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# A functional relation between learning and organization in free recall

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It is well known that multitrial free recall is accompanied by increased organization of output over learning trials, even when the order of presentation is randomized. We compared the relation between learning and organization in 30 young and 30 older adults as they learned categorized materials to a criterion of 100% recall. The importance of this age manipulation was that it allowed us to examine, using two groups that differ significantly in their learning ability, whether organization and learning follow the same function. As was expected, older adults showed less organization on any given learning trial. However, when equated for degree of learning, the older adults showed approximately the same level of organization as the young. This finding suggests that the organization–learning relation remains invariant in the face of significant differences in participants' mnemonic abilities.

No issue is more fundamental to our understanding of human learning than the relationship between learning and organization. Recent years have seen a renewal of interest in output order effects in free recall (Brainerd, Reyna, Harnishfeger, & Howe, 1993; Howard & Kahana, 1999, 2000b; Kahana, 1996; Rohrer & Wixted, 1994; Rohrer, Wixted, Salmon, & Butters, 1995; Romney, Brewer, & Batchelder, 1993; Wingfield, Lindfield, & Kahana, 1998; Wixted & Rohrer, 1993, 1994). Consistent with early work (e.g., Tulving, 1968), many of these later analyses have suggested two major organizational factors that influence the structure of memory retrieval. In self-initiated memory retrieval, participants rely both on preexisting knowledge of such semantic relations as may be present in a list of items (semantic memory) and on newly formed contextual associations among list items (episodic memory).

A very reliable output order effect observed in free recall is learners' tendency to recall categorically related words in clusters, even when the order of presentation of list items has been randomized (see, e.g., Bousfield, 1953; Patterson, Meltzer, & Mandler, 1971; Pollio, Richards, & Lucas, 1969; Romney et al., 1993). With lists of unrelated items (i.e., items that are not constrained by preexisting categorical or associative relations), a subjective organization tends to develop that is revealed by the correlation of output order between successive recall trials (Sternberg & Tulving, 1977; Tulving, 1962).

Findings such as these have been taken by some to suggest that organization precedes learning, that the participant discovers semantic or categorical relationships between items and uses these relationships to support learning (Tulving, 1966). In its extreme form, this hypothesis would suggest that organization is a cause, rather than a consequence, of learning (Tulving, 1968). A view derived from these early studies was that poor learners are not good at organizing material, with organization seen as a strategy that effective learners invoke to facilitate learning (Crowder, 1976, p. 323).

An alternative to the view that organization causes learning is the possibility that increasing organization and increasing recall are both by-products of a single, albeit complex, learning process (see Brown, Conover, Flores, & Goodman, 1991; DeMarie-Dreblow, 1991). If this were the case, a manipulation that produced impaired learning would also produce impaired organization. These two positions—that increases in organization cause increases in learning, and that increases in both organization and learning are consequences of a common process—are not the only ones that are logically possible. It is also possible, if perhaps less plausible, that increases in learning cause increases in organization. Because all of these positions predict the well-known correlation between measures of memory organization and measures of learning (e.g., Tulving, 1962), distinguishing among them experimentally may not be possible (Crowder, 1976).

Our interest in this paper is in the fundamental question of whether the organization–learning relationship is an invariant feature of the human memory system that is not vulnerable to individual differences in mnemonic ability. To examine this question, we took advantage of the well-known finding that older adults, even when matched with young adults on education and verbal ability, typically show significant impairments in laboratory memory tasks (Kausler, 1994). Although it is known that older adults

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generally exhibit less organization than the young (see Hultsch, 1974; Rankin, Karol, & Tuten, 1984; Smith, 1980; Witte, Freund, & Sebby, 1990; Witte, Freund, & Brown-Whistler, 1993), it is not known whether the functional relation between organization and learning is the same or different for these two groups, who are known to differ in mnemonic ability and rates of learning.

There are reasons why the precise form of the organization–learning relationship might not be universal. Models of human memory often posit multiple mechanisms in the learning process (e.g., Murdock, 1997; Shiffrin & Raaijmakers, 1992). Similarly, cognitive-aging theorists often suggest that the learning and memory deficits associated with normal aging are a consequence of specific impairments in some processes and not in others (e.g., Kausler, 1994; Light, 1991). Following from these positions, it seems plausible that the organization–learning relationship might vary across age groups or across experimental variables.

Consider, for example, two different learning mechanisms responsible for the increase in organization with learning. One mechanism, labeled $R$, causes organization ($O$) to increase with learning ($L$) according to the equation $O_R = \beta_R L_R + \varepsilon_R$ (where $\beta_R$ is a constant and $\varepsilon_R$ is a random variable). The other mechanism, labeled $I$, causes organization to increase with learning according to the equation $O_I = \beta_I L_I + \varepsilon_I$. $R$ and $I$ could be any two mechanisms or strategies, such as relational versus item-specific encoding (see, e.g., Burns, 1990; Humphreys, Bain, & Pike, 1989; Hunt & Einstein, 1981) or elaborative versus rote encoding (see, e.g., Craik & Lockhart, 1972). The important point, however, is that to the extent that $\beta_I$ differs from $\beta_R$ and $\varepsilon_I$ from $\varepsilon_R$ across age groups, as might follow from a specific impairment argument, the organization–learning relation would be different for these two groups. By contrast, one might observe the same organization–learning relationship across age groups differing in mnemonic ability, either because they rely to an equal extent on both mechanisms or because learning and organization derive from a single mechanism. In either case, such an equivalence would suggest that the organization–learning relation is a fundamental property of the human memory system, in which participants with good and poor mnemonic ability would exhibit the same level of organization at any given level of performance.

In the experiment to be reported, we had young and older adults learn categorized word lists to a criterion of 100% correct recall, allowing us to examine the degree of organization at each level of learning. As part of the experiment, we also varied the semantic structure of the lists, using lists composed of either high- or low-prototypicality category exemplars. In such an experiment, an equivalent level of organization for an equivalent level of performance would not be the only possible outcome. If the older adults compensate for their learning deficit by enhanced use of organization, then at a given performance level, they might actually show higher levels of organization than the young. The final possibility is that older adults would still exhibit less organization than young adults, even when the two groups are equated for level of performance.

## METHOD

### Participants

The young participants were 30 university undergraduates, 11 men and 19 women, with ages ranging from 18 to 22 years ($M = 20.0$ years, $SD = 1.2$). At time of testing, the group had a mean of 14.0 years of formal education ($SD = 1.2$) and a mean WAIS–R vocabulary score of 51.6 ($SD = 5.2$). The group had a mean forward digit span of 7.2 ($SD = 1.3$) and a mean backward digit span of 5.7 ($SD = 1.2$).

The older participants were 30 healthy adults, 11 men and 19 women, with ages ranging from 66 to 86 years ($M = 72.9$ years, $SD = 5.3$). The older group had a mean of 15.8 years of formal education ($SD = 2.2$) and a mean WAIS–R vocabulary score of 50.4 ($SD = 9.8$). The group had a mean forward digit span of 6.6 ($SD = 1.3$) and a mean backward digit span of 5.4 ($SD = 1.4$). The older participants thus had an average of 1.8 more years of formal education than the young participants [$t(44) = 3.97, p < .001$], but the two groups did not differ significantly in WAIS–R vocabulary [$t(44) < 1$] or in their forward [$t(58) = 1.69$, n.s.] or backward [$t(58) < 1$] digit spans. All the participants reported themselves to be in good health, and all the participants were tested to ensure that they had no difficulty reading the words as they would appear on the computer screen.

### Stimuli

Two different 20-word lists were constructed for this experiment. Each list consisted of five category exemplars drawn from each of four categories. One of these lists consisted of exemplars that were highly prototypical of their category; the other list consisted of lower prototypicality exemplars.

In order to develop these lists, we obtained prototypicality ratings for 44 different categories. In previous work (e.g., Uyeda & Mandler, 1980), prototypicality ratings have been obtained for items that were generated in word association norms. In our case, we first had 25 university undergraduates who did not serve in the main experiment attempt to generate four high-, four medium-, and four low-prototypicality exemplars for each of the 44 categories. From these responses, we selected 21 categories together with those exemplars that were generated by 3 or more participants. These categories and their exemplars were then presented to a different group of 48 participants, who made prototypicality judgments on the exemplars, using a method similar to that used by Rosch (1975). The participants rated each exemplar on a 7-point scale (1 = *not at all prototypical*, 7 = *highly prototypical*).

From these ratings, we constructed the two lists, each with five categories and four exemplars per category. Care was taken to ensure that the exemplars would not readily fall into more than one category. The mean prototypicality rating for category exemplars in the high-prototypicality list was 6.44 ($SD = 0.37$), and for the category exemplars in the low-prototypicality list, it was 4.39 ($SD = 0.61$). The word frequencies of the category exemplars spanned a wide range. For the high-prototypicality lists, frequencies of occurrence in the Francis and Kučera (1982) norms ranged from 1 to 717 for the high-prototypicality list and from 1 to 123 for the low-prototypicality list. Mean word frequencies for the high- and low-prototypicality lists were 123.5 and 21.1, respectively.

### Procedure

The experiment utilized a within-participants design to achieve maximal power in comparing across groups. Pilot testing showed that participants more uniformly categorized during retrieval when the first list in the set consisted of high-prototypicality items. As a consequence, we had all the participants first learn the high-prototypicality list and then learn the low-prototypicality list.

The words in the study lists were presented one at a time in random order in the center of a computer screen, with a presentation rate of 1.5 sec per word. After the last list word was presented, the participants saw a row of asterisks, accompanied by an audible tone. At this point, they were asked to recall all of the words they could remember, in any order. The participants' spoken responses were recorded for later scoring. If the participant could not recall all 20 words, the list was presented again following the same procedures, but with the words presented in a new random order. This study–test procedure was repeated until the participant successfully recalled all of the list words. Once this criterion of 100% correct recall was achieved, the second list was presented following the same procedures. The experiment was preceded by a brief practice session in which a single 12-word list (three exemplars in each of four categories) was used to familiarize the participants with the experimental study–test procedure. As in the main experiment, the participants were given repeated study–test trials until they could recall all of the list words.

## RESULTS

Figure 1 shows recall probability as a function of number of study–test trials for the young and older participants for the high-prototypicality (left panel) and low-prototypicality (right panel) lists. These learning curves are shown fit by a Gompertz double exponential function (see, e.g., Murdock & Cook, 1960). It can be seen that the young participants learned both high- and low-prototypicality lists more quickly than did the older participants. Also, for both groups of participants, the high-prototypicality list was learned with fewer trials than was the low-prototypicality list, with this age difference exaggerated for the low-prototypicality list. Recall data for the first 12 trials were submitted to a mixed factorial analysis of variance (ANOVA; age group × prototypicality × trial), with age group as a between-participants factor and prototypicality and trials as within-participants factors. (As is common in the analysis of learning curves, where some participants reach a 100% correct criterion before others, we assumed that once criterion was attained, subsequent trials would continue to yield 100% recall.) This ANOVA confirmed the observations described above, showing a main effect of age [$F(1,58) = 30.94$, $MS_e = 0.07$, $p < .0001$], of prototypicality [$F(1,58) = 12.11$, $MS_e = 0.03$, $p < .001$], and of trials [$F(1,638) = 3.12$, $MS_e = 0.01$, $p < .0001$]. There was also a significant age × prototypicality interaction [$F(1,58) = 4.44$, $MS_e = 0.03$, $p < .05$].[1]

There have been two basic approaches to the measurement of organization in free recall. One approach has been to measure the degree to which participants' output order is consistent with the semantic relations among list items (e.g., Cooke, Durso, & Schvaneveldt, 1986; Romney et al., 1993; see Shuell, 1969, for a review of the early literature). Another approach has been to measure organization as the consistency of output order across successive recall trials (see Sternberg & Tulving, 1977, for a review). This latter approach, initially used to measure subjective organization in random word lists, can also be used to measure the organization of categorized materials.

For our purposes, we used a modified version of Sternberg and Tulving's (1977) pair frequency measure, based on the number of times that word pairs appear in adjacent output orders across trials, regardless of order. Because we were interested in the consistency of recall for items in terms of their category membership, we modified the pair frequency measure to include only adjacent pairs that belonged to the same semantic category.[2] When the in-

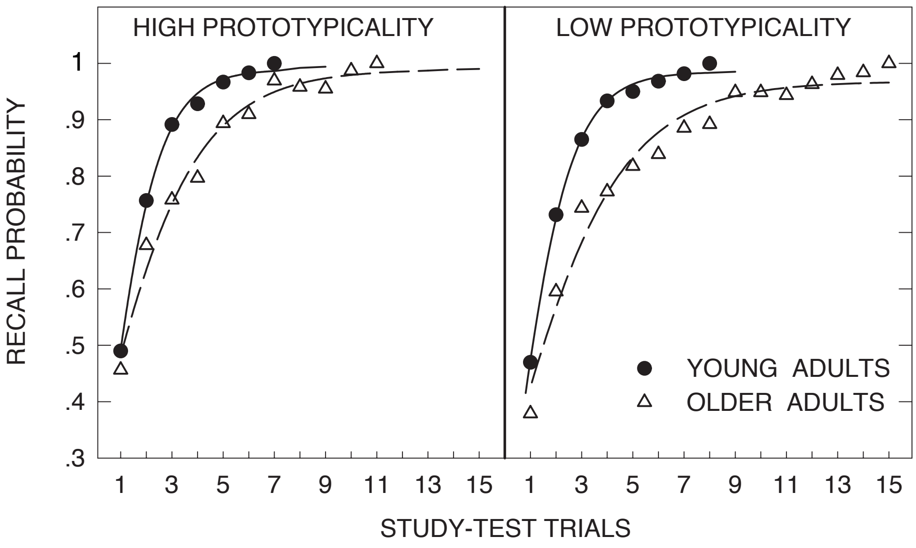


**Figure 1. Recall probability as a function of study–test trials for young and older adults learning word lists consisting of high prototypicality (left panel) and low prototypicality (right panel) category exemplars. Curves show a Gompertz double-exponential function fit to these data.**

crease in organization across study–test trials is examined, using this measure, our data confirm the well-known finding that organization tends to increase monotonically with learning trials. We found this effect for both high- and low-prototypicality lists and for both young and older participants. Consistent with the existing literature (e.g., Hultsch, 1974; Rankin et al., 1984; Smith, 1980; Witte et al., 1990; Witte et al., 1993), we also found that the older adults showed a slower increase in organization with study trials. This was true for both the high- and the low-prototypicality lists. (Our use of the modified pair frequency measure was predicated on its applicability to a potentially wide range of tasks. We found similar results when using Bousfield's, 1953, ratio of repetition measure and the standard pair frequency measure of subjective organization [e.g., Sternberg & Tulving, 1977]).

This finding of an apparent age deficit in organization, however, has to be interpreted in light of the fact that the older adults required more learning trials to attain the same level of recall performance as the young adults. We take this into account in Figure 2, where we plot the buildup of organization over learning trials as a function, not of number of learning trials, but of recall performance. The left panel of Figure 2 shows the recall–organization relationship for young and older participants learning the high-prototypicality list. The right panel shows the recall–organization relationship for the low-prototypicality list. Controlling for level of recall, an analysis of covariance failed to reveal any differences in modified pair frequency between young and older participants [for the high prototypicality list, $F(1,229) < 1$, $MS_e = 2.74$; for the low prototoypicality list, $F(1,227) = 1.26$, $MS_e = 2.43$, n.s.].

Contrary to claims of an organization deficit in older adults, the data in Figure 2 show that once one controls for the demonstrably slower learning rate in older adults, the organization–learning relationship appears as an empirical regularity that holds equally for the young and the older participants. That is, learning and organization can be seen to proceed in lock step for the two participant groups even though their rates of learning are very different.

## DISCUSSION

The increase in organization with learning has long been considered a basic feature of self-initiated memory retrieval (Tulving, 1968). The importance of the age manipulation in this present experiment was that it allowed us to demonstrate, using two groups that differ significantly in their learning ability, that organization and learning follow approximately the same function. Furthermore, this empirical regularity was seen in lists that differed in the prototypicality of their category exemplars.

This demonstration of an invariance in the recall–organization relation across groups that differ in their mnemonic ability can be seen as following from the view that memory retrieval in free recall is driven by (1) seman-

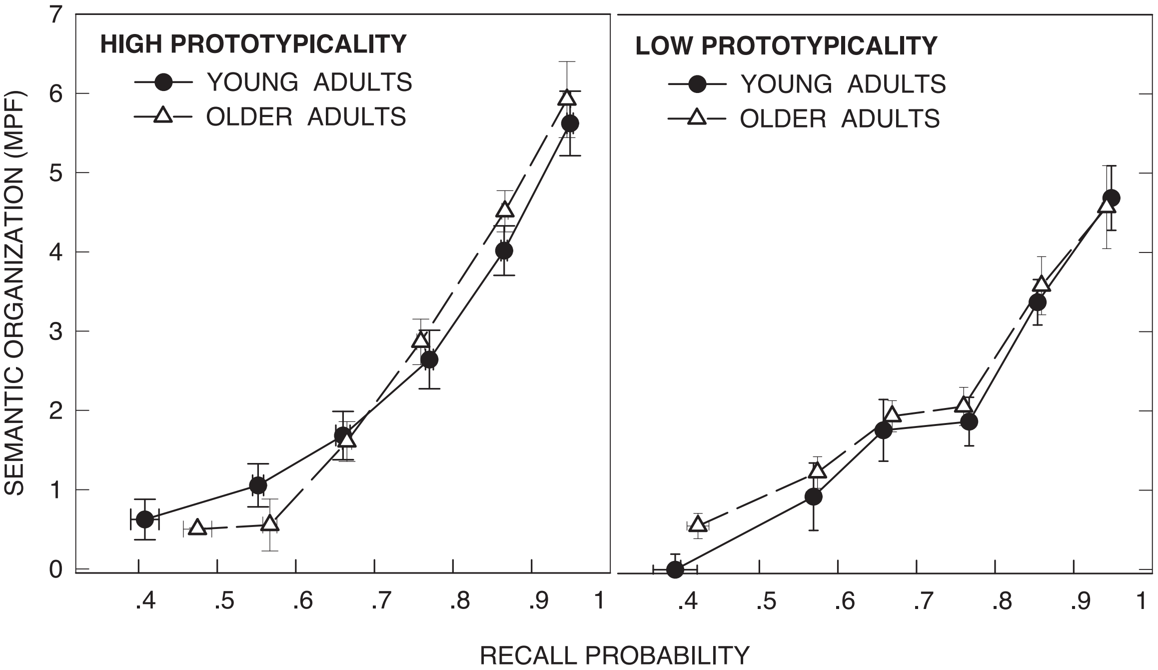


**Figure 2. The relation between semantic organization, as measured by modified pair frequency (MPF), and recall probability, for young and older adults. For trials that fell within a given accuracy range, we computed the mean and standard error of participants' MPF scores. These scores are plotted on the *y*-axis as a function of mean accuracy scores. Error bars, plotted for both MPF and accuracy, indicate one standard error of the mean. The left panel shows data for word lists consisting of high-prototypicality category exemplars; the right panel shows data for word lists consisting of low-prototypicality category exemplars.**

tic relations among list items and (2) episodic associations based on co-occurrence in temporal context (Howard & Kahana, 1999; Tulving, 1968). According to this view, prior to the presentation of an experimental list, items that belong to a common category are associated with one another. As the list is presented to the participant, items also may become associated with one another as a consequence of their joint rehearsal or their temporal contiguity (see, e.g., Howard & Kahana, 1999, 2000a; Murdock, 1997; Shiffrin & Raaijmakers, 1992). Repeated presentation of the list, each time in a different random order, will obscure the temporal structure defined by the contiguity relations among list items. As this occurs, the effect of the preexperimental semantic relations among items will, by definition, become increasingly important. This progressive increase in an emerging dominance of semantic over temporal factors will thus produce an increasingly stereotyped output order (as is manifest in our organization measure), even though the order of input varies randomly from trial to trial. Our results show that the effect of adult aging is to slow the learning process but not to change its essential form.

The question of whether older adults generally show less organization in their learning and recall has been somewhat controversial in the aging literature (e.g., Kausler, 1994; Light, 1991; Norris & West, 1990). In the present study, in which we equated young and older adults for degree of learning, we demonstrate the same functional relation between learning and organization in free recall for both age groups.

Modern theories of memory have recognized that the learning process is a complex one, driven by multiple mechanisms. Cognitive aging theorists have suggested as well that different mechanisms supporting learning and memory fail to different degrees in normal aging. As we pointed out in our introduction, each of these mechanisms, on its own, can give rise to a particular form of the organization–learning relation. Our finding that young and older adults exhibit the same degree of organization when equated for degree of learning can not be readily reconciled with the view that mechanisms that give rise to different organization–learning relations are differentially impaired in normal aging.

Rather, it seems that either (1) all mechanisms supporting free-recall learning independently produce the same organization–learning function or (2) different mechanisms produce different organization–learning functions but these mechanisms are not *differentially* impaired in normal aging. Whichever is the case, these data offer a striking demonstration that the organization–learning relation remains invariant in normal aging in the face of significant differences in mnemonic ability.

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## NOTES

1. Because the low-prototypicality list was always the second list that our participants learned, a part of this latter interaction might have been due to a differentially greater impact of proactive interference on the older participants than on the young participants (Arenberg, 1967; Kane & Hasher, 1995).

2. Our modification involved only a minor change from the traditional pair frequency calculation (e.g., Bousfield & Bousfield, 1966; Sternberg & Tulving, 1977). In our case, the expected modified pair frequency is calculated as $E[\text{mpf}] = [2c(c-1)]/(h-h_t)(k-k_t)$, where $h$ and $k$ are the number of words recalled on trials $i$ and $i+1$, respectively; $h_t$ and $k_t$ are the number of between-category transitions on trials $i$ and $i+1$; finally, $c$ is the number of words common to the participants' recall on trials $i$ and $i+1$.

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