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General Slowing in Semantic Priming and Word Recognition

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Analyses of lexical decision studies revealed that (a) older (*O*) adults' mean semantic priming effect was 1.44 times that of younger (*Y*) adults, (b) regression lines describing the relations between older and younger adults' latencies in related ($O = 1.54\,Y - 112$) and unrelated conditions ($O = 1.50\,Y - 93$) were not significantly different, and (c) that there was a proportional relation between older and younger adults' priming effects ($O = 1.48\,Y - 2$). Analyses of word-naming studies yielded similar results. Analyses of delayed pronunciation data (Balota & Duchek, 1988) revealed that word recognition was 1.47 times slower in older adults, whereas older adults' output processes were only 1.26 times slower. Overall, analyses of whole latencies and durations of component processes provide converging evidence for a general slowing factor of approximately 1.5 for lexical information processing.

During the past decade, numerous studies have focused on possible age-related deficits in semantic priming (e.g., Balota & Duchek, 1988; Bowles & Poon, 1985, 1988; Burke, White, & Diaz, 1987; Burke & Yee, 1984; Howard, 1983; Howard, McAndrews, & Lasaga, 1981; Madden, 1986, 1988, 1989). The experimental paradigm most commonly used in this research has been the lexical decision task (LDT) in which subjects decide whether target letter strings are words. Typical experiments include a related condition in which the target word and a preceding prime word are semantically related (e.g., bread–butter), and an unrelated condition in which the prime and the target are not semantically related (e.g., doctor–butter). The difference between the response latencies in these two conditions is commonly termed the *semantic priming effect.*

It is widely accepted that spreading activation is one of the primary mechanisms underlying the semantic priming effect (e.g., Anderson, 1976; Balota & Duchek, 1992; cf. Becker, 1980, 1985; Lorch, 1982; Neely, 1977, 1990; Posner & Snyder, 1975; Ratcliff & McKoon, 1988). Spreading activation within the semantic network is thought to operate as follows: Presentation of a word (the prime) causes not only activation of its own node within the network, but in addition, activation spreads momentarily to nearby nodes, where it usually only reaches subthreshold levels. If a second word is presented and its node is already partially activated (as would be the case for related targets), then it can be identified more quickly than words whose nodes are not partially activated (unrelated targets). An important issue in the area of cognitive aging is whether older adults are deficient in either the degree to which nodes are activated or the speed with which activation spreads within the semantic network, and this issue has been addressed through experimental comparisons of semantic priming in older and younger adults (e.g., Balota & Duchek, 1988; Burke et al., 1987; Howard, Shaw, & Heisey, 1986; Madden, 1989).

Age-related differences in semantic priming are also of interest from the perspective of the distinction between automatic and attentional processing. The critical variable from this perspective is the stimulus onset asynchrony (SOA), that is, the time that elapses between the onset of the prime and the onset of the target. On the basis of the results of numerous experiments, it is widely believed that priming effects at short SOAs are solely due to automatic processes, whereas at long SOAs effortful processes also contribute to priming effects (see Neely, 1990, for a recent review). Thus, manipulations of SOA have been seen as a means for testing the hypothesis of Hasher and Zacks (1979; Zacks & Hasher, 1988) regarding age-related differences in automatic versus attentional processing (Burke & Harrold, 1988; Burke et al., 1987; Howard, 1988; Howard et al., 1986). Hasher and Zacks have proposed that age-related decreases in attentional capacity cause attentional processing to be affected by aging, whereas automatic processing is spared any adverse effects. Both Burke (Burke & Harrold, 1988; Burke et al., 1987) and Howard (Howard, 1988; Howard et al., 1986) have noted that this leads to the prediction that priming effects for younger and older adults at shorter SOAs should be more nearly equivalent than at longer SOAs, where older adults should show less priming than younger adults.

What do the results of semantic priming studies using the LDT paradigm reveal? Is semantic priming impaired in older adults, and if so, is this deficit attributable to age-related differences in attentional processing or spreading activation? Contrary perhaps to expectation, the data do not reveal consistently smaller semantic priming effects for older adults as compared with younger adults, even at relatively long SOAs. In fact, priming effects are typically larger in older adults, although Age × Condition interactions are usually not significant in individual studies (e.g., Howard et al., 1981; Madden, 1988, 1989).

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Larger semantic priming effects in older adults have been observed in recent research on word naming as well as in LDT studies. Considerable evidence suggests that priming effects on LDT tasks may be influenced by decision processes that operate following lexical access (e.g., Balota & Chumbley, 1984; Balota & Lorch, 1986; Neely, 1990; Seidenberg, Waters, Sanders, & Langer, 1984; West & Stanovich, 1982). It has been argued that priming in the word-naming task is not confounded by postaccess processes because the naming task (unlike LDT) does not involve a binary decision (e.g., Balota & Duchek, 1988; Balota & Lorch, 1986), and thus naming provides a better experimental paradigm for the investigation of spreading activation (see Balota, Ferraro, & Connor, 1991, for further discussion of differences between the LDT and word naming). As in LDT studies, older adults' semantic priming effects on naming tasks are generally larger than those of younger adults, although the differences are not statistically significant (Balota & Duchek, 1988; Cerella & Fozard, 1984; Nebes, Boller, & Holland, 1986).

In contrast to the results of statistical tests in individual studies, a recent meta-analysis by Laver and Burke (1990) concluded on the basis of semantic priming data from both LDT and naming experiments that the larger size of priming effects in older adults is statistically significant when data are aggregated across studies. How might larger priming effects in older adults be interpreted? One approach is to focus on the relative rather than the absolute size of the effect. Both Howard (1988) and Burke and Harrold (1988) have noted that older and younger adults' priming effects may be equivalent when measured as percentages of latencies in unrelated or baseline conditions and have interpreted such results as evidence for age constancy in semantic priming.

The existence of equivalence in the relative magnitude of priming effects in older and younger adults is consistent with previous reports of general slowing in the lexical domain (Lima, Hale, & Myerson, 1991; Madden, 1989; Salthouse, 1985b). These reports suggest that to predict the mean latency of an older adult group on a specific lexical task with reasonable accuracy, one only needs to know two things: the mean latency of a younger adult group on the same lexical task, which serves as an index of the amount of processing required (Cerella, Poon, & Williams, 1980; Hale, Myerson, & Wagstaff, 1987; Salthouse, 1985b), and the form of the general, task-invariant relation between older and younger adults' latencies.

With respect to the form of the general relation for the lexical domain, Salthouse (1985b), Madden (1989), and Lima et al. (1991) all reported that the latencies of older adults on lexical tasks are linear functions of the latencies of younger adults with small, negative intercepts. If, for present purposes, one ignores the small intercept values, then general lexical slowing predicts that older adults' latencies should be approximately equal to younger adults' latencies in corresponding conditions multiplied by a constant general slowing factor, *S*. Thus, the relative prime effect for old adults, $(O_u - O_r)/O_u$, should be equal to $(S * Y_u - S * Y_r)/(S * Y_u)$, where *O* and *Y* refer to the latencies of older and younger adults, respectively, and the subscripts *u* and *r* distinguish the unrelated and related conditions. Canceling *S* reveals that the relative prime effect for old adults is equal to the relative prime effect for young adults.

Moreover, general lexical slowing predicts the value of the age ratio of semantic priming effects, that is, the value of $(O_u - O_r)/(Y_u - Y_r)$. Because the older adults' priming effect is approximately equal to $(S * Y_u - S * Y_r)$, the value of the age ratio will always be approximately *S*, the general slowing factor for lexical processing. It should be noted that this derivation is quite general and applies not just to semantic priming effects but also to the duration of any cognitive process isolated through componential analysis. Moreover, the same argument may be used in reverse; that is, assuming a single general slowing factor that applies to all component processes, one may derive a linear relation between older and younger adults' latencies. In this sense, the general slowing of all component processes, at least within the lexical domain, constitutes a theoretical explanation of the empirical relation between older and younger adults' latencies.

The value of the general lexical slowing factor *S* may be estimated from the results of previous meta-analyses, more specifically from the value of the slope of the relation between older and younger adults' latencies on lexical information-processing tasks. Salthouse (1985b) conducted a meta-analysis of LDT priming studies and reported a slope of 1.59, and Madden (1989) recently reported a slope value of 1.56 for his own large set of LDT data.

A similar slope estimate was obtained by Lima et al. (1991), who examined two separate data sets, one consisting of LDT data exclusively and the other consisting of latency data from a variety of other tasks in which the stimuli were words. Lima et al. found that the relation between the latencies of older and younger adults was not significantly different for the two data sets and was well described by a linear function with a slope of 1.48. However, when data from nonlexical tasks were fit with a linear function, the slope of the nonlexical line was significantly greater than that of a line fit to lexical data covering the same latency range for young adults (Lima et al., 1991). In fact, Hale and her colleagues (Hale, Lima, & Myerson, 1991; Hale et al., 1987) have proposed that, in contrast to the linear relation between lexical latencies, the relation between older and younger adults' latencies on nonlexical tasks is positively accelerated.

Within the lexical domain, the results of the Lima et al. (1991), Madden (1989), and Salthouse (1985b) meta-analyses suggest that the value of the general slowing factor, *S*, is approximately 1.5, leading to the prediction that older adults' semantic priming effects should be, on the average, approximately 1.5 times larger than those of younger adults. The hypothesis of general lexical slowing also leads to another prediction: The age ratio of prime effects should be relatively independent of SOA. That is, the general slowing hypothesis does not distinguish between automatic and attentional processing (Hale, 1990), and thus general lexical slowing predicts that the age ratio should be approximately the same for both short and long SOAs. Furthermore, the age ratios of priming effects should be of similar size in LDT and naming studies, on the basis of the assumption that both lexical access and postaccess decision making, like all other cognitive processes (at least within the lexical domain), are equally slowed. If the preceding predictions were to be supported, this would not only provide further evidence of general slowing in the lexical domain, but would also provide the first demonstration that the size of age differences at the component level can be predicted from meta-analyses at the whole latency level.

Previous meta-analyses by Salthouse (1985b) and Laver and Burke (1990) examined the relation between the semantic priming effects of older and younger adults and found that the slope of the regression line was substantially less than the value of approximately 1.5 predicted by general slowing of lexical processing. Laver and Burke reported a slope of 0.94, and Salthouse actually obtained a slope of 0.54 for priming effects calculated from the same whole latencies for which the age-related slowing factor was 1.59. These findings represent a clear inconsistency between results at the whole latency and component levels as well as between different analyses at the component level, and they constitute challenges to the general lexical slowing hypothesis that are addressed herein.

Why do the results of analyses of whole latencies appear to be more consistent than the results of analyses of semantic priming effects? One possibility is that this is because priming effects are difference scores, and difference scores are inherently much less reliable than the raw scores from which they are derived. In fact, the inherent reliability problems are such that Cronbach and Furby (1970) recommended that difference scores simply not be used. Similarly, Salthouse (1985b), although acknowledging the appeal of difference scores as measures of the speed of mental processes, warned against their use: "Unfortunately, the low reliability of difference scores reduces the usefulness of this measure despite its theoretical interest" (p. 239).

Although studies of semantic priming commonly use within-subject designs, thereby reducing the effects of sampling error, these designs by no means eliminate the reliability problem associated with difference scores. This is because the fundamental source of the difficulty is propagation of error (Barford, 1985; Young, 1962). We show that for the typical older subject, the standard error of the difference between the latencies in the unrelated and related conditions of LDT tasks is approximately the same size as the semantic priming effect! Moreover, in contrast to the 100% error in the semantic priming effect, there is less than a 10% error in the unrelated and related latencies, as measured by the standard error of the mean.

Thus, the relative uncertainty in the estimate of the size of the semantic priming effect is an order of magnitude greater than the uncertainty in the estimates of the latencies from which the priming effect was calculated. This low reliability could be responsible for the observed failures to reject the null hypothesis of no difference between the semantic priming effects of a younger and an older adult group in single studies as well as for problems determining the relation between older and younger adults' priming effects when an additional source of error is introduced, that is, the need to estimate this relation on the basis of data from multiple pairs of groups from different studies. The present article explores the application of a variety of analytic techniques in an attempt to overcome the reliability problems that may have interfered with previous efforts to integrate the results of studies of age differences in semantic priming.

Finally, the hypothesized general slowing of lexical processing predicts an age difference in the time course of semantic priming and other lexical processes. More specifically, a general slowing factor of approximately 1.5 should be observed when age-related differences are inferred from the rate of change in response latencies measured at multiple SOAs. However, semantic priming may be a difficult process to examine using this approach because the spread of activation may be so rapid that, even when the spreading slows with age, no differences are discernible. Ratcliff and McKoon (1981) and Wickelgren (1976) have suggested that the spread of activation in automatic priming may take only a few milliseconds in young adults, in which case the age-related difference in spreading activation rate predicted by general slowing would probably not be detectable with current methods. In contrast, the entire word recognition process, from feature identification to lexical access, takes several hundreds of milliseconds and therefore may provide a better opportunity to compare the time course of lexical information processing in older and younger adults. Accordingly, data from a delayed-pronunciation experiment by Balota and Duchek (1988) are analyzed to examine possible age-differences in the time course of word recognition from the perspective of general slowing in the lexical domain.

Analyses of Lexical Decision Data

To test the predictions of the hypothesis of general lexical slowing with respect to semantic priming, we conducted meta-analyses of studies that examined the performances of older and younger adults on lexical decision or word-naming tasks and were published in journal articles between 1980 and 1990. The LDT data set consisted of latency data from pairs of unrelated and related conditions (i.e., experimental tasks that involved semantic priming) for younger adult groups (range of mean ages 19–28 years) and older adult groups (range of mean ages 67–72 years). Condition pairs (i.e., the related condition and the corresponding unrelated condition) in which younger adults' latencies in the related condition exceeded their latencies in the unrelated condition, that is, in which younger adults did not show semantic priming or in which the accuracy of performance for younger or older adults in either condition was less than 80%, were excluded from the analysis.

Applying these criteria resulted in an LDT data set that included 11 studies and a total of 22 condition pairs. Latencies, error rates, ages of subjects, number of subjects per group, number of trials per condition, semantic priming effects, and age ratios of priming effects are all given in Table 1. For the Burke et al. (1987) study, the related data and unrelated data are from the expected–same condition (e.g., TREE–ELM) and unexpected–different condition (e.g., TREE–FOG), respectively. Data from the unexpected–same condition (e.g., VEGETABLE–SPINACH) and expected–different condition (e.g., VEGETABLE–DOG), in which subjects were led to consciously expect an animal name following the word VEGETABLE, were excluded from the analysis, because in these conditions the expectancy manipulation was at odds with the relatedness manipulation. One condition pair from Burke and Yee (1984) was excluded because the younger adults' latency for the related condition exceeded that for the unrelated condition. Highly inaccurate performance by both older and younger adults resulted in excluding one study entirely (Chiarello, Church, & Hoyer, 1985).

Only two of the included studies reported significant age

Table 1
Summary of Semantic Priming Results From Studies Included in Lexical Decision Data Set

					Mean latencies (in ms)				Error rates (%)				Priming effect		
					Unrelated		Related		Unrelated		Related		Size		
Authors	Data source	SOA	*N*	Trials	Y	O	Y	O	Y	O	Y	O	Y	O	Ratio (O/Y)
Bowles & Poon (1985)	Table 1	850	24	20	924	977	843	884	5.0	5.0	3.0	4.0	81	93	1.15
Bowles & Poon (1988)	Table 1: XXX condition	850	18	18	732	905	655	770	3.0	8.0	3.0	3.0	77	135	1.75
	Table 1: THE condition	850	18	18	704	963	673	735	3.0	5.0	1.0	0.0	31	228	7.35
Burke, White, & Diaz (1987)[a]	Table 4	410	32	5/20	726	916	615	741	16.9	9.4	1.7	1.1	111	175	1.58
	Table 4	1,550	32	5/20	760	977	630	784	5.6	3.1	2.2	1.6	130	193	1.48
Burke & Yee (1984)[b]	Table 3: Associated word	—	20	5	946	1,361	907	1,365	1.0	0.0	0.0	0.0	39	−4	−0.10
	Table 3: Instrument	—	20	5	981	1,487	930	1,381	3.0	1.0	2.0	1.0	51	106	2.08
Howard (1983)[c]	Table 3: High dominance	0	20	9	998	1,436	804	1,349	2.8	3.3	1.1	1.7	194	87	0.45
	Table 3: Low dominance	0	20	9	978	1,540	865	1,435	2.8	2.2	1.1	1.1	113	105	0.93
Howard, McAndrews, & Lasaga (1981)	Table 3: Category	0	12	14	1,070	1,446	1,007	1,280	2.0	3.8	0.9	2.3	63	166	2.63
	Table 3: Descriptive	0	12	14	987	1,562	912	1,446	2.0	3.8	0.9	2.3	75	116	1.55
Howard, Shaw, & Heisey (1986)	Table 3	150	18	14	558	733	524	724	9.1	4.0	6.7	2.4	34	9	0.27
	Table 3	450	18	14	541	713	494	668	6.3	7.5	4.0	3.2	47	45	0.96
	Table 3	1,000	18	14	512	794	478	737	5.2	5.1	5.5	3.2	34	57	1.68
Madden (1986)	Table 2: Easy words	500	24	12	591	819	531	729	0.7	0.3	0.0	0.3	60	90	1.50
	Table 2: Difficult words	500	24	12	726	994	636	864	3.1	2.4	1.4	1.0	90	130	1.44
Madden (1988)	Table 1: Intact word targets	500	24	12	595	802	532	718	0.7	2.4	0.3	0.3	63	84	1.33
	Table 1: Degraded word targets	500	24	12	760	1,113	657	955	6.9	7.6	1.7	4.5	103	158	1.53
Madden (1989)	Table 1	—	18	24	574	836	525	732	2.8	2.5	1.4	0.5	49	104	2.12
	Table 1	—	18	24	557	783	496	690	3.0	3.0	0.9	2.3	61	93	1.52
	Table 3	—	24	24	554	752	499	688	1.7	2.8	1.0	1.4	55	64	1.16
Nebes, Brady, & Huff (1989)	Table 1	750[d]	16	15	593	727	553	662	1.0	0.0	1.0	1.0	40	65	1.63

Note. *N* = number of subjects per age group in each condition; Trials = number of trials in each condition. Dashes indicate that SOA cannot be determined for these studies. SOA = stimulus onset asynchrony; Y = young; O = old.
[a] Data are based on 5 trials from the unexpected-different (unrelated) condition and 20 trials from the expected-same (related) condition. [b] One condition from this study was omitted because the young adults' related latency exceeded their unrelated latency. [c] Older adults' data are taken from Experiment 1; younger adults' data are taken from Experiment 2. [d] SOA reported for this study is an approximate value.

differences in accuracy. In one case (Howard et al., 1986), older adults were more accurate, whereas in the other case (Bowles & Poon, 1988), older adults were less accurate. Neither study reported evidence of age differences in speed–accuracy tradeoffs.

In addition to examining the semantic priming effect (i.e., the difference between latencies in unrelated and related conditions), some cognitive aging experiments have also measured latencies obtained from a "neutral" condition. Response latencies to neutral stimuli (e.g., a string of Xs) have been used as a baseline condition to measure both facilitation (the reduction in latency calculated by subtracting the related condition from the neutral condition) and inhibition (the increase in latency calculated by subtracting the neutral condition from the unrelated condition). However, because the neutral condition has proven to be somewhat problematic (de Groot, Thomassen, & Hudson, 1982; Jonides & Mack, 1984), the present article focuses exclusively on the semantic priming effect and does not attempt to distinguish between facilitation and inhibition.

As may be seen in Table 1, older adults' semantic priming effects were larger than those of younger adults in 17 of the 22 cases of the lexical decision data set, even though significant Age × Condition interactions were observed in only two experiments (Bowles & Poon, 1988; Madden, 1989, Experiment 1). Frequency histograms of semantic priming effects for younger and older adults are shown in the top and middle panels of Figure 1, and the bottom panel shows a frequency histogram of priming effect age ratios obtained in individual experiments.

For purposes of estimating a general slowing factor, the semantic priming effect data were aggregated in two ways: First, the mean priming effects for older adults and the mean effects for younger adults were determined, and the ratio of these mean values was then calculated. Second, the ratio of the older adults' priming effects to younger adults' priming effects was determined for each of the 22 cases, and the mean and median of the ratios were then determined. With both methods of calculating means, cases may be weighted according to the sample size (N). In the present analyses, case weights were based on the square root of $N - 1$, reflecting confidence intervals.[1]

Each of the two methods of aggregating data described earlier has its advantages and disadvantages. For instance, as pointed out by Laver and Burke (1990), taking the mean of the ratios is conceptually similar to a repeated measures approach and minimizes the contribution of differences between experimental procedures and samples to the estimate of the age ratio. However, this method suffers from the fact that it tends to lead to positively skewed distributions of ratio values and biased estimates of the mean. Although this problem can sometimes be alleviated by using the logarithmic transformation, this solution has its own limitations and fails completely when ratios are negative. Alternatively, the median of the ratios may be appropriate because of the assymetry of the distributions of ratios. For purposes of comparison, the ratio of the mean semantic priming effects in older and younger adults as well as the mean ratio and the median of the ratios were determined. The weighted mean semantic priming effect for older adults was 107.0 ms, 1.44 times the 74.5 ms value for younger adults. The weighted mean of the ratios of older adults' priming effects to younger adults' priming effects (1.62) was higher than the ratio of the means, but it should be noted that the median age ratio of semantic priming effects was 1.51.

The preceding findings regarding the ratio of older and younger adults' semantic priming effects are in good agreement with estimates of approximately 1.5 for the value of a general lexical slowing factor on the basis of the slope of the line describing the relation between the latencies of older and younger adults (see Figure 2). The weighted regression line describing the data from related-prime conditions ($O = 1.54\,Y - 112$, values are in milliseconds) was nearly identical to the line describing the data from unrelated-prime conditions ($O = 1.50\,Y - 93$). In neither instance was the intercept value significantly different from zero (both $ts < 1.0$). Inspection of residual plots and Cook's distance values did not reveal the presence of any influential outliers.

Multiple regression, with prime condition as an indicator (or dummy) variable, was used to test for possible differences in the regression coefficients. That is, the multiple regression equation $O = b_0 + prime * b_1 + b_2 * Y + prime * b_3 * Y$, where *prime* is an indicator variable that has the value 0 for data from unrelated-prime conditions and 1 for data from related-prime conditions, was fit to the whole lexical decision data set. Note that the intercept and slope for unrelated conditions, that is, $prime = 0$, are b_0 and b_2, and the intercept and slope for related conditions, that is, $prime = 1$, are $b_0 + b_1$ and $b_2 + b_3$. Thus, the values of b_1 and b_3 are estimates of the differences between the corresponding regression coefficients for the two conditions that, when divided by their estimated asymptotic standard deviations, yield values of t that may be used to test the significance of these differences (Neter, Wasserman, & Kutner, 1983, pp. 328–345).

There were no significant differences between the intercepts or slopes of the weighted regression lines for the unrelated and related conditions ($ts < 1.0$), and a single linear function ($O = 1.52\,Y - 99$) accounted for 84.6% of the variance in older adults' latencies. Thus, the general lexical slowing factor estimated using both linear regression and the ratio of weighted mean semantic priming effects as well as the median age ratio of the priming effects was approximately 1.5, as predicted. The hypothesis of general lexical slowing predicts further that, when older adults' priming effects are regressed on those of younger adults, the slope of the regression line is approximately 1.5. Contrary to this prediction, the slope of the weighted regression line was less than 1.0 ($O = 0.53\,Y + 68$), and the correlation between the priming effects of older and younger adults was not significant ($r = .364$).

However, inspection of a residual plot revealed two outliers,

[1] Weighting based on the number of trials was also considered. However, this technique is problematic for semantic priming effects when the number of related and unrelated trials are not equal, for example, Burke, White and Diaz (1987), and combining sample size and number of trials involves making a possibly unjustified assumption about the relative contributions of between-subjects and within-subject variability. Nonetheless, analyses using weights on the basis of the square root of the product of sample size and number of trials (using the average of the number of unrelated and related trials where necessary) were conducted and in all cases yielded similar results to those reported here that used weights on the basis of sample size alone.

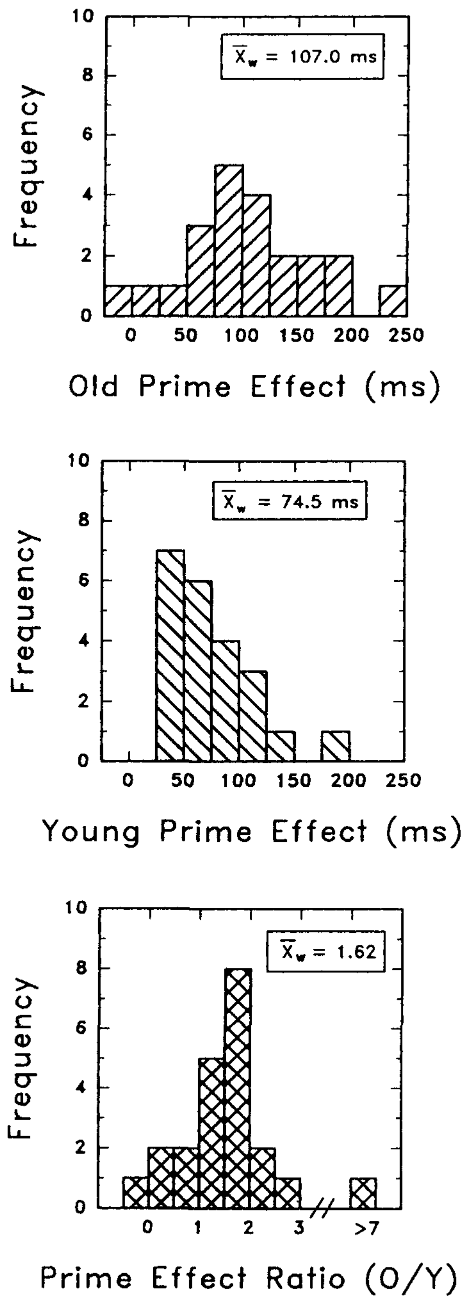

Figure 1. Frequency distributions of older adults' (upper panel) and younger adults' (middle panel) semantic priming effects and the age ratio of priming effects (lower panel). (Data are taken from the lexical decision studies listed in Table 1. O = older; Y = younger; $\bar{X}_w$ = weighted mean.)

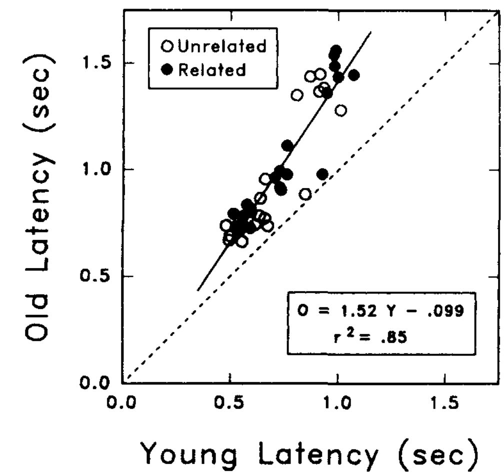

Figure 2. Older adults' latencies as a function of younger adults' latencies. (The solid line represents the weighted regression line. If older and younger adults' latencies in corresponding conditions were equal, the data points would fall along the dotted line. Data are taken from the lexical decision studies listed in Table 1. O = older; Y = younger.)

with Cook's distance values indicating the possibility of substantial influence on the relation between the priming effects of older and younger adults (Neter et al., 1983, pp. 407–409), and therefore further analyses were conducted. These analyses revealed that one outlier, with a standardized residual value of −2.08, reduced the correlation coefficient by .199 (i.e., $r = .563$ with the outlier deleted), and that the second outlier, with a standardized residual value of 2.67, reduced the correlation coefficient by .181 (i.e., $r = .545$ with the outlier deleted). Moreover, the combined influence of both outliers on the correlation coefficient was even greater than the sum of the two influences considered separately ($r = .807$ with both outliers deleted). Figure 3 shows all of the data (the two outliers are shown as filled circles) and the best fitting linear function fit to the data set with the outliers deleted. This equation ($O = 1.48\,Y - 2$, accounting for 65.1% of the variance) was consistent with the prediction of a general lexical slowing factor of approximately 1.5.

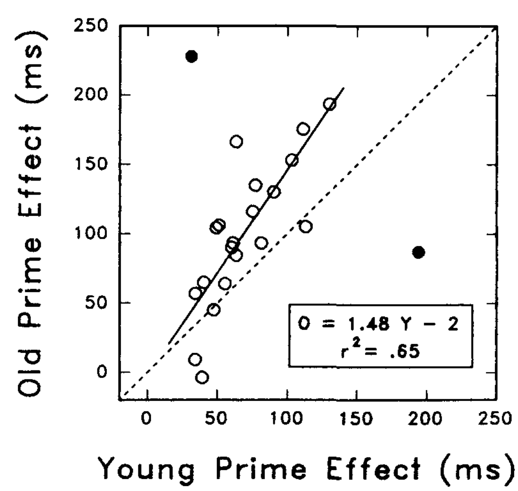

Figure 3. Older adults' semantic priming effect as a function of younger adults' semantic priming effect. (The solid line represents the weighted regression line calculated without the influence of the two outliers [represented as solid points]. If older and younger adults' priming effects in corresponding conditions were equal, the data points would fall along the dotted line. Data are taken from the lexical decision studies listed in Table 1. O = older; Y = younger.)

An additional analysis examined the effect of SOA on the age ratio of semantic priming effects (older adults' priming effect divided by younger adults' priming effect). The age ratio did not vary in a systematic manner as a function of SOA, as may be seen in Figure 4 and as indicated by the lack of a significant correlation between age ratio of priming effects and SOA (r = .227) as well as by the lack of any significant curvilinear trend as indicated by the coefficient for the quadratic component (t < 1.0). Deletion of the one obvious outlier did not produce an increase in the correlation coefficient.

Analyses of Word-Naming and Delayed Pronunciation Data

Although only four studies that examined semantic priming in older and younger adults using word-naming tasks were published in journal articles between 1980 and 1990, any differences between results obtained using naming and LDT would be of potential theoretical significance. Therefore, the available naming data were used to estimate the ratio of older adults' (range of mean ages 67–73 years) semantic priming effects to those of younger adults (range of mean ages 23–25 years). For three of these studies, the semantic priming effect was calculated as the difference between related and unrelated conditions, as with the LDT studies analyzed previously. For the fourth study (Balota & Duchek, 1988), there was no unrelated condition in the usual sense of having a different word prime that was semantically unrelated to the target presented on each trial. Instead, there was a neutral condition in which the same prime word (*blank*) was presented on half of the trials, and the difference between the latency on such trials and the latency on related trials constituted the semantic priming effect. As with the LDT data set, condition pairs in which the priming effect was not obtained in the young adult group were not included in our analysis. This criterion resulted in the exclusion of two conditions from one study (Balota & Duchek, 1988). Included in the naming data set were a total of 12 condition pairs from four studies (see Table 2).

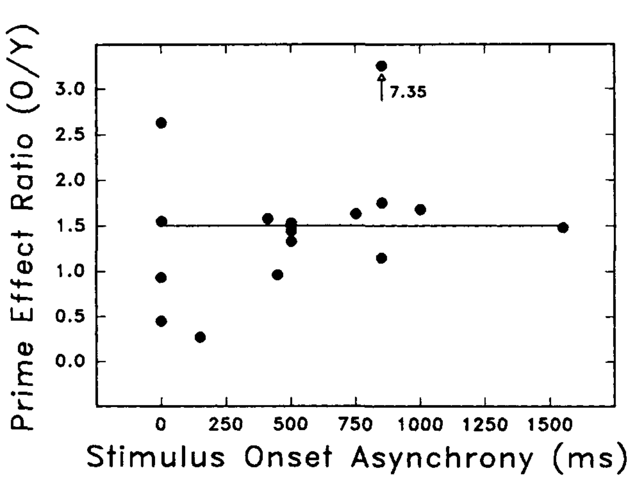

Figure 4. The age ratio of semantic priming effects as a function of stimulus onset asynchony. (The solid line represents the value of 1.5 for the prime effect age ratio predicted by general lexical slowing. Data are taken from the lexical decision studies listed in Table 1. O = older; Y = younger.)

Semantic priming data were aggregated as in preceding analyses: First, the mean priming effects for older and younger adults were determined separately, and the ratio of these mean values was then calculated. Second, the ratio of older adults' priming effects to younger adults' priming effects was calculated for each of the 12 cases given in Table 2, and the mean and median ratio were then determined. Each of these methods was used with weighting on the basis of sample size.

The ratio of the weighted mean priming effects (older adults/younger adults) calculated from the naming data was 1.41. As with the LDT data, the weighted mean of the age ratios (1.66) was larger, but the value for the median age ratio (1.38) was close to that for the ratio of the means. As may be seen in Figure 5, there was a clear relation between the size of older adults' priming effects and those of younger adults in the same conditions (r = .939). Moreover, the slope of the weighted regression equation ($O = 1.44\ Y$, accounting for 88.2% of the variance) was in good agreement with the prediction of a general lexical slowing factor of approximately 1.5.

The naming data set contained no extreme outliers such as were seen in the LDT data set. This may be due to the large role played by one exemplary study of word naming (Balota & Duchek, 1988) that used 60 subjects in each age group, more than any other LDT or naming experiment (median and modal value of N = 24), and provided data from eight conditions that met the present criteria for semantic priming. When these data were analyzed separately, the relation between older and younger adults' semantic priming effects was well described by the equation $O = 1.44\ Y$ (81.4% of the variance accounted for). The slope of this line agreed closely with both the slope of the line describing the relation between the whole latencies of older and younger adults in this experiment, $O = 1.48\ Y - 121$ (91.6% of the variance accounted for), and the prediction of a general lexical slowing factor of approximately 1.5.

With regard to the time course of semantic priming, no age-related differences were discernible in the relations between semantic priming effect and SOA reported by Balota and Duchek (1988). The data were reasonably clear in this regard, and no reanalysis was performed. Importantly, the same subjects who performed the semantic priming task were also tested on a delayed-pronunciation task. The data from this latter task provided an opportunity to analyze the time course of the word recognition process in the absence of semantic priming and may illuminate the question of possible age differences in the time course of lexical information processing.

Figure 6 shows the latency to pronounce a word as a function of the delay between the presentation of that word on a video monitor and the subsequent presentation of a cue to begin pronunciation. These word-naming data are well described by exponential decay functions of the following form: $y = a + b * \exp(-c * t)$, where y is the latency of pronunciation timed from the presentation of the cue, a is the asymptotic latency, b is the difference between the y-intercept and the asymptotic latency, c is the decay rate, and t is the time between presentation of the word and presentation of the cue. Exponential decay functions fit to the data from the two age groups separately accounted for

Table 2
Summary of Semantic Priming Results From Studies Included in Word-Naming Data Set

					Mean latencies (in ms)				Priming effect		
					Unrelated		Related		Size		
Authors	Data source	SOA	*N*	Trials	Y	O	Y	O	Y	O	Ratio (O/Y)
Balota & Duchek (1988)[a]	Figure 1: High strength	200	60	8	539	679	537	674	2	5	2.50
	Figure 1: High strength	350	60	8	535	666	520	643	15	23	1.53
	Figure 1: High strength	500	60	8	526	661	514	641	12	20	1.67
	Figure 1: High strength	650	60	8	523	653	506	628	17	25	1.47
	Figure 1: High strength	800	60	8	523	645	509	627	14	18	1.29
	Figure 1: Low strength	500	60	8	533	665	531	656	2	9	4.50
	Figure 1: Low strength	650	60	8	529	658	524	659	5	−1	−0.20
	Figure 1: Low strength	800	60	8	529	656	525	651	4	5	1.25
Cerella & Fozard (1984)	Table 1: Intact	1,000	12	20	548	582	520	555	28	27	0.96
	Table 1: Degraded	1,000	12	20	626	664	582	608	44	56	1.27
Nebes, Boller, & Holland (1986)	Table 2	—	18	25	533	714	492	639	41	75	1.83
Nebes, Brady, & Huff (1989)	Table 1	—	16	15	506	574	484	552	22	22	1.00

Note. *N* = number of subjects per age group in each condition; Trials = number of trials in each condition. Dashes indicate that SOA was not reported for these studies. SOA = stimulus onset asynchrony; Y = young; O = old.
[a] The condition labeled *unrelated* here used the same neutral prime word (*blank*) on each trial. Also, two conditions from this study were omitted because in each case the young adults' related latency exceeded their unrelated latency.

99.9% of the variance in the pronunciation latencies of older and younger adults.

The data from older and younger adults were also fit using nonlinear multiple regression with age as an indicator variable, so that comparisons of estimated parameter values could be performed (Neter et al., 1983, pp. 328-345). That is, the multiple regression equation $y = a_0 + age * a_1 + (b_0 + age * b_1) \exp[-(c_0 + age * c_1) * t]$, where *age* is an indicator variable that has the value 0 for data from the younger adults and 1 for data from the older adults, was fit to the whole delayed-pronunciation data set. Note that the estimated parameters for younger adults, that is, $age = 0$, are a_0, b_0, and c_0, and the estimated parameters for older adults, that is, $age = 1$, are $a_0 + a_1$, $b_0 + b_1$,

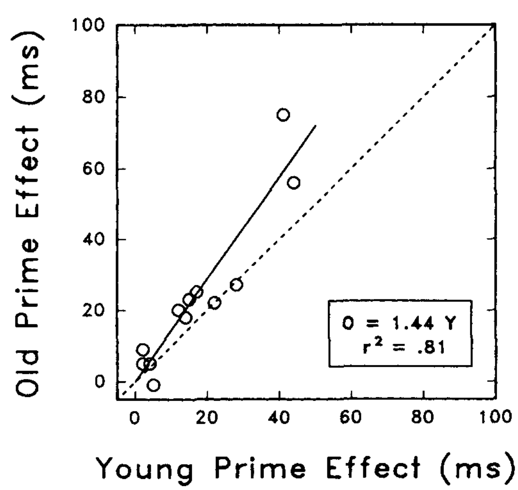

Figure 5. Older adults' semantic priming effect as a function of younger adults' semantic priming effect. (The solid line represents the weighted regression line. If older and younger adults' priming effects in corresponding conditions were equal, the data points would fall along the dotted line. Data are taken from the word-naming studies listed in Table 2. O = older; Y = younger.)

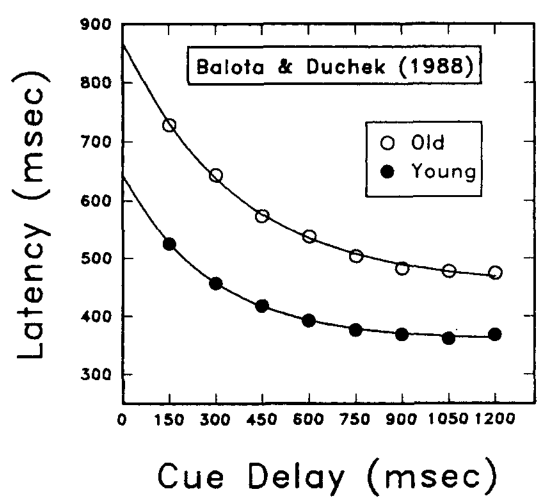

Figure 6. Delayed-pronunciation latencies from older and younger adults as a function of cue delay. (Solid curves represent the best fitting exponential decay functions [parameters and fit statistics given in Table 3]. From "Age-Related Differences in Lexical Access, Spreading Activation, and Simple Pronunciation" by D. A. Balota and J. M. Duchek, 1988, *Psychology and Aging, 3,* p. 89. Copyright 1988 by the American Psychological Association. Adapted by permission.)

and $c_0 + c_1$. Thus, the values of a_1, b_1, and c_1 are estimates of the differences between the parameter values for older and younger adults. All three of these differences proved to be significant (see Table 3).

The logic of Balota and Duchek (1988) provides the basis for the following interpretation of the nonlinear regression parameters. The asymptotic latency represents the time required to begin pronouncing a word that one is fully prepared to pronounce, hence *a* is equal to the mean duration of output processes. The difference between the *y*-intercept (i.e., the estimated time required to pronounce a word when no preparation time is given) and the asymptotic latency (i.e., the duration of output processes) represents the time required to process information before the beginning of output processes, hence *b* is equal to the mean cumulative duration of all processes involved in word recognition, from the most basic visual analyses up until threshold activation of lexical representations. Finally, the decay parameter, *c*, measures the rate at which word recognition proceeds, that is, the conditional probability that the word recognition process will be completed in the next millisecond, given that it has not already been completed. Thus, the present results indicate that older adults are significantly slower in word recognition and output processes, and provide measures of how much slower these processes are in older adults.

The hypothesis of general lexical slowing predicts that all of the cognitive processes that involve processing lexical information are equally slowed in older adults. This hypothesis may be tested using the method of nonlinear multiple regression to determine whether the parameter values for older adults are significantly different from those predicted by a general lexical slowing factor of approximately 1.5. (Because *c* represents a rate rather than a duration, the prediction is that the value for older adults will be approximately two thirds of the value for younger adults, rather than approximately 1.5 times the younger adult value as is the case for the other two parameters.) The nonlinear multiple regression equation $y = a_0 + age * 0.5a_0 + age * a_1 + (b_0 + age * 5b_0 + age * b_1)\exp[-(c_0 - age * .33c_0 + age * c_1) * t]$ was fit to the whole delayed-pronunciation data set. Note that the estimated parameters for younger adults, that is, $age = 0$, are a_0, b_0, and c_0, and the estimated parameters for older adults, that is, $age = 1$, are $1.5a_0 + a_1$, $1.5b_0 + b_1$, and $.67c_0 + c_1$. Thus, the values of a_1, b_1, and c_1 are estimates of the differences between observed and predicted parameter values.

The estimated values of *b* and *c* (which represent the time required for word recognition and the rate at which word recognition proceeds) were consistent with general lexical slowing (see Table 3). That is, the value of *b* for older adults was increased by a factor of 1.47 over the value for younger adults, as compared with the predicted general slowing factor of approximately 1.5, and the value of *c* for older adults was decreased by a factor of 0.76 relative to the value for younger adults, which was not significantly different from the factor of approximately 0.67 predicted by general lexical slowing. In contrast, the estimated values of *a* (which represent the duration of output processes in pronunciation) imply that these output processes were slowed by a factor of 1.26 in older adults compared with younger adults, which is significantly less than 1.5.

Discussion

The cognitive aging literature contains a number of studies that have examined the semantic priming effect within the framework of lexical decision and word-naming tasks. Most of these studies have failed to find significant Age × Condition interactions and have been interpreted as showing equivalent semantic priming effects in older and younger adults (e.g., Burke et al., 1987; Cerella & Fozard, 1984; Howard, 1988). However, a recent meta-analysis by Laver and Burke (1990) reported that, when data are aggregated across studies, the semantic priming effects of older adults are significantly larger than those of younger adults. Given this age difference in priming effects, a major goal of the present study was to determine, more specifically, whether the priming effects of older adults are approximately 1.5 times larger than those of younger adults as predicted on the basis of general slowing of lexical information processing (e.g., Lima et al., 1991; Madden, 1989; Salthouse, 1985b). In addition, further evidence for a general slowing factor of approximately 1.5 was sought in various other measures of lexical information processing.

The results of a number of the present analyses strongly support the predictions of the general lexical slowing hypothesis. The meta-analysis of a large LDT data set revealed an age ratio of 1.44 (estimated by taking the ratio of the weighted mean priming effects for older and younger adults), and a second meta-analysis of data from naming tasks revealed a similar age ratio of 1.41. These findings support the general lexical slowing hypothesis in two ways: First, the observed values for both tasks are close to the predicted value of approximately 1.5. Second, postaccess processes may contribute to semantic priming effects on both tasks, but these processes are different for naming and lexical decisions (Balota et al., 1991; Neely, 1990); therefore, the present finding of similar age ratios for the two tasks, de-

Table 3
Fit Statistics for Figure 6 and Results of Comparisons of Parameter Estimates

Function	Parameter	Estimates: Young	Estimates: Old	Young vs. old (t)	Old/young: Predicted	Old/young: Observed	Predicted vs. observed (t)
	a	358	451	13.53**	1.50	1.26	10.56**
$y = a + b * e^{-c*t}$	b	285	418	8.04**	1.50	1.47	0.38
	c	.00354	.00269	2.56*	0.67	0.76	1.31

* $p < .05$. ** $p < .001$.

spite differences in postaccess processes, provides further evidence of the general nature of cognitive slowing.

In addition, multiple regression analyses of the present LDT data set strengthen the fundamental empirical claim underlying the hypothesis of general lexical slowing. Within the lexical domain, older adults' mean latencies may be predicted with reasonable accuracy from younger adults' mean latencies in the corresponding conditions without taking into account the nature of the task or experimental condition. The latencies of older adults can be predicted because the relation between older and younger adults' latencies is very well described by a linear function (Lima et al., 1991; Madden, 1989; Salthouse, 1985b). However, it still could be the case that even more accurate predictions might be made if condition (e.g., unrelated and related) were taken into account.

This possibility, which had not been tested in previous meta-analyses of semantic priming (Laver & Burke, 1990; Lima et al., 1991; Madden, 1989; Salthouse, 1985b), was not supported by the present results. If older adults' semantic priming effects were equal to or smaller than those of younger adults, as has been sometimes suggested, then the regression line describing data from related conditions should lie above the line describing data from unrelated conditions. The present analysis demonstrated that the weighted regression lines describing LDT data from the two conditions were not significantly different, with slopes of approximately 1.5 in both cases.

With regard to word recognition, the present results suggest that the same general slowing factor of approximately 1.5 applies to the cumulative duration of all of the processes involved, from basic visual analyses to activation of lexical representations. The ratio of the word recognition component durations of older and younger adults' delayed pronunciation latencies, reported by Balota and Duchek (1988), was estimated at 1.47 using nonlinear curve-fitting techniques. In addition, the nonlinear multiple regression analysis revealed an age-related slowing of the rate of completion of the word recognition process that did not differ significantly from the value of approximately 0.67 (i.e., 1/1.5) predicted by general slowing. Thus, both duration and rate measures provide independent, converging evidence for general slowing of word recognition.

The findings of the present study, as summarized to this point, provide strong support for the general lexical slowing hypothesis. It should be noted that this support is based on the results of analyses at both the whole latency and component levels. Moreover, these analyses were based on data from different tasks and used a variety of analytical approaches. Linear regression analyses of the relation between the whole LDT latencies of older and younger adults, nonlinear curve fitting of the time course of the word recognition process in delayed pronunciation, and aggregate analyses of semantic priming effects in both LDT and word naming all converge on a single value of approximately 1.5 for an age-related cognitive slowing factor in the lexical domain.

Interestingly, the Balota and Duchek (1988) data reveal that output processes in word naming, although slower in older adults, are significantly less slowed than word recognition processes. The duration of older adults' output processes (before the beginning of pronunciation) was estimated to be 1.26 times that for younger adults, close to the 1.29 value reported by Balota and Duchek for the age ratio of pronunciation durations. These results suggest the existence of a second slowing factor governing both premotor and motor output processes, consistent with Cerella's (1985) multilayered slowing model.

In addition to the evidence for differential slowing of output processes, recent research suggests that lexical and nonlexical information processing may be differentially affected by aging. Both the degree of slowing and the form of the relation (linear vs. nonlinear) between older and younger adults' latencies are reported to be different for the two domains, with lexical processing being less age sensitive than nonlexical processing (Hale et al., 1991; Lima et al., 1991). Although age-related cognitive slowing may be domain specific, within a domain the term *general slowing* would seem to capture the fact that the degree of slowing does not appear to depend on the nature of the task or the specific cognitive processing components involved.

Nor does the degree of slowing as revealed by age differences in semantic priming effects appear to depend on the SOA used, at least within the range explored in the present investigation. A meta-analysis was conducted of all studies from the LDT data set, and no significant correlation was observed when the age ratio of priming effects was examined as a function of SOA. Thus, the present findings are consistent with those of Burke et al. (1987) and Howard et al. (1986) in failing to find support for Hasher and Zacks's (1979) hypothesis that aging affects only attentional, and not automatic, processes, at least as reflected in priming at long and short SOAs, respectively.

Although aggregate analysis of the effect of SOA on the age ratio of LDT priming effects revealed no systematic variation, considerable unsystematic variation was apparent. The results of previous LDT studies that manipulated SOA have been inconsistent: The data of Burke et al. (1987) show little change in the age ratio with SOA, the Howard et al. (1986) data show an increase in the age ratio at longer SOAs, and the Madden (1989, Experiment 1) data show a decrease. It is possible that some orderly relation exists but that this relation is obscured by the effects of procedural differences, sampling errors, or problems with measurement reliability.

Some combination of these three factors may also be responsible for the fact that the results of previous regression analyses of older and younger adults' priming effects have also been inconsistent, both with each other and with regression analyses of whole latencies from semantic priming studies. From the standpoint of general slowing, the results of previous meta-analyses of semantic priming were somewhat paradoxical; that is, regression analyses of whole latencies from semantic priming studies implied age-related slowing of all cognitive processes involved in these lexical tasks (Lima et al., 1991; Madden, 1989; Salthouse, 1985b), but regression analyses of priming effects did not substantiate this conclusion (Laver & Burke, 1990; Salthouse, 1985b).

In the present investigation, analysis of naming data did reveal a proportional relation between older and younger adults' priming effects consistent with general lexical slowing, and a similar relation was observed for the LDT data after two influential outliers were removed from the data set. Both outliers come from studies in which the primes were category names and the targets were category members varying in dominance

(Bowles & Poon, 1988; Howard, 1983), yet one study produced the largest age ratio of priming effects, and the other produced one of the smallest. The Balota and Duchek (1988) naming study also used category names as primes and exemplars varying in dominance as targets. Balota and Duchek (1988) used enough conditions so that it was possible to conduct regression analyses of both whole latencies and semantic priming effects on the basis of the data from this study alone, and the results of these analyses were both consistent with a general lexical slowing factor of approximately 1.5.

Thus, the present effort suggests that results at the component level are fundamentally consistent with those at the whole latency level and that both support general lexical slowing. Apparent inconsistencies appear to be attributable to the lower reliability of semantic priming effects relative to whole latencies. This difference in reliability may be due to the fact that priming effects are difference scores, and difference scores are inherently much less reliable than the raw scores from which they are derived because of propagation of error (Young, 1962). Consider a typical older subject whose mean latencies in the unrelated and related conditions were 1,037 and 929 ms (the weighted mean values for the LDT data set) on the basis of 14 trials in each condition (the median value). Typical standard deviations for such a subject would be approximately 299 and 258 ms.[2] The best measure of the accuracy with which a sum or difference estimates the true sum or difference is the adjusted standard error of the mean: $S = [\sigma_n^2/(n-1) + \sigma_m^2/(m-1)]^{1/2}$, where σ_n and σ_m are the standard deviations of two quantities measured n and m times each (Barford, 1985). Thus, for the typical older subject, the standard error of the 108-ms difference between the unrelated and related conditions would be approximately 110 ms. That is, the standard error of the semantic priming effect would be as large as the priming effect itself!

In contrast to the 100% error in the semantic priming effect, there is only an 8% error in the unrelated and related latencies, as measured by the standard error of the mean. Thus, the uncertainty in the estimate of the size of the semantic priming effect is more than an order of magnitude greater than the uncertainty in the estimates of the latencies from which the priming effect was calculated. Ignoring between-subjects differences, it would take more than 100 subjects to reduce the standard error to 10% of the mean. Low reliability leads to failures to reject the null hypothesis of no difference between the semantic priming effects of a younger and an older adult group in single studies, as well as to problems in determining the relation between older and younger adults' priming effects when an additional source of error is introduced, that is, the need to estimate this relation on the basis of data from multiple pairs of groups from different studies.

Nevertheless, the Balota and Duchek (1988) results demonstrate that, when such problems are recognized and appropriate precautions are taken, orderly relations between difference scores as well as between difference scores and other variables are obtainable. Regression analyses of their data revealed that there is a proportional relation between older and younger adults' priming effects and that there is excellent agreement between the slopes of the regressions for whole latencies and priming effects. These slopes were 1.48 and 1.44, respectively, close to the value of approximately 1.5 predicted by general lexical slowing. Importantly, the Balota and Duchek investigation differed from other studies in the number of observations per cell (more than three times as many as in typical priming studies) and also in that the same two groups of 60 subjects participated in five pairs of unrelated and related conditions—more subjects and more conditions than in any other study of age differences in priming.

The large number of observations were used by Balota and Duchek (1988) because they suspected that failures to find significant interactions might be the consequence of the small number of observations per cell used in typical studies of age-related differences in semantic priming. Previous failures to observe the relation between older and younger adults' priming effects predicted by general slowing, including our own LDT meta-analysis with outliers included, may also be attributable to the fact that methods (e.g., large *N*s and multiple conditions) appropriate to the use of less reliable data for such purposes were not used in the original investigations. It must be acknowledged, of course, that these were not the purposes for which the data were originally collected, and so the present comments in no way reflect on the adequacy of the original studies.

The preceding discussion attests to the relevance of three important points made by Salthouse (1985b) in his discussion of general methodological issues in the study of cognitive aging: (a) Given the methodological limitations of many cognitive aging studies, failures to find age differences, such as the often-reported lack of significant age differences in semantic priming, should be carefully scrutinized; (b) the sample sizes typically used, even when they are adequate to detect significant differences, may not be sufficient to provide the point estimates of population means necessary for meta-analyses that are concerned not with effect sizes but with the relations between variables; and (c) researchers must concern themselves with the reliability of their measures, as the use of less reliable measures, even though sometimes dictated by theoretical considerations, only exacerbates the problems caused by the other methodological concerns.

Finally, one apparent inconsistency in the present results bears important consideration. The general slowing of the time course of word recognition observed in our analysis of Balota and Duchek's (1988) delayed-pronunciation data is in apparent conflict with the equivalence in the time course of spreading activation for older and younger adults reported by these authors in their analysis of the semantic priming data from a different part of the same investigation. At least two resolutions

[2] These values were estimated on the basis of the results of linear regressions performed on three data sets (Cerella, DiCarra, Williams, & Bowles, 1986; Hale, Lima, & Myerson, 1991; Myerson, Hale, & Fry, 1992). There is an age-invariant, task-independent linear relation between the measures of dispersion and central tendency of response latencies (Hale, 1987; Myerson & Hale, in press) such that the within-subject standard deviation is approximately equal to .375 times the mean minus 90 (units = milliseconds). This formula was used to estimate the dispersion of latencies as none of the studies of semantic priming reported within-subject standard deviations. However, the argument concerning propagation of error is, of course, quite general and does not depend upon the particular values selected for purposes of illustration.

of this conflict are possible: On the one hand, the processes, or at least the major portion of them, involved in word recognition may be slowed, whereas spreading activation is not. On the other hand, even though the spread of activation slows with age, the change may not be detectable because the time it takes for activation to spread is still extremely brief. For instance, as hypothesized by Wickelgren (1976) and Ratcliff and McKoon (1981), the time required for the spread of activation is approximately several milliseconds. This would lead to the prediction of an age difference in the time needed for activation to spread that would also be approximately several milliseconds. Clearly, such a small difference would not be detectable. But how can such rapid activation spread be reconciled with the size of the priming effects that are typically reported?

The key to answering this question can be found in the distinction between a process and the product of that process (Salthouse, 1985b). Except when SOA is varied, it is the product of priming, rather than the process of priming itself, that is being directly measured. That is, more processing is required to access a word in the absence of priming, and the semantic priming effect measures the time required for that additional processing. If the nature of the additional processing required in older adults corresponds to that required in younger adults, an assumption termed the *correspondence axiom* by Cerella (1990), and that processing is slowed, then larger priming effects in older adults are predicted. Moreover, this interpretation resolves the apparent paradox created by larger priming effects in older adults in the absence of age-related slowing of the time course of semantic priming, because different things are being measured in the two cases: Only the time course data directly reflect the priming process, whereas the priming effects assess the product of priming, that is, the amount of additional processing required in the absence of priming.

Although the lack of significant Age × Condition interactions in most priming studies may have led researchers to think in terms of the sparing or age constancy of lexical access (e.g., Cerella & Fozard, 1984), the few researchers obtaining significant interactions have tended to posit a compensatory strategy on the part of older adults that makes greater use of context (e.g., Bowles & Poon, 1988; Madden, 1988). The fact that this compensation leads to priming effects in older adults that are larger than those in younger adults by the same factor of approximately 1.5 that describes the general slowing of other lexical processes (Lima et al., 1991), however, argues against the need for separate explanations of the magnitudes of the observed age differences. We would suggest that the distinction between compensation and complexity effects is simply which condition, the one resulting in slower responses or the one resulting in faster responses, is thought of as the baseline condition. Either way, the phenomenon is essentially the same: In the lexical domain, the difference between slower and faster responses will be approximately 1.5 times as large in older adults. Thus, general lexical slowing provides a parsimonious account of two phenomena that had previously required separate explanations.

It is important, however, to clearly distinguish between what the general slowing hypothesis offers and what it does not offer. General lexical slowing predicts the approximate magnitude of age differences in response latencies on lexical tasks and in the durations of component processes and explains these predictions on the basis of an extremely parsimonious assumption about the effects of age on processing speed, that is, that all lexical information processing is equivalently slowed. What general lexical slowing does not do, however, is predict or explain why particular tasks result in specific latencies, or why particular experimental manipulations produce effects of specific magnitudes. With respect to priming, for example, general lexical slowing offers no predictions as to how large priming effects will be under different circumstances when age is held constant. Nor are any predictions offered as to which manipulations will make tasks more complex. The general lexical slowing hypothesis is concerned purely with age effects, and its predictions regarding task effects in older adults must take the corresponding task effects in younger adults as a given. Thus, the general slowing hypothesis represents a complement rather than an alternative to traditional cognitive theories.

As one of the most robust phenomena in cognitive aging (Salthouse, 1985a), general slowing is clearly of interest in its own right. In addition, Salthouse (1985b) has argued that slowing is important because of its consequences for age-related differences in the performance of even nonspeeded tasks (short-term and working-memory tasks being outstanding examples). Recent support for this position comes from both cross-sectional and longitudinal investigations of performance on mental ability tests (Hertzog, 1989; Salthouse, 1991; Schaie, 1989). The results of these studies demonstrate that much of the age-related difference in mental abilities disappears when differences in speed are statistically controlled, although the residual age differences suggest that these abilities differ in the extent to which they are dependent on speed of processing. These findings, as well as those of the present study regarding the implications of general slowing for semantic priming and word recognition, provide further testimony to the fundamental role played by processing speed in cognitive aging.

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