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Age-Related Differences in Lexical Access, Spreading Activation, and Simple Pronunciation

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An experiment was conducted to address age-related differences in lexical access, spreading activation, and pronunciation. Both young and older adults participated in a delayed pronunciation task to trace the time course of lexical access and a semantic priming task to trace the time course of spreading activation. In the delayed pronunciation task, subjects were presented a word and then, after varying delays, were presented a cue to pronounce the word aloud. Older adults benefited considerably more from the preexposure to the word than did the younger adults, suggesting an age-related difference in lexical access time. In the semantic priming pronunciation task, semantic relatedness (related vs. neutral), strength of the relationship (high vs. low), and prime–target stimulus onset asynchrony (200 ms, 350 ms, 500 ms, 650 ms, and 800 ms) were factorially crossed with age to investigate age-related differences in the buildup of semantic activation across time. The results from this task indicated that the activation pattern of the older adults closely mimicked that of the younger adults. Finally, the results of both tasks indicated that older adults were slower at both their onset to pronounce and their actual production durations (i.e., from onset to offset) in the pronunciation task. The results were interpreted as suggesting that input and output processes are slowed with age, but that the basic retrieval mechanism of spreading activation is spared by age.

One of the more frequent complaints of older adults is a deterioration in memory performance. Although there has been considerable experimental research documenting such age-related memory changes, there still is not a clear understanding of their theoretical underpinnings.

A theoretical mechanism that has been used to discuss a wide variety of memory and cognitive processing in the young adult population is spreading activation (see Anderson, 1983; Balota & Lorch, 1986; Ratcliff & McKoon, 1981). In fact, Anderson (1983) has recently detailed how a spreading activation framework accounts for both the basic depth of processing and encoding specificity effects, the two tasks in which older adults show localized deficiencies (e.g., Duchek, 1984; Eber, Hermann, & Botwinick, 1980; Rabinowitz, Craik, & Ackerman, 1982).

According to the spreading activation framework, memory is represented as a set of concepts (nodes) that are interconnected by associative pathways. When part of the memory network is activated, activation spreads along the associative pathways to related areas in memory. This spread of activation serves to make these related areas of the memory network more available for subsequent cognitive processing, and influences the direction of attention both at encoding and retrieval.

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A number of studies have provided evidence about spreading activation in young and older adults. Although the majority of studies (e.g., Bowles & Poon, 1985a; Burke, White & Diaz, 1987; Byrd, 1984; Cerella & Fozard, 1984; Chiarello, Church, & Hoyer, 1985; Howard, 1983; Howard, Lasaga, & McAndrews, 1980; Howard, McAndrews, & Lasaga, 1981; Mueller, Kausler, & Faherty, 1980) have suggested that there are no age-related changes in spreading activation, there have been studies that suggest that there are age-related changes (e.g., Bowles & Poon, 1985b; Eysenck, 1975; Howard, Shaw, & Heisey, 1986; Petros, Zehr, & Chabot, 1983). Furthermore, the majority of the past studies have used the lexical decision task to address spreading activation. This is noteworthy because there is now considerable evidence that suggests that lexical decision performance not only reflects spreading activation but is also influenced by postaccess decision processes (Balota & Chumbley, 1984; Balota & Lorch, 1986; Chumbley & Balota, 1984; Lupker, 1984; Neely, 1986; Seidenberg, Waters, Sanders, & Langer, 1984; West & Stanovich, 1982). These postaccess decision processes become even more important when one considers that older adults may use different decision criteria (Botwinick, 1984). In fact, Chiarello et al. (1985) have recently provided some evidence that there are age-related differences in the decision component of the lexical decision task.

The present study was conducted as an attempt to provide further information regarding age-related differences in the characteristics of the spreading activation mechanism. One important characteristic is how the activation changes as a function of the strength of the underlying association. For example, in a production task, Freedman and Loftus, (1971), Loftus (1973), and Loftus and Loftus (1974) have found that subjects were faster to produce an exemplar of a category that began with a specified letter if the exemplar was strongly associated to the category (e.g., *dog* to *animal-d*) compared with when it was only weakly associated (e.g., *swan* to *animal-s*). Given this finding, Lorch (1982) noted that strength of an underlying association could influence the spread of activation in a number of distinct ways. For example, strength may influence the rate at which activation builds up at a particular concept with both strong and weak associations eventually yielding the same level of overall activation. On the other hand, strength may build up at the same rate for both strong and weak associations, but produce different final levels of activation. And finally, strength may influence both the rate and level of activation.

Lorch (1982) empirically teased apart these different alternatives by manipulating both the strength of the association and the time for processing the relation in a semantic priming paradigm. The notion is that response latency to a target should be a reflection of the activation of its underlying conceptual representation. Thus, one can trace activation across time for both strong and weak associations to determine which of the underlying models is correct. The results of the Lorch study indicated that activation increased across the delays and that strength determined the level of activation at all delays (i.e., strength and delay had additive effects).

This same theoretical framework may also be used to investigate the characteristics of the spreading activation process in young and older adults. One might expect, on the basis of the general "slowing" hypothesis (see Birren, 1974; Cerella, 1985), that activation may build up more slowly for older adults compared with younger adults. It is also possible that older adults may reflect a characteristically different pattern of activation such that they may produce effects of strength on both rate and overall level of activation. Such findings would be informative to interpret within a general activation model of memory and processing and shed some light on the underlying mechanisms for the age-related memory changes.

In the present study, all of the subjects participated in a semantic priming pronunciation experiment. On each trial, subjects were visually presented for varying durations a prime word that was followed by a target word that the subjects pronounced aloud. The primes were either related primes varying in strength of relation or the neutral word *blank*. *Blank* was used as a control condition to eliminate any item effects and as a baseline to measure the facilitation due to the related prime conditions (i.e., the indicant of spreading activation). Thus, in this study, there were four major variables of interest: age, stimulus onset asynchrony (SOA) between the prime and target, strength of the underlying relationship, and prime type (i.e., neutral vs. related prime).

The present study was also designed to address an important related variable in this area of research. That is, it is possible that older adults access lexical representations more slowly than younger adults. This is important because it has been demonstrated that manipulations that influence lexical access (e.g., visual degradation) interact with semantic context (e.g., Becker & Killion, 1977). Thus, it would be useful to tease apart any age-related differences in lexical access processes from age-related differences in semantic activation processes. In pursuit of this goal, in addition to the semantic priming pronunciation task, all of the present subjects engaged in a delayed pronunciation task. The delayed pronunciation task involved the presentation of a to-be-pronounced word that was followed, after varying delays, by a cue to pronounce the word aloud. The notion is that both the young and older adults should be able to complete lexical access before the response cue is presented at the longer delays (e.g., 900-ms cue delay). In this way, one can use the decrease in response latency between the shorter and longer delays as an indicant of lexical access time.[1] For example, if the older adults are 30 ms slower for lexical access than the younger adults, they should benefit 30 ms more than the younger subjects from a preview of the stimulus word, which is sufficiently long for lexical access to be completed. Thus, if there is an age-related difference in lexical access, then the older adults should benefit more than the younger adults from an extended preview of the to-be-pronounced word; whereas, if there is no age-related difference, then the older and younger adults should benefit equally from such a preview.

There is one final characteristic of this study that should be noted. With the current apparatus, it was not only possible to obtain latencies to begin pronunciation but it was also possible to obtain duration estimates of the time between the onset and offset of pronunciation for a given word. This additional measure is interesting because there is some evidence that there are developmental differences found in childhood on production durations (see Huttenlocher, 1984), and therefore, the present results may extend this observation to the other end of the developmental spectrum.

In sum, the present study is quite unique in that it traces the time course of age-related differences in lexical access and preparation times (as reflected by the delayed pronunciation task), spreading activation (as reflected by the semantic priming task), and actual output of the verbal response (as reflected by the production durations in both tasks).

Method

Design

The semantic priming task was a 2 (young vs. older adults) × 2 (related prime vs. neutral) × 2 (strong vs. weak relationship) × 5 (prime-target SOAs) mixed-factor design. The delayed pronunciation task was a 2 (young vs. older adults) × 8 (target-cue SOAs) mixed-factor design. Age was the only between-subjects factor in both tasks. One half of the subjects within each age group received the semantic priming task first, whereas the remaining half received the delayed pronunciation task first.

Subjects

A total of 60 young adults (40 women and 20 men) and 60 older adults (42 women and 18 men) participated in this study. Subjects were each paid $8 for participating. The mean age for the older adults was 70.7

[1] In the present article we assume a sequential stage model of pronunciation in which lexical access is first completed and then postaccess motor retrieval and production processes occur. An alternative to this view is the cascade framework developed by McClelland (1979). Such an alternative would assume that lexical access overlaps with transmission of information to the postaccess stages. For simplicity we have assumed the discrete framework; however, it is important to note that our arguments regarding the age-related differences in lexical access processes should also hold for a cascaded model of the pronunciation task.

years (range = 63–79 years), and the mean age for the young adults was 24.6 years (range = 18–36 years). Subjects were administered the Wechsler Adult Intelligence Scale (WAIS; Wechsler, 1981) Vocabulary subsection (Items 21–40), along with a questionnaire including general questions concerning activity, education, and health status. The older adults had a slightly higher education level (M = 14.3 years) compared with the younger adults (M = 13.9 years) and also scored slightly higher on the WAIS (M = 29.2 for the older adults, and M = 26.2 for the younger adults). Although the difference in educational level did not approach significance, the difference in WAIS performance did significantly favor the older adults, $p < .05$, by t test. Kausler and Puckett (1980) reported similar increases in vocabulary with age. All of the subjects reported themselves as being in a healthy condition for their age. Finally, note that all of the older adults were recruited from the community, whereas one half of our younger adults were recruited from the community, and the remaining half were enrolled at Washington University. In this way we could address whether there was a difference in student versus nonstudent populations. Such analyses did not yield any significant interactions with the variables of interest.

Because our interest is in the main effect or interactions, or both, involving the between-subjects factor age, the present design produced 960 observations per cell in the semantic priming task and 600 observations per cell in the delayed pronunciation task. In our review of the literature addressing age-related changes in semantic priming, the average number of observations per cell is approximately 250. This relatively small number of observations could be problematic when one considers a predicted difference only in degree of priming but not in direction. Because of this concern, we more than tripled the average number of observations in the past studies.

Apparatus

Stimulus presentation and data collection were controlled by an Apple IIe microcomputer, which was equipped with a Mountain Hardware clock. A voice key was connected to the computer to obtain millisecond pronunciation onset latencies and production durations. To accurately measure production latencies, a special machine language program was written to take into account any complete sound stoppage within the production of a word due to such phonemes as stop consonants. Note also that because there were no hardware modifications to synchronize the timer with the location of the signal on the CRT, onset latency had an error of as much as plus or minus 8 ms (see Reed, 1979). Any such error would occur randomly across conditions.

Materials

Semantic priming materials. A total of 320 word pairs were used for the critical items in this experiment. All of the critical items were the same as those used by Lorch (1982, Experiment 3). One half of the critical items were category–exemplar word pairs that were selected by Lorch from the Battig and Montague (1969) and Shapiro and Palermo (1970) norms. One half of these category–exemplar word pairs were high-dominant pairs, whereas half were low-dominant pairs. The remaining one half of the critical pairs consisted of free associates that were selected by Lorch from the Jenkins (1970) and Keppel and Strand (1970) norms. One half of the associates were high-associate pairs, and half were low-associate pairs. Frequency of usage (on the basis of the Kucera & Francis, 1967, norms), length in letters, and type of initial word phoneme were approximately equated across levels of strength (i.e., dominance or association values); see Lorch (1982) for further characteristics of this word list. Finally, note here that Burke and Peters (1986) recently provided evidence that there is considerable consistency in word associations produced for young and older adults. Thus, it is likely that the present related pairs have relatively consistent levels of associative strength across our age groups.

In addition to these critical items, there were 36 practice items, and 8 buffer items that were selected from the previously listed norms. The characteristics (i.e., percentages of high and low degrees of association and categorically and associatively related pairs) of these practice buffer items were the same as for the critical items.

There were three blocks of trials. The first block was practice. Each of the two test blocks contained 160 prime–target pairs with 8 prime–target pairs for each of the 20 conditions (i.e., 2[word vs. neutral prime] × 2[high- vs. low-strength] × 5[prime–target SOA]) across each of six groups of 10 subjects. Each target word was rotated across subjects, such that it was primed by either a word or neutral prime at each of the 5 prime–target SOAs. A given subject never saw the same word twice within the experiment. Thus, the target items were counterbalanced across prime–type and SOA, but not strength. However, it is important to note that a given item served as its own baseline concerning facilitation effects because it occurred in both the neutral and related prime conditions across subjects. Thus, the confounding of strength by item is not of importance in the present study. Finally, each test block was preceded by four buffer trials, and within a test block, items were randomly ordered anew for each subject.

Delayed pronunciation materials. A total of 136 middle- to high-frequency words were chosen from the Kucera and Francis (1967) norms. The words ranged in length from three to nine letters. None of the words selected were items that also appeared in the semantic priming task, but the items were similar in both length and frequency to the words in the semantic priming task. Like the semantic priming task, the delayed pronunciation task involved three blocks of trials; a practice block and two test blocks. The practice block involved 32 trials, with each of the eight delay conditions occurring four times. The two test blocks each contained 48 trials with six items in each of the eight delay conditions. Words were counterbalanced across subjects, such that each word occurred with each delay condition across a set of 8 subjects. Each test block was preceded by four buffer trials, and within a test block, items were randomly ordered anew for each subject.

Procedure

Semantic priming. Subjects were instructed that they would be presented with two words sequentially on each trial of the experiment. They were instructed to read the first word silently to themselves and were told that the major aspect of the task involved pronouncing the second word as quickly and as accurately as possible after it was presented. Subjects were not explicitly told about any relations between the prime and target words. They were told that their voice would trigger the computer to erase the stimuli from the screen. After the screen was erased, the following message was presented on each trial "If you correctly pronounced the word, press the '0' button, otherwise press the '1' button." Subjects were informed to press the 1 button in response to this message whenever they felt that a correct pronunciation did *not* trigger the computer (e.g., on the occasions in which an extraneous sound such as a cough or possibly a mispronunciation triggered the computer). If the subjects felt that a correct pronunciation did trigger the computer, they were instructed to press the 0 button. The experimenter remained in the room for the first 10–15 practice trials to ensure that subjects fully understood and followed the instructions.

The exact sequence of events on each trial was as follows: (a) A row of three asterisks separated by blank spaces was presented in the center of the screen for 300 ms; (b) a blank screen was presented for 300 ms; (c) a warning tone was presented for 150 ms; (d) a blank screen was presented for 300 ms; (e) the prime word was presented immediately above where the asterisks had been presented for either a 200-ms, 350-ms, 500-ms, 650-ms, or 800-ms delay; (f) the target word was presented immediately below where the asterisks had been presented until the computer detected the voice onset, at which time the screen was erased;

and (g) the message "If you correctly pronounced the word, press the '0' button, otherwise press the '1' button" was presented until a button press was detected that erased the screen and initiated a 3-s intertrial interval.

Upon arriving for the experiment, subjects were comfortably seated in front of the computer, approximately 60 cm from the screen. Because of differences across subjects in voice volume, the gain on the voice key was individually set, such that the voice key would be triggered throughout the vowels of a relatively long word (e.g., catastrophe) that was spoken at the normal sound level by the subject, as indicated by a light-emitting diode on the voice key.

There were four break periods in the experiment. Subjects received a 30-s break halfway through the practice trials, and there was a 1-min break before each of the test blocks. All of the subjects participated individually in a small isolated testing room.

Delayed pronunciation. The procedure for the delayed pronunciation task was precisely the same as the semantic priming task, with these major exceptions: First, subjects only received one word, and second, after varying delays of 150 ms, 300 ms, 450 ms, 600 ms, 750 ms, 900 ms, 1,050 ms, or 1,200 ms, one parenthesis was presented in the space immediately to the left of the word and one parenthesis was presented in the space immediately to the right of the word, thereby enclosing the word. The parentheses were presented as the subjects' cue to pronounce the word aloud. Subjects were told that they should prepare their pronunciation during the delay interval, but that they should always wait until the parentheses were presented to begin their pronunciation. The instructions emphasized that if they ever felt they had jumped the gun (i.e., began to pronounce the word before the parentheses were presented), then they should press the 1 button in response to the error message for that trial. The error message was precisely the same as in the semantic priming task.

Results

Although all 120 subjects participated in both the semantic priming task and the delayed pronunciation task, the data from the first 10 subjects in both the young and older adult groups were lost from the delayed pronunciation task due to an equipment failure.

In both tasks, an analysis of variance (ANOVA) was initially conducted on the subjects' mean performance per condition to determine if there were any main effects or interactions. Subjects were treated as the only random factor in this analysis. However, because different items served in different conditions, the error variance due to items was included in the Subjects × Condition interactions and, therefore, any significant effects or interactions should also generalize across items. The only exceptions to this are the main effect of strength and the interaction between strength and age. Because strength was a between-item manipulation, both of these effects will only generalize across subjects.

Response latencies exceeding 1,250 ms or 2.5 *SD* above each subject's mean, and response latencies less than 175 ms or less than 2.5 *SD* below each subject's mean, were treated as outliers.

Semantic Priming Onset Latencies

Figure 1 displays the mean response latency as a function of strength, prime relatedness, age, and SOA. There are five points to note in Figure 1. First, response latency was considerably slower for the older adults compared with the younger adults. Second, overall response latency appears to decrease across the 200–500-ms SOAs. Third, the difference between the neutral prime condition and the related prime condition was larger for the high-strength conditions than for the low-strength conditions for both groups of subjects. Fourth, compared with its corresponding neutral prime conditions, the related prime conditions facilitated performance more at the longer SOAs than at the shorter SOAs. Fifth, the overall pattern for the young and older adults appears to be very similar.

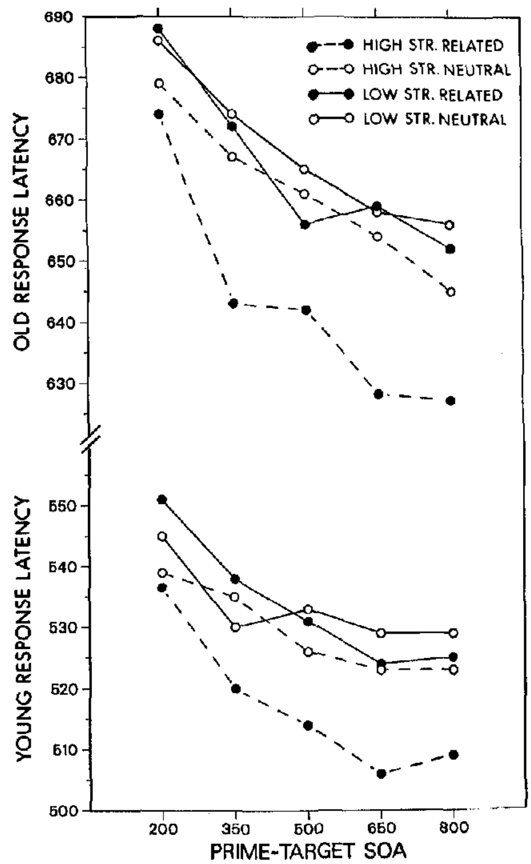

Figure 1. Mean response latency in the semantic priming task as a function of age, prime relatedness, strength, and stimulus onset asynchrony (SOA). (STR. = strength.)

Figure 2 displays the mean priming effect (i.e., the difference between the neutral and its corresponding related prime condition) as a function of age, strength, and SOA. As shown in Figure 2, the high-strength items produced a larger semantic priming effect than the low-strength items, and the priming effects appear to build up across time (i.e., for the high-strength items, the priming effect appears to build up between the 200- and 350-ms SOA; whereas, for the low-strength items, the build-up appears to be between the 350- and 500-ms SOA). More important, although the older adults appear to be producing a slightly larger overall priming effect, the rate at which the activation builds up across time is very similar to the younger adults, with the possible exception of the 650-ms SOA low-dominant items. Thus, the effects of age appear to be additive with the effects of strength and SOA.

The above observations were supported by a 2 (age) × 5

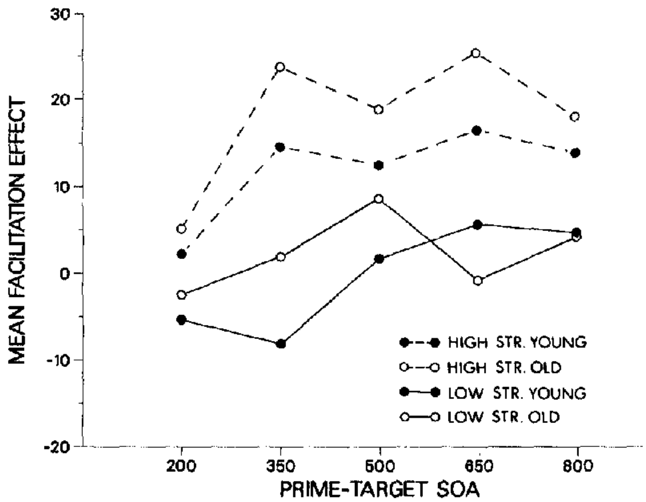

Figure 2. Mean facilitation effect (neutral minus related prime condition) in the semantic priming task as a function of age, strength, and stimulus onset asynchrony (SOA). (STR. = strength.)

(SOA) × 2 (strength) × 2 (prime relatedness) mixed-factor analysis of variance.[2] This analysis yielded highly significant main effects of age, $F(1, 118) = 60.27$, $MS_e = 170{,}485.7$, $p < .001$; strength, $F(1, 118) = 142.68$, $MS_e = 644.95$, $p < .001$; prime relatedness, $F(1, 118) = 31.45$, $MS_e = 1{,}237$, $p < .001$; and SOA, $F(4, 472) = 19.57$, $MS_e = 3{,}403$, $p < .001$. In addition, this analysis yielded highly significant interactions between strength and prime relatedness, $F(1, 118) = 56.11$, $MS_e = 531.3$, $p < .001$, and prime and SOA, $F(4, 472) = 4.24$, $MS_e = 640.5$, $p < .005$. The only variable that interacted with age was strength, $F(1, 118) = 4.26$, $MS_e = 644.9$, $p < .05$, which indicated that the strength effect was slightly larger for the older adults (16 ms) than for the younger adults (10 ms). The Relatedness × Age interaction only approached significance, $F(1, 118) = 2.37$, $MS_e = 1{,}237$, $p < .13$. However, note that although the Age × Relatedness × Strength interaction did not reach significance, the Age × Strength interaction was significant when a related prime was presented, $F(1, 118) = 4.84$, $MS_e = 589.7$, $p < .03$, but did not approach significance when the neutral word *blank* was presented as the prime, $F < 1.0$. More important for the present discussion, neither the Age × SOA × Relatedness, $F(4, 472) = .59$, $MS_e = 640.5$, nor the Age × SOA × Strength × Relatedness interaction, $F(4, 472) = .38$, $MS_e = 904.1$, approached significance. None of the remaining interactions between age and any of the other variables approached significance, all Fs < 1.49.

Although the overall interaction between SOA, relatedness, and age did not approach significance, four planned contrasts were made at each of the two sequential SOAs (e.g., SOA 200 vs. SOA 350, and SOA 350 vs. SOA 500) to determine if any of these individual comparisons yielded any evidence of age differences in the buildup of activation across time. None of these analyses yielded an interaction between age, SOA, and prime, nor between age, SOA, dominance, and prime (all Fs $<$ 1.14). Thus, these results provide little evidence for the notion that activation builds up at a different rate as a function of age.

Because some of the conditions produced relatively small priming effects, post hoc comparisons were conducted at each SOA separately for the high- and low-strength targets. These tests were conducted because one cannot make any strong statements about activation building up across time if some of the conditions were not producing significant priming effects. The results of these comparisons were quite clear. For the high-strength items, with the exception of the 200-ms SOA, all of the SOAs produced highly significant priming effects (all ps $<$ .001). None of the individual comparisons for the low-strength items produced a significant priming effect. However, it is important to note that if one collapses across the 500-, 650-, and 800-ms SOAs (the three longest SOAs), one finds a significant priming effect for the low-strength items, $F(1, 118) = 4.53$, $MS_e = 751$. Moreover, this influence of prime appears to build across time for the low-strength items. That is, if one collapses across the 200- and 350-ms SOAs and also collapses across the 500-, 650-, and 800-ms SOAs, one finds a highly significant interaction between relatedness and SOA, $F(1, 118) = 7.52$, $MS_e = 256$. Thus, these analyses indicate that there is a significant priming effect for the low-strength items at the longer SOAs, and also that this effect builds up across time.[3]

There is one final point to note about the semantic priming pronunciation onset latencies. Figure 3 displays the facilitation effects collapsed across age. As shown in this figure, it appears that the priming effect asymptotes across the longer delays. In fact, if one only considers the 500-, 650-, and 800-ms SOAs, the interaction between prime relatedness and SOA no longer approaches significance, $F < 1.00$. Lorch (1982) found that the activation increased across similar delays. Also, as shown in Figure 3, the activation appears to build up at different rates for the high-strength and low-strength items. That is, for the high-strength items, there appears to be an increase in activation between the 200-ms and 350-ms SOAs, whereas, for the low-strength items, there appears to be an increase in activation between the 350-ms and 500-ms SOAs. In fact, if one considers the high-strength items, there is a highly significant Prime × SOA interaction across Delays 1 and 2, $F(1, 118) = 12.66$, $MS_e = 573.6$, $p < .001$, whereas for the low-strength items, this interaction did not approach significance, $F < 1.00$. On the other

[2] Analyses of variance on both the semantic priming results and the delayed pronunciation results were also conducted that included the factor order-of-task, that is, whether subjects received the delayed pronunciation task first, or whether they received the semantic priming task first. Because this factor was not completely crossed with list, it was not included in the analyses reported. However, additional analyses indicated that this factor did not interact with the variables of interest in the present data.

[3] As shown in Figure 3, there is a slight tendency for a negative priming effect (i.e., faster latencies in the neutral condition than in the related condition) at the 200- and 350-ms SOAs for the low-strength conditions. There are three points to note here. First, this negative priming effect did not reach significance. Second, as Jonides and Mack (1984) and de Groot, Thomassen, and Hudson (1982) have discussed, it is rather difficult to establish a truly "neutral" prime condition against which to measure facilitation and inhibition effects. Finally, this "negative" priming pattern in no way compromises our arguments, because we are interested in how the difference between the related and neutral prime conditions changes as a function of SOA.

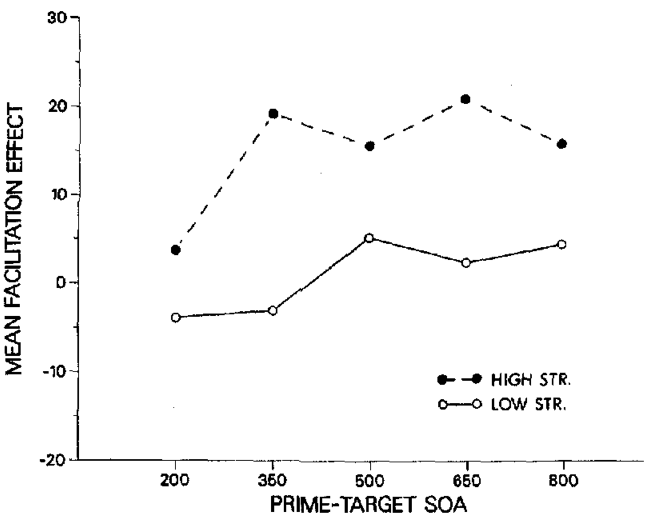

Figure 3. Mean facilitation effect (neutral minus related prime condition) in the semantic priming task as a function of strength and stimulus onset asynchrony (SOA). (STR. = strength.)

hand, for Delays 2 and 3, the interaction between prime and SOA, did not approach significance for the high-strength items, $F < 1.00$, whereas, for the low-strength items the interaction did approach significance, $F(1, 118) = 2.80$, $MS_e = 728$, $p < .10$. Although these comparisons are post hoc, they are interesting because of their implications regarding how activation builds up across time. At the very least, we feel that this pattern suggests that further research is needed to address this issue.

Semantic Priming Outlier and Error Analyses

Because subjects did not directly discriminate between errors in pronunciation and extraneous triggerings of the voice key (see the Method section), an analysis was conducted on the mean number of responses per condition that were included in the overall analysis (i.e., excluding outliers and trials in which the subject pressed the 1 button to discard the previous trial). Note, however, that the error and outlier rates did not significantly differ across the age groups. That is, the outlier rate was 4% for the older adults and 3% for the younger adults, and the error rate was 1% for the older adults and 2% for the younger adults.

The overall analysis paralleled the analysis conducted on the onset times. The results of this analysis yielded only two significant main effects. There were more responses in the high-strength (96.4%) condition than in the low-strength condition (95.4%), $F(1, 118) = 21.12$, $MS_e = .654$, $p < .001$, and there were slightly more responses in the related condition (96.2%) than in the unrelated condition (95.7%), $F(1, 118) = 7.53$, $MS_e = .622$, $p < .01$. Although these two main effects were obviously quite small, they were consistent across subjects. More important, neither the main effect of age nor any interaction in which age participated as a factor approached significance, all Fs < 1. Thus, the treatment of outliers or the biasing of pressing the 1 button did not change as a function of age.

Semantic Priming Production Durations

As noted earlier, an analysis was conducted on the production durations (i.e., from the beginning to the end of the production) to determine if there were any age differences in what would appear to be a very automated response. The same analysis as the analysis conducted for the onset latencies was conducted on the production durations. The results of this analysis yielded only one significant effect and that was a highly significant effect of age on production durations, $F(1, 118) = 54.16$, $MS_e = 148{,}537.5$, $p < .0001$. The average production duration for the older adults was 389 ms, whereas the average production duration for the younger adults was only 273 ms. Obviously, this is a dramatic effect on a widely used response for both groups of subjects and further points to the general slowing of the response system in older adults.

Delayed Pronunciation Onset Latencies

Figure 4 displays the mean onset latencies for the delayed pronunciation task as a function of age and SOA. There are three points to note in Figure 4. First, there is again a main effect of age. Second, response latency decreases as a function of delay. Third, the response latency appears to decrease more quickly for the older adults, compared with the younger adults. This latter pattern can be better seen in Figure 5, in which the difference between the younger and older adults is plotted across delay. As shown in Figure 5, the difference between the younger and older adults decreases across delays, with the largest decrease between the 300-ms and 450-ms delays. Thus, the older adults benefit more from the delays than do the younger adults.

The preceding observations were supported by a 2 (age) × 8 (SOA) mixed-factor ANOVA. The results of this analysis yielded

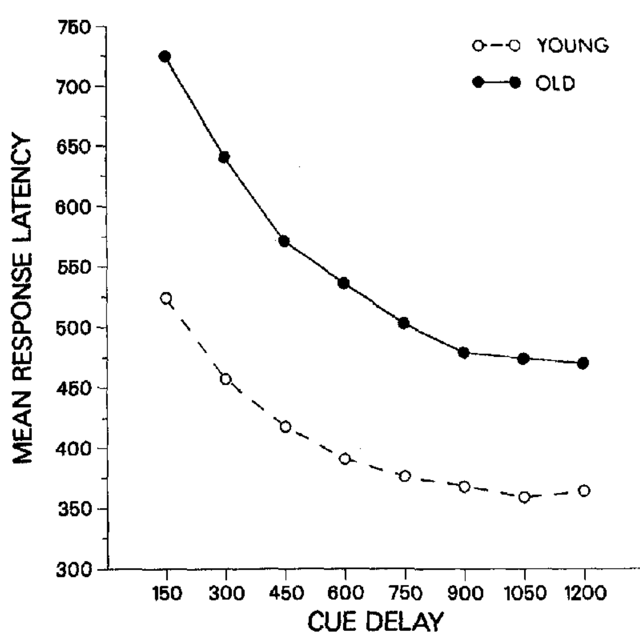

Figure 4. Mean response latency in the delayed pronunciation task as a function of age and cue delay.

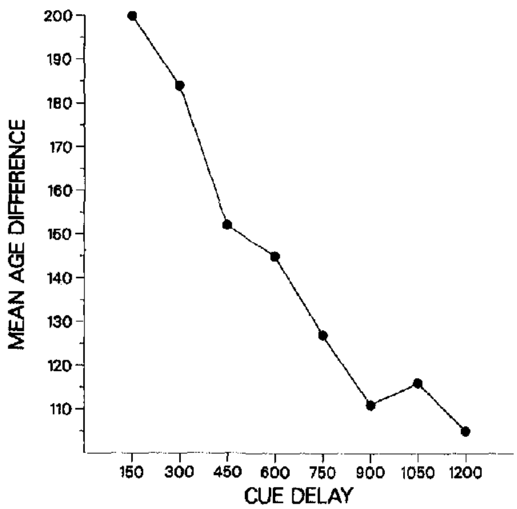

Figure 5. Mean age difference (older adults' response latency minus younger adults' response latency) in the delayed pronunciation task as a function of cue delay.

a highly significant main effect of age, $F(1, 98) = 38.60$, $MS_e = 105{,}423.3$, $p < .0001$, and SOA, $F(7, 686) = 281.27$, $MS_e = 1{,}983.5$, $p < .0001$, and a highly significant Age × SOA interaction, $F(7, 686) = 15.36$, $MS_e = 1{,}983.5$, $p < .0001$. It is also noteworthy that subsequent comparisons at each of the adjacent SOAs (e.g., 150 ms vs. 300 ms, 300 ms vs. 450 ms, and 450 ms vs. 600 ms) only yielded a significant Age × SOA interaction at the 300- ms versus 450-ms SOA comparison, $F(1, 98) = 9.67$, $MS_e = 1{,}284.5$, $p < .003$. In fact, if one compares the last four delays, the interaction between age and SOA does not reach significance, $F(3, 294) = 1.59$, $MS_e = 1{,}343$, $p > .15$. Thus, the older adults appear to especially benefit, compared with the younger adults, from a preview of a word for 300–450 ms.

Delayed Pronunciation Outlier and Error Analysis

A 2 (age) × 8 (delay) ANOVA was also conducted on the number correct for the delayed pronunciation task. This analysis only yielded a significant main effect of delay, $F(7, 686) = 10.78$, $MS_e = .74$, $p < .001$. This effect most likely occurred because at the longer delays subjects were more likely to jump the gun and pronounce the word before the parentheses were presented. Because any response shorter than 175 ms was treated as an outlier, such responses decreased the total number correct at the longer delays. However, even at the longest delay times, 90.4% of the observations were still available. More important, with respect to the present issues, the main effect of age and the interaction between age and SOA did not approach significance, both *F*s < 1.00. Finally, it is again noteworthy that the percentage of outliers and errors did not significantly differ across groups. The mean outlier rate was 5% for the older adults and 4% for the younger adults, and the mean error rate was 2% for both the older and younger adults.

Delayed Pronunciation Production Durations

The results of a 2 (age) × 8 (SOA) ANOVA on the production durations again yielded a highly significant effect of age on production durations, $F(1, 98) = 21.59$, $MS_e = 6{,}636.9$, $p < .001$, with the production durations being 382 ms for the older adults and 297 ms for the younger adults. It is interesting that there was also a significant Age × SOA interaction, $F(7, 686) = 2.45$, $MS_e = 1{,}619$, $p < .05$, which resulted from the fact that production durations increased approximately 23 ms across the delays for the younger adults, whereas for the older adults, production durations decreased 12 ms across the delays. It is noteworthy, however, that neither of these changes by themselves were significant, both *F*s < 1.65.

Discussion

In the present study, an attempt was made to trace age-related changes in the time course of processing from lexical access to semantic activation to the actual duration of the verbal response. In this light, the present results are quite clear. First, the results from the delayed pronunciation task indicated that there was an age-related difference in lexical-access processes. Second, the results from the semantic priming task indicated that there was very little evidence of age-related differences in the rate at which activation builds up at related concepts in semantic memory. Third, the results from the analyses of the production durations indicated that there was a large age-related difference in the duration from onset to offset to pronounce a visually presented word. This study is the first that we are aware of that traces performance across these three aspects of verbal processing. It is interesting that the results indicate that the older adults are slower to input and output the stimulus, but appear to be very similar to younger adults in the characteristics of activating related concepts in memory. We now discuss each of these findings.

Age-Related Changes in Lexical Access

The results from the delayed pronunciation task indicated that the older adults benefited more than the younger adults from a preview of the to-be-pronounced word. The rationale for using the delayed pronunciation task is that with no delays, the younger subjects have a distinct advantage because they are faster to recognize the stimulus and, therefore, faster to begin their pronunciation. However, if one gives both groups a delay, then the older adults can recognize the stimulus during the delay and therefore response latency will no longer reflect the word recognition stage of processing in which there is an age-related difference. At the longer delays, both groups should have had time to both recognize and prepare their response and, therefore, response latency should only reflect age-related differences in output of the response to the cue stimulus. The results supported this analysis in that there was a relatively greater drop in response latency between the 300- and 450-ms delays for the older adults, compared with the younger adults. Considering that the overall response latency for the older adults in the 0-delay semantic priming task was 659 ms, it is plausible that some lower order processing such as lexical access was occurring during the 300–450-ms delay intervals. Also, it is noteworthy that by the 750-ms delay, the difference between the two groups appeared to asymptote, as indicated by the nonsignificant Age × Delay interaction across the last four delays. Thus, at the four longer delays, both groups of subjects apparently were equally prepared to respond to the cue stimulus, and the remaining age-related difference was probably due to differences in output processes.

It should be noted that the current use of the term *lexical access* involves all of the processes that subjects appear to complete between the shorter and longer delays in the delayed pronunciation task. These probably include, among others, basic visual analyses, feature analytic processes, grapheme to phoneme conversions, and the buildup of activation at lexical representations. Thus, the delayed pronunciation task does not give a pure measure of only activation of lexical representations. However, we feel the present results are nonetheless important because they do indicate that some, if not all, of the processes leading to word recognition are slowed in the older adult population.

The argument that word recognition and output processes are slowed in older adults is inconsistent with the conclusions drawn by Cerella and Fozard (1984). In order to isolate lexical access times, Cerella and Fozard also used a delayed pronunciation task; however, in their experiment, there was only a 1,000-ms cue delay used. They used a subtractive method to estimate lexical access time. They subtracted the delayed pronunciation latencies from the normal pronunciation latencies in a semantic priming task. With this method, Cerella and Fozard argued that there were no age-related differences in either lexical access or in output. However, there are a number of points to be noted about this conclusion. First, there was only a small, nonsignificant, 33-ms main effect of age in their normal semantic priming pronunciation experiment. Obviously, one would not expect a difference in lexical access estimates if one doesn't find a difference in pronunciation performance. In the present experiment, we found a highly significant 131-ms difference between our age groups. This difference is much more similar to the approximately 130-ms main effect of age recently reported in a pronunciation task by Nebes, Boller, and Holland (1986). Also, Waugh, Thomas, and Fozard (1978) found a significant 73-ms age effect in a pronunciation task. The small, nonsignificant main effect of age in pronunciation performance can be further questioned because Cerella and Fozard used only 12 subjects per age group. Because the comparison of interest is between-subjects, we used 60 subjects per age group in the present study. In this light, the present study should be a better reflection of age-related differences in the population. Thus, we believe that there are age differences in pronunciation performance, and furthermore, because Cerella and Fozard found only a small difference between their groups in normal pronunciation, it is unlikely that they would have detected age-related differences in lexical access with their subtractive method. A second concern with Cerella and Fozard's delayed pronunciation task is that their experiment involved a repetition of the stimuli and their normal semantic priming task did not involve a repetition. The research by Scarborough, Cortese, and Scarborough (1977) indicates that repetition influences lexical access, although this concern is somewhat lessened by the observation that young and older adults appear to produce equivalent repetition priming (Moscovitch, 1982).

The conclusion that lexical access is slower in older adults is consistent with the finding that older adults often show a tendency for slightly larger priming effects than do younger adults (Bowles & Poon, 1985a, 1985b; Burke et al., 1987; Cerella & Fozard, 1984; Howard et al., 1981; Nebes et al., 1986, but see Howard, 1983, for an opposite pattern). As we noted earlier, there is a considerable amount of research indicating that if lexical access is slowed via a degradation manipulation, semantic priming effects are increased (e.g., Becker & Killion, 1977). The present finding of larger semantic strength effects for the related prime conditions in the older adults compared with the younger adults is consistent with this notion. That is, because the older adults are slower in lexical access, they benefit more than do the younger adults from a high-strength prime compared with a low-strength prime. Furthermore, the results from the delayed pronunciation task suggest that there was an age-related difference in the time needed for lexical access. Thus, the tendency for larger priming effects in older adults is probably a reflection of the increases in lexical access times. In fact, Bowles and Poon (1985b) have recently arrived at a similar conclusion. Bowles and Poon have suggested that older adults have slower word-recognition processes and that this leads to a greater compensatory reliance on context and produces the tendency for larger priming effects often found in older adults (see Stanovich & West, 1983, for a detailed description of such a compensatory model).

Semantic Spreading Activation

The results of the present study indicated that the time course of activation is very similar in young and older adults. Recently, Howard, Shaw et al. (1986) reported lexical decision results that yielded a different pattern. They found at a 150-ms prime–target SOA, a significant 34-ms priming effect for their younger adults and a nonsignificant 9-ms priming effect for their older adults. Although the interaction between prime relatedness and age did not reach significance, the age-related difference in the patterning of means is different from the present results. There are two possible reasons for this difference in patterning of data. First, it is possible that at a 150-ms SOA, age-related differences do arise, but at a 200-ms SOA these age differences are gone. Although this is possible, it seems unlikely because in the present data both groups of subjects were showing only very small priming effects in the 200-ms SOA condition, and if anything, the older adults were showing slightly larger priming effects. A more likely reason for the difference is that the Howard, Shaw et al. study involved a lexical decision task and the present study involved a pronunciation task. Possibly, some of the priming effect found in the young adults at the 150-ms SOA was due to a postaccess checking for a relation between the prime and target. If this is correct, then it is quite interesting that this checking process is sufficiently slowed in the older adults that it does not influence performance at a 150-ms SOA. In any case, as noted earlier, there is increasing evidence that the lexical decision task involves postaccess processes, and it is reasonable to assume such processes might have produced the age-related differences found at the short SOA in the Howard, Shaw et al. study. Clearly, as shown in Figure 2, there was no such difference in activation buildup in the present pronunciation study.

If we assume that the activation patterns are similar for older and younger adults, then what are we to conclude from this research regarding the mechanism (i.e., spreading activation) that presumably drives both episodic and semantic memory encoding and retrieval (see Anderson, 1976, 1983)? As noted in the introduction, older adults produce large deficits in episodic memory tasks that demand semantic processing at both encoding and retrieval. The following are some possible answers to this dilemma. First, in contrast to Anderson's arguments, activation may not be the same in episodic and semantic memory tasks. In fact, Howard, Heisey, and Shaw (1986) have recently begun to investigate episodic activation and have found some evidence of age-related differences in episodic activation. Second, the activation patterns might be the same in the older and younger adults; however, it is still plausible that attention to these activated areas may differ. Burke et al. (1987) recently attempted to directly distinguish between automatic and attentional semantic context effects in a semantic priming lexical decision task. The results of this study indicated that older adults produced very similar patterns of data compared with younger adults in both automatic and attentional priming components. Thus, preliminary research addressing attentional priming effects does not appear to indicate that the deficit is in the direction of attention by the context (also see Chiarello et al., 1985, and Howard, Shaw et al., 1986). However, because of the difficulties involved in interpreting the lexical decision task and its relation to spreading activation, and also the fact that only two time delays were used in the Burke et al. study, it might prove useful to further pursue this issue.

Age-Related Differences in Production Durations

The present results indicated that older adults were slower to pronounce the stimulus words from their onset of pronunciation to their offset compared with the younger adults. Interestingly, Huttenlocher (1984) found that younger children were slower to pronounce words from the onset of the word to its offset. This finding is of interest because it is evidence that a highly automated response is influenced by both ends of the developmental spectrum. However, if one considers that speech production, at this level, is a motor response, then this finding should not be surprising because simple motoric responses are also slowed by age (see Botwinick, 1984). The questions raised by this finding are quite important. It is important to discover how older adults compensate for this slow down in production. That is, are there fewer pauses or does the complete utterance, including the pauses, slow down? Moreover, because there is a relation between the number of items produced in a given time limit and subjects' memory span (Baddeley, Thomson, & Buchanan, 1975; Schweickert & Boruff, 1986), does this relation hold up with older adults—inasmuch as there are relatively small changes in memory span with age (see Craik, 1977)? Finally, what is the impact of this slowdown in conveying information to other older adults and to younger adults, who appear to have different production durations? The present finding of substantial age differences in production duration should serve as a springboard for this research.

Conclusions

In the present study, an attempt was made to trace age-related differences in processes involved in a very simple and naturalistic response: pronunciation of a visually presented word. The results of two tasks converge on the notion that older adults appear to be slower in both recognizing the words and outputting the verbal response, both in terms of onset latencies and production durations. However, the results also indicate that an important explanatory mechanism, spreading activation, does appear to be spared by age, at least within the bounds of our current samples. That is, activation of related concepts in memory appeared to increase at a similar rate for both our young and older adults. These results are consistent with the view that the basic semantic structure and processes that are used to retrieve information from that structure are spared by age.

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