoding trials).

Stimuli

The stimuli were identical to Experiment 1 except that "D" was the critical letter.

Procedure

The procedure was identical to Experiment 2, with four exceptions. First, testing was done by means of index cards. Second, as in Experiment 1, strings were in uppercase font for both encoding and discrimination. Third, there were three

groups, receiving 10, 20, or 30 encoding trials. Fourth, we did not administer neuropsychological tests.

RESULTS AND DISCUSSION

Verbal Reports

In response to the hint probe, 10% of the participants reported either the correct position (second), the correct letter (D), or both. This included 5, 1, and 3 people, respectively, in the conditions of 10, 20, and 30 encoding trials. That the number of aware people did not increase with number of encoding trials is consistent with the argument that this awareness did not develop during the encoding phase. The remaining analyses include only unaware participants.

Sensitivity to the Regularity During Discrimination

Figure 3 shows the mean percentage correct discrimination for the unaware participants as a function of encoding condition. A linear regression yielded a significant effect of encoding condition, $F(1,76) = 6.78$, $MSE = 130.31$, $p < .02$. This linear effect establishes that discrimination accuracy increases with encoding trials and, hence, that the category learning occurred at least in part during the encoding phase. In keeping with this conclusion, at the individual subject level, 71%, 79%, and 92% of the participants in the conditions of 10, 20, and 30 encoding trials, respectively, got 55% or more of the items correct.

GENERAL DISCUSSION

In the present experiments we used a task introduced by Frick and Lee (1995) to ask whether there are age-related deficits in implicit learning of an invariant association. We found that both younger and older adults showed significant and equivalent learning of the regularity, even when the case of the letters was changed between encoding and test. Further, there is strong evidence that the learning is implicit; people in both age groups discriminated exemplars from nonexemplars even when we eliminated those who reported *either* the letter *or* the position, in response to a specific hint question. Thus, the lack of accurate verbal report was unlikely due to difficulties in describing a regularity people sensed, or of which they were unsure. We also showed that the learning of the invariant occurred at least partly during encoding of the exemplars, rather than during discrimination testing; discrimination accuracy did not increase during testing (Experiment 2), but it did increase with encoding presentations (Experiment 3).

Of course, claims of age constancy always warrant scrutiny, and our sample sizes are small. Assuming that the true age difference in discrimination accuracy is 1.8 items, with a standard deviation in each age of 11 (i.e., the values obtained when unaware participants are combined across Experiments 1 and 2), then we would need approximately 300 subjects in each age group to have a power of 0.8 to detect this difference. Further, the samples happened to differ in ability level across the first two experiments, and yet the discrimination accuracy was virtually identical, suggesting that this learning is robust across different samples. Moreover, the failure to detect age deficits cannot be attributed to the discrimination test being generally insensitive. Discrimination accuracy was significantly

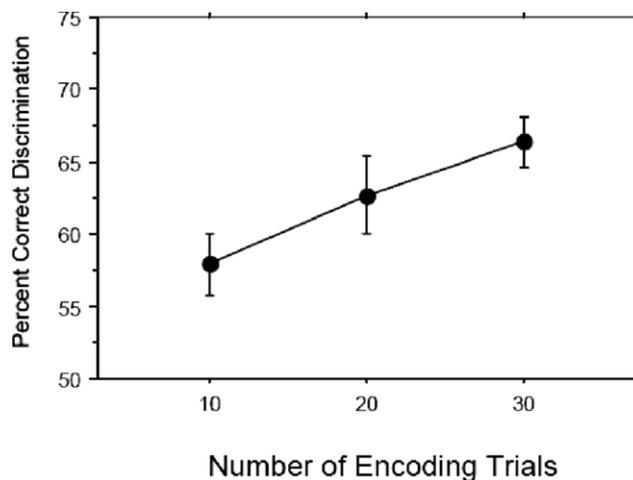


Figure 3. Mean percentage correct discrimination of category exemplars (with standard error bars) by the unaware young adults in Experiment 3 as a function of number of encoding trials.

above chance for each age group in each experiment, and in Experiment 3 it increased significantly with the number of encoding trials. In addition, we were able to show the predicted dissociation in Experiment 2, such that the same older participants who did not differ from the young on discrimination were significantly poorer on immediate string recall.

Thus, although we cannot rule out age deficits so small that they would require an extremely large sample size to detect, we conclude that implicit learning of this invariant association is largely preserved with aging. This is consistent with the relative age constancy seen in implicit learning of first-order sequences (Curran, 1997; Howard & Howard, 1992), of repeating number strings (Turcotte et al., 2005, Experiment 1), and of some artificial grammars (McGeorge et al., 1997). The present findings go beyond these earlier ones in that a stringent test established that the learning is implicit, and in that the learning is of a different type of association.

Many questions remain. The neural bases of invariant learning are unknown, though evidence that it is spared with aging places constraints on its likely neural substrates. In addition, we do not know exactly what people are learning in this associative invariant task, and so we cannot know the extent to which the age constancy observed here would apply to other forms of implicit learning. Previous work with the original nonassociative invariant feature tasks suggests that both similarity and abstraction processes are involved (Kelly & Wilkin, 2006). Articulatory fluency might also contribute; using the original version of the invariant task, Huddy and Burton (2002) showed that articulatory suppression during encoding reduced discrimination accuracy to chance. If this is the case, the age constancy we observed would be in keeping with the findings of Light and colleagues (Light, La Voie, & Kennison, 1995), who reported that older peoples' speed of naming unrelated previously paired words or paired nonwords benefits just as much as young peoples' speed from earlier reading (whether aloud or silent) of those same pairs.

In summary, we have shown that young and older people are equally good at implicit learning of an invariant association,

even when they are unable to describe it. This establishes another form of implicit learning that is spared in healthy aging, revealing another avenue by which older people continue to adapt efficiently to environmental regularities without even knowing it.

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