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Analyses of Adult Age Differences in Associative Learning[1]

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Summary: Data from a recent project concerned with adult age differences in associative learning were reanalyzed to identify the processes involved in the age-related differences in trial-by-trial performance in this task. A measure reflecting the failure to retain feedback relevant to one's previous response accounted for a large proportion of the age differences in the early trials of associative learning. The speed with which individuals completed simple processing operations also contributed to the age differences both in measures of accuracy (percentage correct) and in measures of feedback retention.

Analysen von altersbedingten Leistungsunterschieden beim assoziativen Lernen im Erwachsenenalter

Schlüsselwörter: assoziatives Lernen, Alterseffekte, Rückmeldungsverarbeitung, Verarbeitungsgeschwindigkeit, Unterscheidungsfehler

Zusammenfassung: Zur Identifikation der Prozesse, die zur altersbedingten Leistungsunterschieden in einer assoziativen Lernaufgabe führen, wurden Daten aus einem aktuellen Forschungsprojekt reanalysiert. Zwei Befunde sind von besonderer Bedeutung: Ein Maß, das die Störung des Behaltens relevanter Rückmeldung auf die vorausgehende Antwort widerspiegelt, erklärt besonders in der Anfangsphase des Lernens einen großen Teil der Altersunterschiede. Altersunterschiede lassen sich aber auch auf die Geschwindigkeit zurückführen, mit der die Probanden einfache Verarbeitungsoperationen ausführen. Das betrifft sowohl die Genauigkeit (Anzahl korrekter Antworten) als auch das Behalten von Rückmeldungen.

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Introduction

Large adult age differences in associative learning have been documented for several decades. For instance, Monge (1971) reported that older adults needed almost twice as many anticipation-inspection trials as young adults to attain one errorless trial. Although poorer performance on the part of older adults relative to young adults is a common finding in research on associative learning (see Kausler, 1991, pp. 244-247, for extensive discussion), the reasons for age-related differences are not yet clear. In an attempt to provide a detailed characterization of the nature of age-related differences in associative learning, we report finer-grained correlational analyses of data from associative learning tasks performed by participants in two studies described in Salthouse (1994).

Experimental Tasks

The task used in the Salthouse (1994) studies required research participants to learn associations between pairs of symbols. Displays in the task consisted of a single probe stimulus on the left and a column of alternative response symbols on the right. The research participant used arrow keys on the computer keyboard to move an arrow in front of a response alternative, and feedback about the correct response for that stimulus was presented immediately after the participant's response was registered. The feedback consisted of a brief auditory tone followed by highlighting of the correct response, which was presented for 1.5 sec in Study 1, and until the subject pressed a key to begin the next trial in Study 2.

Because the positions of the response alternatives changed from trial to trial, no learning was possible in this task based on location information. Instead the participant had to learn to associate individual probe stimuli with individual response alternatives. Items in Study 1 consisted of six pairs of unfamiliar symbols, and those in Study 2 consisted of four digit-symbol pairs. The task continued until the participant reached a criterion of three successive trials with all items correct or until a total of 10 trials had been presented.

The research samples were drawn from a continuous age distribution (18 to 89 years), with 240 individuals participating in Study 1, and 125 individuals participating in Study 2. All participants reported themselves to be in good to excellent health, and the average years of education was 13.9 in Study 1 and 15.5 in Study 2.

The primary measure of performance in the task is the percentage of correct responses on each trial. However, some participants reached the learning criterion before the tenth trial; thus performance is also presented in terms of the cumulative percentage of individuals who achieved the criterion at each trial. These two measures are shown in Figure 1 for Study 1, and in Figure 2 for Study 2.

Notice that although the absolute levels of performance differ substantially across the two studies, the same ordering of the three age groups is evident in both panels of each figure. That is, performance was higher for adults in their 20s and 30s than for adults in their 40s and 50s, who in turn performed at higher levels than adults in their

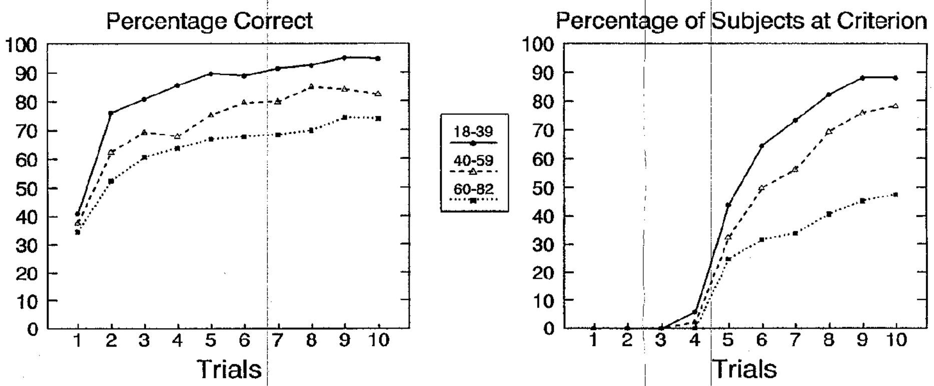

Fig. 1 Percentage correct responses (left panel) and percentage of subjects achieving the learning criterion for three age groups as a function of trials, Study 1. Each curve is represented by between 71 and 85 individuals.

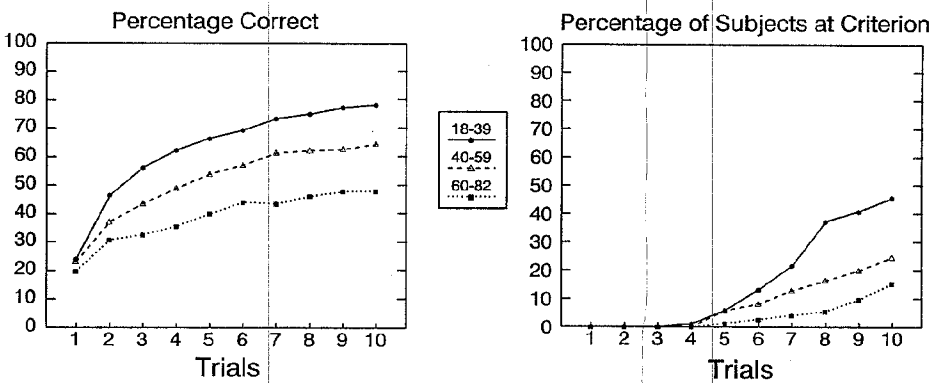

Fig. 2 Percentage correct responses (left panel) and percentage of subjects achieving the learning criterion for three age groups as a function of trials, Study 2. Each curve is represented by between 34 and 46 individuals.

60s and 70s. The major goal of the current report is to identify factors responsible for the age-related differences in trial-by-trial performance evident in these figures.

Analytical Framework

For purposes of this article, associative learning is defined as the change in the measure of percentage correct as a function of the number of trials. Component processes in associative learning can therefore be identified by analyzing responses to specific stimuli across successive trials. Of particular interest are four categories of errors that could occur prior to achieving the learning criterion (see Salthouse, 1994). If a correct response to the stimulus on trial *n* is followed by an incorrect response on trial *n*+1, the error is classified as a forget. If a specific response (e.g., Response A) was incorrect on trial *n* and then was repeated for the same stimulus on trial *n*+1, the error is classified as a perseveration. If an incorrect response on trial *n* is followed by another incorrect response on trial *n*+1, but with the selection of a response alternative that had already been confirmed to another stimulus, the error is classified as a discrimination failure. Finally, if an incorrect response on trial *n* is followed by an incorrect response on trial *n*+1, and the error is neither a perservation nor a discrimination failure, it is classified as an unsuccessful guess.

Each of these errors can be interpreted as reflecting a failure to retain feedback about the item because the correct response is specified after every response by the participant. However, two especially interesting errors are forgets, in which the participant apparently fails to retain positive feedback (i.e., that the last response to this stimulus was correct), and perseverations, in which the participant apparently fails to retain negative or disconfirming feedback (i.e., that the last response to this stimulus was incorrect). Note that with forget errors the subject fails to make the previous response when it should be made, and with perseveration errors he or she makes the previous response when it should not be made.

Because the other kinds of errors could represent a mixture of influences, they are more difficult to interpret. For example, because a discrimination failure corresponds to the selection of a response already confirmed to another stimulus, it may reflect a failure to remember the specific stimulus, confusion about the one-to-one mapping between stimuli and responses in the task, or general weaknesses in reasoning or problem solving. Unsuccessful guesses are even more complicated because this error is defined after the other error categories are excluded.

To express the errors relative to the opportunities for that type of error, we converted the absolute frequencies of the forget errors and perseveration errors to proportions by dividing the number of forget responses on trial *n*+1 by the number of correct responses on trial *n* to yield a forgetting proportion, and by dividing the number of perservation responses on trial *n*+1 by the number of incorrect responses on trial *n* to yield a perservation proportion. The mean proportions ranged from .20 to .40 for the forgetting measure, and ranged from .09 to .14 for the perseveration measure.

The correlations between the forgetting measures and perservation measures were rather low in magnitude, which may have been attributable to the relatively low reliabilities of the individual measures (e.g., in Study 2 they ranged from .15 to .25 for the forgetting measures, and ranged from .28 to .40 for the perseveration measures). Nevertheless, because the correlations were all above zero, and because the two measures were both postulated to represent failure to retain feedback, the measures were combined by averaging z-scores to create a more reliable composite feedback-loss score. Because substantial age-related differences in associative learning are apparent within the first four trials (see Figures 1 and 2), and because progressively more individuals had achieved the criterion and no longer contributed data after trial 4, the trial-by-trial analyses reported below were restricted to data from the first four trials. Nevertheless, similar patterns were obtained when the analyses were conducted on the data from all 10 trials for individuals who failed to achieve the learning criterion.

Theoretical Context

The primary question of interest in this report is the cause of the well-documented adult age differences in learning. A fundamental assumption underlying our research is that progress toward answering this question can be achieved by analyzing trial-by-trial improvement in terms of component processes, and by identifying variables responsible for mediating age-related influences. Although many possible mediating variables could be examined, the focus in this project is on measures of processing speed because of earlier evidence that this construct is involved in mediating age-cognition relations (e.g., Salthouse, 1992, 1993). Based on earlier research, it was predicted that age differences in trial-by-trial improvement would be interpretable in terms of age differences in component processes such as the retention of feedback information, and that those differences would in turn be found to share age-related variance with measures of processing speed.

Results

The initial analysis examined the relations between age and the percentage-correct and feedback-loss measures across successive trials. The relevant correlations are presented in Table 1. Note that the correlations with the percentage correct measures were all negative from trial 2 on, and that the correlations with the composite measure of feedback loss were all positive, although only those from Study 1 were significantly different from zero.

Table 1 Correlations with Age

	Trials			
	1	*2*	*3*	*4*
Percentage Correct				
Study 1	−.12	−.29*	−.42*	−.44*
Study 2	−.15	−.34*	−.30*	−.30*
Percentage Forgetting				
Study 1	–	.09	.15	.18*
Study 2	–	.07	.13	.17
Percentage Perseverations				
Study 1	–	.35*	.25*	.33*
Study 2	–	.13	.23	.17
Feedback-Loss Composite				
Study 1	–	.29*	.28*	.33*
Study 2	–	.13	.22	.21

*p < .01

A primary goal of the current article was to describe the relation between feedback loss and trial-by-trial performance during the early phases of associative learning. However, because the participants in these studies also performed several tasks designed to assess speed of processing, the role of processing speed on the relations among age, feedback loss, and percentage correct was also examined. The processing-speed measure was obtained by converting the reaction times in two computer-administered reaction-time tasks (Digit Digit and Digit Symbol, see Salthouse, 1994) into z-scores, and then averaging the two z-scores.

A series of path analyses, using the LISREL 8 (Jöreskog & Sörbom, 1993) structural equation program, were conducted on the data from each study. The first analysis examined the relations between age and the measure of percentage correct

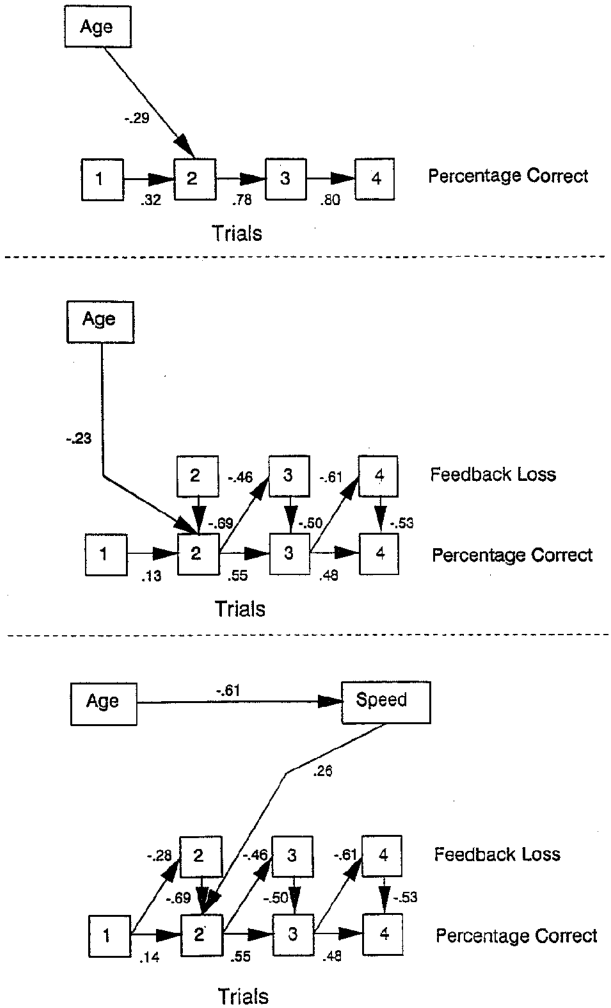

Fig. 3 Path diagrams illustrating independent relations among age, reaction time speed, feedback loss, and percentage correct across the first four associative learning trials, Study 1. Fit statistics for the models were: Top panel – X^2 (df=3) = 31.99, RMR = .044, GFI = .94, AGFI = .76; Middle panel – X^2 (df=15) = 53.48, RMR = .055, GFI = .95, AGFI = .88; Bottom panel – X^2 (df=19) = 55.84, RMR = .050, GFI = .95, AGFI = .89

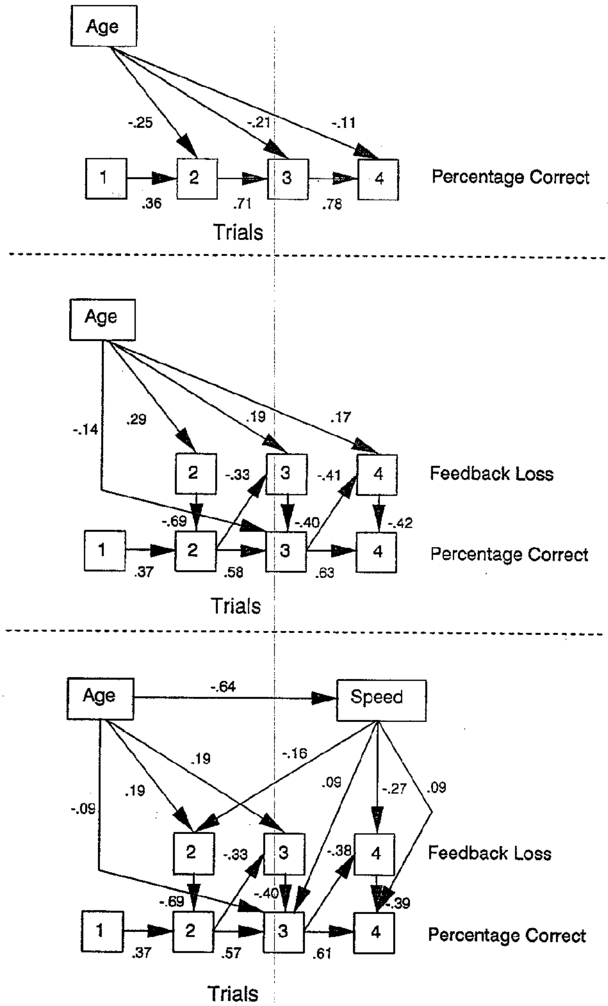

Fig. 4 Path diagrams illustrating independent relations among age, reaction time speed, feedback loss, and percentage correct across the first four associative learning trials, Study 2. Fit statistics for the models were: Top panel – X^2 (df=5) = 20.85, RMR = .062, GFI = .94, AGFI = .82; Middle panel – X^2 (df=16) = 35.69, RMR = .059, GFI = .94, AGFI = .86; Bottom panel – X^2 (df=24) = 43.89, RMR = .080, GFI = .93, AGFI = .87

across the first four trials of the task. The second analysis added the composite measure of feedback loss to the model, and the third analysis added the composite measure of processing speed. The resulting path diagrams for these models, with all significant path coefficients expressed in standardized units, are shown in Figure 3 for Study 1, and in Figure 4 for Study 2.

The results in the top panel of Figure 3 reveal that there were significant independent age-related influences on the percentage correct measure on trials 2, 3, and 4. The distinct age-related effects on successive trials suggest that it is not simply the case that all age-related effects in the early trials were merely propagated to later trials. If that were the case then unique age-related influences would occur only in the early trials and the effects on later trials would be mediated through performance on the early trials. The existence of independent age-related effects on trials 2, 3, and 4 suggests that new, or additional, variance is available for association with age on successive trials. This may reflect an increase in the amount of reliable variance, or the emergence of different age-sensitive processes from one trial to the next.

The addition of the feedback-loss measure (in the middle panel of Figure 3) alters the pattern of age-related influences considerably. That is, when the measure of feedback loss is considered, the only direct link between age and percentage correct is the path of -.14 on trial 3. This pattern suggests that a large proportion of the age-related influences are mediated through increased levels of feedback loss. That is, increased age is associated with a greater probability of failing to retain feedback, which in turn is associated with lower accuracy in selecting the correct response for a target stimulus.

Examination of the bottom panel of Figure 3 reveals that including the composite processing-speed measure in the model attenuates the direct age-related effects on the feedback-loss measure. At least some of the increase with age in the loss of feedback may therefore be mediated by an age-related decrease in the speed of executing relevant processing operations.

Inspection of Figure 4 reveals that the age-related effects were weaker in Study 2 than in Study 1. Only one of the relations between age and percentage correct was significant, and no significant relations occurred between age and the measures of feedback loss in this study. Both of these patterns may be consequences of the much higher levels of performance in Study 2 (cf. Figure 2 vs. Figure 1), which could be attributable to the use of fewer stimulus-response pairs (i.e., four instead of six), to the use of more familiar stimulus terms (i.e., digits rather than symbols), to the self-paced inspection duration as opposed to the 1.5 sec duration in Study 1, or to the fact that the participants in this study had higher average levels of education than the participants in Study 1 (i.e., 15.5 years compared to 13.9). It is nevertheless interesting to note that all of the age-related effects in the percentage correct measure in this study (on trial 2) were apparently mediated by speed of processing.

Conclusions

Several conclusions can be derived from the path diagrams in Figures 3 and 4. First, independent age-related influences initially occur on the second trial, and at least in Study 1, continue to be manifested on the third and fourth trials. These latter effects imply that either the type, or the amount, of variance in the percentage correct measures increases across successive trials because if this were not the case then all of the age-related influences would be mediated through the earlier measures. That is, the existence of independent and distinct influences on measures in an ordered sequence implies that later measures in the sequence have new or additional variance available for association above that present in the early measures in the sequence. One conclusion from the present analyses, therefore, is that somewhat different processes appear to be involved at successive phases of learning in this task, and that the efficiency or effectiveness of several of these processes is negatively related to age.

A second conclusion pertains to the role of retaining feedback about one's prior response in the trial-by-trial improvement on this task. This role is evident in the moderate relations between the feedback-loss measure and the percentage correct measure, and by the reduction, or even elimination, of the age-related influences on percentage correct when the feedback-loss measure was included in the analyses. The coefficients for the paths between the feedback-loss and percentage-correct measures were only moderate in magnitude, and thus not all of the variance in the percentage-correct measures could be accounted for by the feedback-loss measures. Nevertheless, it is apparent that one of the correlates of poor performance on this task is a high proportion of errors in which the subject behaves as though he or she failed to retain the feedback concerning his or her prior response to a target stimulus. The second conclusion from the present analyses, therefore, is that one factor contributing to individual differences, and particularly age-related differences, in associative learning is the ability to remember and use feedback regarding the correctness of previous responses.

The third conclusion from the analyses reported here concerns the role of processing speed on the relations between age and associative-learning performance. The speed construct in these analyses was represented by the reaction times in two tasks (i.e., physical identity judgments in the Digit Digit task, and substitution judgments in the Digit Symbol task) that have little resemblance to the associative learning task. Despite the lack of similarity, the speed variable was significantly related to several of the percentage-correct and feedback-loss measures. Furthermore, when the speed variable was included in the analyses, most of the relations between age and the other measures were reduced or eliminated. These results are consistent with the speculation that the composite speed variable serves as an index of the speed with which many processing operations can be executed, and that faster execution of relevant operations leads to higher percentage correct values and to lower levels of feedback loss. Because of the strong negative relations between age and speed, the third major conclusion of these analyses is that the slower speed of processing with increased age contributes to some of the adult age differences in associative learning. This conclusion is compatible with the results of many other recent studies (e.g., Salthouse, 1992, 1993, 1994), and provides further support for the hypothesis that the rate at which elementary cognitive operations can be executed is an important factor in adult age differences in cognition.

Although these three conclusions help explain the age differences in associative learning, the level of understanding is still far from complete. The factors responsible for the remaining direct or unmediated age effects have not yet been identified, nor have all of the determinants of the percentage correct and feedback-loss measures been specified. Future research should therefore address these issues, as well as explore the generalizability of the present conclusions to other types of tasks. Nevertheless, the present analyses demonstrate the usefulness of the decompositional or analytical perspective on adult age differences in cognition, and provide another means of identifying salient factors contributing to age differences in learning.

References

Jöreskog, K.G., & Sörbom, D. (1993). LISREL 8: User's Reference Guide. Chicago: Scientific Software International.
Kausler, D.H. (1991). Experimental psychology, cognition, and human aging. New York: Springer-Verlag.
Monge, R.H. (1971). Studies of verbal learning from the college years through middle age. Journal of Gerontology, 26, 324-329.
Salthouse, T.A. (1992). Mechanisms of Age-Cognition Relations in Adulthood. Hillsdale, N.J.: Lawrence Erlbaum Associates.
Salthouse, T.A. (1993). Speed mediation of adult age differences in cognition. Developmental Psychology, 29, 722-738.
Salthouse, T.A. (1994). Aging associations: Influence of speed on adult age differences in associative learning. Journal of Experimental Psychology: Learning, Memory and Cognition, 20, 1486-1503.

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