Why Do Semantic Priming Effects Increase in Old Age? A Meta-Analysis

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This study reports a meta-analysis comparing the size of semantic priming effects on young and older adults' lexical decision and pronunciation latency. The analysis included 15 studies with 49 conditions varying the semantic relatedness of a prime stimulus (single word or whole sentence) and a target word. An effect-size analysis on the difference between young and older adults' semantic priming effect (unrelated minus related latency) indicated that semantic priming effects are relatively larger for older than for young adults. There was no evidence for nonhomogeneity in this age difference across the different conditions. The relationship between young and older adults' semantic priming effects was described by a function with a positive intercept and a slope of 1.0. This pattern of findings favors aging models postulating process-specific slowing rather than general cognitive slowing.

The effect of aging on activation processes is of considerable interest because of the key role of these processes in recent models of human cognition (Anderson, 1983; Dell, 1986; MacKay, 1987; McClelland & Rumelhart, 1981). Mental operations that depend on activation processes in such models are operations that have been postulated to decline with age, for example, semantic encoding and inferencing (e.g., Cohen, 1979; Craik & Byrd, 1982), word retrieval (Bowles, Olsher, & Poorn, 1989; Burke, MacKay, Worthley, & Wade, 1991), and new connection formation in memory (MacKay & Burke, 1990). Thus, age-related changes in activation processes would provide an elegant explanatory mechanism for a number of age-related cognitive declines. Moreover, age changes in activation processes are an important testing ground in the development of models that account for a broad range of cognitive aging phenomena through changes in parameters of specific processes, for example, a reduced rate of transmission of priming across connections (e.g., MacKay & Burke, 1990a, 1988b) or general slowing of all mental processes including activation processes (e.g., Cerella, 1990; Myerson, Hale, Waggstaff, Poorn, & Smith, 1980).

One of the primary methods for examining activation processes has been the investigation of the effects of semantic context on word recognition, the semantic priming paradigm. In lexical decision or pronunciation tasks, both young and older adults respond more quickly and accurately when a target word is preceded by a semantically related word or sentence context compared with an unrelated context. Under current models, this semantic priming effect depends on activation of semantic memory representations. Although the facilitatory effects of context on word recognition have been known for about 100 years (e.g., Cattell, 1885/1947), only relatively recently has their relation to aging been systematically investigated. In virtually all aging studies, the size of the semantic priming effect does not differ statistically between young and older adults, even though older adults often show a larger difference between related and unrelated contexts.

In the present study, we use meta-analytic techniques to evaluate whether there are age-related changes in the size of semantic priming effects. These techniques provide a more comprehensive evaluation of age differences than do analyses within individual studies (cf. Cook et al., 1992). We start by considering current models of semantic priming (e.g., Neely, 1991), which lead to the expectation of age-related increases in semantic priming effects. After presenting the results of our meta-analysis, we then examine in detail the significance of our findings for models of cognitive aging, contrasting models that posit general slowing of mental processes with models that postulate age changes in specific processes.

Spreading Activation Accounts of Semantic Priming

Two activation mechanisms have been postulated to explain semantic priming effects on word recognition, one automatic and one attentional, with the extent of involvement of each depending on the conditions of the experiment (e.g., Neely, 1977, 1991; Posner & Snyder, 1975; Stanovich & West, 1983). Processing the prime word automatically produces a spread of activation through the semantic network to memory nodes for words semantically related to the prime, increasing their level of activation above resting level. This boost reduces the amount of additional activation required for recognition of a related target so that less visual encoding of the target is needed and the primed target is recognized more quickly (e.g., Balota & Lorch, 1986; Collins & Loftus, 1975).
A second mechanism, expectancy, involves an attentional activation process. Under conditions inducing the expectation that a particular type of word will follow the prime word, for example, a word that is semantically related to the prime or is in a particular category, subjects generate a set of expected words whose level of activation is increased through this attentional process. As with automatic spreading activation, expectancy-based activation speeds responses by reducing the amount of additional activation required for recognition (e.g., Neely, 1977; Posner & Snyder, 1975).

Automatic or attentional spreading activation from semantic context reduces the amount of sensory processing needed for word recognition. Higher level, semantic sources of activation interact with lower level, sensory sources of activation. Within this interactive-compensatory framework, factors that slow word recognition will also increase the size of semantic priming effects (Madden, 1988; Morton, 1959; Stanovich & West, 1983). Empirical findings are generally consistent with this; Semantic priming effects are larger for long, low-frequency words than for short, high-frequency words (e.g., Becker, 1979; Madden, 1986); for degraded than for intact words (e.g., Madden, 1988; Meyer, Szwaneveldt, & Ruddy, 1975); for poor readers than for good readers (e.g., West & Stanovich, 1978); and for younger than for older children (Stanovich, Nathan, West, & Vala-Rossi, 1985). Fischer and Goodman (1978) divided their word targets into a fast and a slow group and their subjects into a fast and a slow group on the basis of lexical decision latency. For both words and subjects, only the slow groups showed significant semantic priming effects. These effects can be described with a horse race analogy: A slow horse will save more time than a fast horse when the distance is reduced by a constant amount.

This account of semantic priming effects leads to a clear expectation that older adults would show larger semantic priming effects than would young adults given the considerable evidence that visual perceptual analysis slows with age (e.g., Fozard, 1990; Kline & Birren, 1975). A similar prediction for older adults has been made on the basis of Sternberg's (1966) highly influential additive factors logic. Sternberg postulated that if two variables affect different stages of information processing, their effects on RT will be additive, and if they affect the same stage, their effects will be interactive. Inasmuch as aging slows the stimulus encoding process, under additive-factors logic it should also increase semantic priming effects.3

Present Study

The goals of the present study were both empirical and theoretical. First, we conducted a meta-analysis of age differences in the size of semantic priming effects to determine whether significant age differences would emerge in a comprehensive analysis. To shed some light on the mechanism underlying the observed age differences, we also evaluated the relation between the size of young and older adults' priming effects.

Proponents of a strong form of the general slowing hypothesis have suggested that a single aging factor describes the relation of young and old reaction time (RT) in all cognitive tasks (e.g., Cerella, 1990; Myerson et al., 1990) or in tasks within a particular cognitive domain (e.g., Cerella, 1983, 1990; Hale, Myerson, & Wagstaff, 1987; Lima, Hale, & Myerson, 1991). Lima et al. plotted older adults' RT as a function of young adults' RT using data from 10 lexical decision studies and 9 other studies involving various lexical tasks. The best-fitting linear function had a 1.3 slope parameter. They concluded that a single slowing factor of 1.5 describes older adults' performance on all lexical tasks. Within this framework, the difference between related and unrelated latencies (i.e., the priming effect) for young and older adults should maintain this same relation (Ferraro, Hale, Myerson, & Lima, 1990). Our analyses of the relation between young and older adults' priming effects allow us to evaluate, in the Discussion section, the usefulness of theoretical approaches to aging that postulate general effects of aging versus process-specific effects.

Method

Studies

Studies included in the meta-analysis were obtained in several ways: through a computer search of the PsychINFO Database of abstracts (including dissertations) using the keywords semantic priming and aging; from references in relevant published studies; and through solicitations for unpublished manuscripts and conference presentations from researchers engaged in semantic priming research. The meta-analysis included semantic priming studies that were, with one exception, published between 1975 and 1990 and that met the following criteria: (a) The task was lexical decision or pronunciation of English words, and the dependent variable was RT measured in milliseconds; (b) healthy young and older adults were tested; and (c) variables included the semantic relatedness of a priming stimulus (single word or sentence) and a target word that were presented either sequentially or simultaneously. Both related and unrelated semantic conditions were required; studies that used a semantically neutral condition in lieu of an unrelated condition were excluded because of the difficulty of finding a truly neutral prime (see Neely, 1991).

The 15 studies that met these criteria are shown in Table 1 together with the number of subjects and the size of the priming effect for both age groups in each condition in each study.

1 There is an additional class of mechanisms that involves post-recognitions processes that may facilitate binary decisions such as lexical decision but not pronunciation (e.g., Balota & Lorch, 1986; Ratcliff & McKoon, 1988; see Neely, 1991, for an excellent review). For example, the subject calculates whether the prime and target words are related and uses this information in selecting a response. Relatedness would bias "yes, it's a word" responses thus speeding decisions for related compared with unrelated targets. Age effects on these strategies, post-lexical processes are not the focus of the present study because the involvement of activation processes in such strategies is unknown. Our meta-analysis includes both lexical decision and pronunciation tasks. We will not concern ourselves with the possibility of age differences in this type of strategy inscrupulous our analysis provides no evidence that the age effect on semantic priming varies for lexical decision and pronunciation.

2 Recent models have replaced the sequentially ordered discrete stages assumed in Sternberg's (1966) approach with interactive processes that occur in parallel and allow information from late stages to influence early stages (e.g., McClelland, 1979; McClelland & Rumelhart, 1981). Nonetheless, additive-factors logic may apply even with an interactive model (McClelland, 1979).

3 If related lexical decision RT for older adults is Oₐ and for young adults is Yₐ and unrelated RT for older adults is Oₐᵤ and for young adults is Yₐᵤ, then, according to Lima et al. (1991), Oₐ - 1.5 * Yₐ and Oₐᵤ - 1.5 * Yₐᵤ. By substitution, priming effects are Oₐᵤ - Oₐ = 1.5 * (Yₐᵤ - Yₐ).
Procedure

Effect size. The goal of this meta-analysis was to determine whether there was a significant effect of age on semantic priming effects. The first step was to compute the average priming effect for each age group within an experiment. The priming effect was the value obtained by subtracting the mean RT on related trials from the mean RT on unrelated trials, separately for each of the two age groups. (Note that for lexical decision latencies, only latencies for positive responses were included.) Mean prime effect, not mean RT, was the dependent measure in the meta-analysis. If a study included an additional independent variable, the priming effects are reported in Table 1 at each level of that variable. Forty-nine distinct levels with a mean priming effect for both age groups were thus generated. Examples of these additional factors included degraded versus intact targets (Cerella & Fozard, 1984; Madden, 1988), perceptually easy versus perceptually difficult words (Madden, 1986), high- versus low-dominant category exemplars (Howard, 1983), and targets that are members of the prime word's category versus targets that are descriptive properties of the prime word (Howard, McAndrews, & Lasaga, 1981).

Using Hedges's (1984) procedure, we next estimated the effect size for the age difference in priming in each of the 49 conditions. This called for subtracting the young priming effect from the old priming effect in each condition and then dividing these effect sizes by a standardizing denominator, typically a pooled standard deviation from the two groups. However, no variance information on the priming effect measure was available from the original studies, because their analyses were based on raw RT, not effect size. Although estimation of the population effect size in Hedges's meta-analytic procedure does not require standardization of individual effect sizes if a common metric was used in the individual studies (e.g., milliseconds in each of the 15 semantic priming studies), estimating the homogeneity of the effect sizes does. Unstandardized effect sizes can substantially inflate the homogeneity test statistic ($I^2$, distributed as $\chi^2$) leading to erroneous conclusions of heterogeneity among effect sizes. Therefore, it was necessary to establish some effective standardizing denominator. Although no variance information was available on the priming effects, information was available on the variability of the raw RTs from many of the 15 original studies. Standard deviations were obtained in all four cells (young and older adults in related and unrelated prime-target conditions) from 41 of the 49 experimental conditions. The four standard deviations from each condition were pooled to obtain 41 separate estimates of variability. The weighted mean of these estimates (with cell $n$ as the weighting factor) was then calculated as 50.43. This was our best estimate of the variability in the Hedges's procedure. For each of the 49 conditions, we estimated the variance from the older priming effect to produce a raw age effect. Each of these differences was then divided by the standardizing denominator computed earlier giving us $G$, the biased estimator of effect size that is due to the age factor.

We next calculated an unbiased estimator of effect size, $d$, for each study where

$$d = c_n^a$$

and

$c_n = (8n - 12)/(8n - 9).$

The value $c_n$ is a weighting function that is based on the sample size of each study. Equations 1 and 2 correct for small sample sizes ($n < 30$) in which $d$ is biased upward. The formulas (here and later) are for the case in which the two groups have equal $n$s, as was true in all 49 conditions. Table 1 gives the $d$ values for each of the 49 conditions grouped by their parent study.

Following the Hedges's (1984) procedure, we calculated a variance for each $d$ value,

$$v = (d^2 + 8)/(4n).$$

These variances were used to compute the value $w$,

$$w = 1/v,$$

that is another weighting factor for each of the unbiased effect-size estimates. This served to weight each $d$ value by its sampling error.
Conditions with larger samples have less error and were given larger weight.

The next step was to take \( \sum d \) and \( \sum \delta d \) across all 48 conditions. To obtain \( d \), the weighted average of all the effect-size estimates, we calculated

\[
d = \frac{\sum \delta d - \sum \delta}{\sum d}
\]

The variance \( \sigma^2 \) of this weighted average is \( 1/\sum d \). Thus, a composite effect-size estimate and its variance were calculated. This information was reported in a confidence interval,

\[
d < \bar{d} + z_{0.05} \sigma / \sqrt{\sum d}
\]

In this confidence interval, \( z_{0.05} \) is a normal deviate and \( \bar{d} \) is the true effect size in the population. In this analysis, alpha was always set at .05.

Homogeneity: We also determined the homogeneity of the effect sizes by testing whether the effect-size estimates in each study came from the same population. In addition to \( \sum d \) and \( \sum \delta d \), \( \sum \delta d^2 \) was computed across all conditions. These three sums go into the statistic that determines the homogeneity of the effect sizes,

\[
H = \sum \delta d^2 / (\sum d^2),
\]

\( H \) is distributed as a \( \chi^2 \) with \( k - 1 \) degrees of freedom, where \( k \) is the number of data blocks in the analysis.

Results

Effect Size

Of the 49 unbiased effect-size estimates listed in Table 1, only 10 were negative, and a sign test indicated that there were significantly more positive differences, \( p < .001 \). The 49 effect sizes ranged from -0.44 to 1.27. Their weighted average was 0.10 (95% confidence interval = 0.04 to 0.17). Because this confidence interval does not include zero, the effect size is statistically significantly indicating that there is a larger priming effect in older adults.

In several of the studies in Table 1, a group of subjects contributed more than one effect size. To ensure the independence of these estimates, another weighted average was computed using only 1 effect size per experiment. This yielded the 18 effect sizes listed in Table 2. Only 2 of these were negative, and a sign test indicated significantly more positive effects, \( p < .001 \). Their weighted average was 0.13 (95% confidence interval = 0.02 to 0.24).

Homogeneity

The homogeneity across all studies was analyzed using the 49 estimates of effect size. The results indicated that the set of effect sizes may be considered homogeneous, \( H(48) = 28.85, ns \). In a second analysis with one effect size for each of the 18 separate experiments, the set of effect sizes was also homogeneous, \( H(17) = 7.83, ns \). Thus, the average effect size is a reasonable representation of the effect in each experiment (Cook et al., 1992).

Relation Between Young and Older Adults’ Priming Effects

We used regression analysis to evaluate the relationship between young and older adults’ priming effects, in particular, to determine whether the relation was proportional as predicted by general slowing equations (Lima et al., 1991). Each of the 49 older adult priming effects shown in Table 1 was plotted as a function of the young adult priming effect in the same condition. The scatterplot and linear regression curve are shown in Figure 1. The best-fitting linear function \( r^2 = .55 \) for the priming effects in millisecond units for older adults (O) and young adults (Y) is

\[
O = 0.96Y + 22.
\]

The slope was not significantly different from 1.0, \( t(47) = -0.34 \), and the intercept was significantly different from zero, \( t(47) = 2.38, p < .01 \). An analysis of the residuals demonstrated that they were not systematically related to the size of the young adults’ priming effect. This analysis did, however, reveal one point that was an outlier because its residual was three standard deviations greater than the mean of the residuals. In a second linear regression analysis, we eliminated this point (which is circled in Figure 1), and the best-fitting linear function for the remaining 48 points \( r^2 = .69 \) was

\[
O = 0.97Y + 17.
\]

Again the slope was not significantly different from 1.0, \( t(46) = -0.30 \), and the intercept was significantly different from zero, \( t(46) = 3.02, p < .005 \).

Relation Between Young and Older Adults’ RT

The 1.0 slope and the additive relation between young and older adults’ priming effects were surprising in view of Lima et al.’s (1991) estimate of a 1.5 slowing factor for all lexical tasks. To explore this discrepancy further, we plotted the absolute mean RT for older adults as a function of the absolute mean RT for young adults, first for related targets in each of the 49 conditions and then for unrelated targets in each of the 49 conditions. The best-fitting functions for each data set yielded \( r^2 = .77 \) and \( .79 \) for related and unrelated conditions, respectively, and their slopes and intercepts did not differ statistically \( p > .20 \) and \( -0.44, p > .1 \), respectively). Therefore, we plotted related and
unrelated RTs together (see Figure 2) and computed a single best-fitting linear function \( r^2 = .78 \),

\[
O = 1.01Y + 178.
\] (10)

Again, the slope was not different from 1.0, \( t(96) = 0.10 \). Consistent with Equation 9, the relation between young and older adults' RT was additive, not proportional. This function did not, however, provide an equivalent estimate for all values because, as can be seen in Figure 3, the absolute size of the residuals increased systematically as young adults' RT increased.

The slopes obtained in the present study for young-old priming effects and absolute latencies deviated from slopes for young-old latencies obtained by Lima et al. (1991), who used many of the same studies. We completed a series of analyses to increase our understanding of this discrepancy. First, we computed the best-fitting function for latencies to word targets in the seven lexical decision studies common to the present meta-analysis and that of Lima et al. In this (and the next) analysis, we added latencies in neutral and blank prime conditions that were used by Lima et al., but not by us, in the analyses reported earlier. This produced a total of 46 conditions in the seven studies. We obtained \( r^2 = .83 \)

\[
O = 1.16Y + 152.
\] (11)

The slope was still not significantly different from 1.0, \( t(44) = 1.97, .05 < p < .10 \).

Our next step was to use all 10 of the lexical decision studies in the Lima et al. (1991) analysis to determine whether the difference between the slope parameter in Equations 10 and 11 and the 1.5 slope parameter obtained by Lima et al. is a consequence of the difference in the particular studies selected. In this analysis, we attempted to replicate the Lima et al. analysis of word responses in the 57 conditions from 10 lexical decision studies as described in their Table 1. We obtained \( r^2 = .88 \)

\[
O = 1.20Y + 98.
\] (12)

Analysis of the residuals revealed no outlying points that were three standard deviations greater than the mean of the residuals. The slope is significantly greater than 1.0, \( t(55) = 3.47, p < .005 \), but it is also considerably less than the 1.52 slope reported by Lima et al. (in their Table 2) for these data. We determined that this discrepancy is entirely because of differences in the selection of data from Howard (1983). In the present study, we used data from young and older adults in Howard's Experiment 1, whereas Lima et al. used older adults' data from Experiment 1 but replaced the young data with the young data from Experiment 2, which used the same stimuli and procedure (S. D. Lima, personal communication, December 4, 1991). The mean age of Experiment 1 young subjects was 31 years, which exceeded Lima et al.'s maximum young age of 29 years. When we made this change, we obtained the same regression equation as Lima et al. \( r^2 = .936 \),

\[
O = 1.52Y - 93.
\] (13)

Discussion

Our meta-analysis of effect size indicates a significantly greater priming effect for older than for young adults. The ho-
Are Age-Related Increases in Semantic Priming Attributable to General Slowing?

The ubiquitous finding that older adults perform more slowly than do young adults on a broad range of cognitive tasks (e.g., Birren, 1965; Salthouse 1985a) has led some investigators to propose that a single slowing factor may describe cognitive aging in general (e.g., Myerson et al., 1990) or within a particular cognitive category such as verbal versus nonverbal (Lima et al., 1991). This claim has been supported mathematically by showing that when older adults’ mean latency is plotted as a function of young adults’ mean latency in the same condition, the result is a linear function with a slope greater than 1 (Cerella, 1985; Cerella, Poon, & Williams, 1980; Lima et al., 1991; Madden, 1989; Nées & Madden, 1988) or a positively accelerated power function (Cerella, 1990; Hale et al., 1987; Myerson et al., 1990). Both functions predict that any factor that increases RT, here unrelated as opposed to related conditions, should have a larger effect on older than on young adults. This prediction is consistent with our finding of larger semantic priming effects for older than for young adults.

However, the general slowing assumption underlying this prediction is not consistent with interactive activation explanations of semantic priming described earlier (e.g., Neely, 1991). That is, an explanation of larger priming effects for older adults requires that the amount of spreading activation that accumulates in the target node is the same across age, using the horse race analogy, the reduction in distance in the race is the same for fast and slow horses. However, under the general slowing hypothesis, the rate of spreading activation is slower for older than for young adults because all cognitive processes (at least within a particular domain) slow with age. Thus, the accumulation of activation at any point in time would be less for older than for young adults, and this would counteract older adults’ greater savings in perceptual processing time. In summary, the viability of general slowing explanations of age effects on semantic priming depends on the development of some other model of semantic priming effects.

Other aspects of our results were not compatible with certain general slowing predictions. The relation between young and older adults’ slowing effects was not predicted by general slowing equations reported in previous studies: The young-old RT function for lexical decision and other lexical tasks has been reported as linear with a slope of about 1.5 (Ferrara et al., 1990; Lima et al., 1991; Madden, 1989). The conditions included in this meta-analysis yielded 1.0 slopes for both priming effects and RTs, and considerable variability was unaccounted for. Thus, the present results challenge the view that there is a proportional relation between young and older adults’ RT in lexical tasks or that there is a single slowing factor that describes performance on all lexical tasks. The results also raise two issues to be addressed in future investigations of a general slowing factor.

Reliability of slowing factors across studies. The discrepancy between our slope parameter for the young-old RT plot and that obtained in some previous studies is clearly related to differences in the selection of studies and data within studies. In their thorough analysis, Lima et al. (1991) demonstrated that the equation describing their young-old RT function held for both word and nonword responses in selected lexical decision studies and for other verbal tasks such as pronunciation. The present results demonstrate, however, that their 1.5 slope parameter does not hold with a different set of lexical decision and pronunciation studies nor with a subset of the studies they used. Indeed, when we analyzed the identical 10 lexical decision studies used by Lima et al., the slope parameter increased by 25% when, to conform to their procedure, we changed which young RT data was used in one study (Howard, 1983); this increase in slope was caused by changes in only 4 out of a total of 57 conditions.

Thus, we question the reliability of estimates of the slowing factor obtained in different meta-analyses. Indeed, the literature shows considerable variation in the quantitative estimates of a slowing factor. For example, the slope of the young-old RT function has been reported as varying between 1.08 and 1.70 (Cerella et al., 1980 and between 1.2 and 2.0 (Salthouse, 1985a). As Baron and Mattila (1989) pointed out about the latter range,
"This wide range of possible deficits, 20% to 100%, is difficult to reconcile with a fundamental aspect of the generalized slowing hypothesis—that a single value (or at least a circumscribed range of values) can be used to characterize slowing independently of the experiment or task" (p. 71).

Some investigators have suggested that more precise estimates of the slowing factor require consideration of the mental operations involved in a task, for example, central versus sensorimotor operations (Cerella et al., 1980). Rogers and Fisk (1990) reported that the slope of the young-old RT functions for visual and memory search tasks varied with practice and type of task (see also Fisk & Rogers, 1991). As in the present study, Rogers and Fisk (1990) obtained slopes around 1.0 and a positive intercept, suggesting an additive rather than a multiplicative relation between young and older adults' RT. Such results suggest that identification of slowing factors cannot be made independently of an analysis of mental operations involved in a task, and it is unclear which, if any, operations share a common slowing factor (see Light, 1991; Rogers & Fisk, 1990, for a similar view).

Deriving slowing factors: Sensitivity of techniques. The present data suggest that linear regression of young-old RT plots can be insensitive to age differences in the effects of experimental conditions: The best-fitting linear function for young-old related RTs did not differ significantly from the function for unrelated RTs in slope or intercept. Thus, we combined the two sets of young-old data points and obtained Equation 10 for the best-fitting linear function (p2 = .78). Because this equation describes an additive relation between young and older adults' RT, it leads to the prediction of no age difference in priming effects. That is, given a slope of 1.0 and an intercept of 178, older adults' priming effects (Ounet-Oset) are predicted as being the same as young adults' priming effects (Yunet-Yset):  

\[ O_{unet} - O_{set} = (Y_{unet} + 178) - (Y_{set} + 178) \]  

\[ O_{unet} - O_{set} = Y_{unet} - Y_{set} \]  

(14) (15)

In contrast, both the effect size meta-analysis and the function for young-old priming effects indicated larger priming effects for older adults. The different outcomes of the analyses of absolute RT and of priming effects may result because the absolute RT analysis treats the data as if semantic relatedness were a between-experiments factor, thereby losing the sensitivity that a repeated measures analysis offers. The effect-size meta-analysis and the regression of priming effects (not mean RT) gain analytic sensitivity by treating the data from a given experiment as within-experiment measures. Indeed, in meta-analyses where an individual study becomes the unit of analysis, considering data from different conditions within the same study as repeated measures, as in the present effect-size analysis, may provide a useful test of conclusions that are based on regression of RTs.

Consistent with these comments, Fisk, Fisher, and Rogers (1992) recently demonstrated that the best-fitting linear functions for young-old RT plots can be insensitive to significant variation in the effects of different conditions or tasks, even when the percentage of variance accounted for is very high. Thus, we concur with their view that linear regression of young-old data plots can lead to overly strong conclusions regarding the constancy of age-related slowing across different conditions (see also Fisher, 1992).

Are Age-Related Increases in Semantic Priming Attributable to Deficits in Specific Processes?

Attentional resources and semantic processing. The processing resources hypothesis proposes that older adults function with diminished attentional resources (e.g., Craik & Byrd, 1982; Hasher & Zacks, 1979; Salthouse, 1985b). The amount of expectancy-based or attentional spreading activation would be expected to be reduced in older adults because they operate with a smaller pool of attention. The meta-analysis included conditions that varied factors such as Stimulus Onset Asynchrony (SOA) and instructions that affect attentional processes. However, our results did not indicate heterogeneous effect sizes across conditions; this is consistent with previous studies finding no evidence for age declines in attentional priming effects (e.g., Burke, White, & Diaz, 1987; Chiarello, Church, & Hoyer, 1985; but see Balota, Black, & Choney, 1992, for an exception).

The view that older adults semantically encode words less richly than do young adults (e.g., Craik & Byrd, 1982) also predicts reduced priming effects in old age. Conditions that reduce semantic processing of prime words diminish semantic priming effects (e.g., Friedland, Henik, & Tzelgov, 1991; Smith, Theodor, & Franklin, 1983). Thus, the present finding of larger priming effects for older than for young adults suggests that age is not a condition that reduces semantic processing.

Slowing of sensory processing. The present finding that semantic priming effects are larger for older than for young adults is consistent with a spreading activation model in which bottom-up, sensory processing interacts with top-down, semantic processing during word recognition (e.g., Stanovich & West, 1983). Factors that slow sensory processing of words are expected to increase the facilitation from semantic context, and this has been demonstrated for stimulus variables such as degradation (Meyer et al., 1978), for subject variables such as reading ability (West & Stanovich, 1978), and, in this study, adult age. Because spreading semantic activation complements activation from sensory analysis, it provides greater savings in time when sensory processes are slower, as is the case with old compared with young adults (e.g., Fozard, 1990). Within this framework, increases in semantic priming effects are a consequence of age-related slowing of sensory processes and age consistency in spreading semantic activation (Balota & Duchek, 1988).

The conclusion that temporal properties of spreading semantic activation are age constant is difficult to accept because of the pervasive slowing of other cognitive processes. Nonetheless, this conclusion has been reached virtually every study of aging and speed of spreading activation. The primary technique for evaluating the speed of spreading activation is to limit the time available for transmission of activation by controlling the prime–target interval (SOA). Studies that varied SOA have produced no evidence that older adults require longer SOAs than young adults to benefit from semantic context (Balota et al., 1992; Bauleta & Duchek, 1988; Burke et al., 1987; Malden, 1989; but see Howard, Shaw, & Heisey, 1986).

A recent and very careful study by Bowles (in press) using the shortest SOAs yet, strengthens the conclusion that the speed of spreading semantic activation does not slow with age. On each trial of her picture-naming task, Bowles's subjects saw a word prime followed by a mask, a brief blank screen, and then a picture target that was semantically related or unrelated to the
preceding prime word. Prime word exposure duration was based on individual recognition thresholds, with older adults' threshold about 13 ms longer than young adults'. Both age groups developed priming effects on naming latency with SOAs consisting of their recognition threshold plus 5 ms: SOAs of about 105 ms and 118 ms for young and older adults, respectively. Although young adults did show priming at a slightly shorter absolute SOA than did older adults, there was no difference in the onset of priming relative to prime recognition.

The Bowles (in press) study demonstrated the significance of age-related increases in perceptual recognition time, which might delay the onset of spreading activation, but which should not be allowed to confound measures of its speed. Her results are consistent with age constancy in the speed of spreading semantic activation. There is, however, an alternative explanation that can account for age increases in semantic priming effects and the age equivalent effects of SOA within a model that postulates age-related decreases in activation processes.

**Semantic priming and transmission deficits.** An age-related reduction in the rate of spreading activation has been proposed as a mechanism underlying a range of age-related cognitive declines (MacKay & Burke, 1990; Salthouse, 1988). The paradox of reduced activation processes and preserved semantic priming effects was explicitly addressed in the formulation of the transmission deficit hypothesis (Burke et al., 1991; MacKay & Burke, 1990), which is based on a detailed and explicit interactive activation model of language processing, the Node Structure Theory (NST; MacKay, 1987). The paradox is explained within this model by the nature of the activating mechanism and by the phenomenon of summation of priming.

Within the NST, activation of a node causes retrieval of the information it represents and requires special activating mechanism that activates the most primed node in some domain. Priming is subthreshold excitation that prepares a node for activation and is similar in some respects to spreading activation in other models (e.g., Collins & Loftus, 1975). Activation is accomplished by multiplication of the level of priming by some factor per unit time until a threshold is reached; however, a minimal level of priming is necessary to trigger the activation process. The strength of connections between nodes determines the rate and amount of priming transmitted between them. The transmission deficit hypothesis proposes that increasing the age of the subject weakens the connection strength, which decreases the transmission of priming across connections (Burke et al., 1991; MacKay & Burke, 1990). This can slow retrieval of information, for example, by increasing the length of time necessary to accumulate the minimal level of priming necessary for activation to occur.

However, the functional effect of a transmission deficit depends on the architecture of the memory system involved. Within semantic memory, transmission of priming is aided by the many indirect connections that link related concepts. For example, semantically related words such as "star" and "planet" are indirectly connected through their links to and from shared predicates such as "are in the sky," "are visible at night," "move with seasons," and so forth. Thus, following presentation of "star," priming summates at the lexical node for "planet" through the many connections to and from these common predicates. Holding all other factors equal, an increase in the number of connections transmitting priming will reduce the effect of transmission deficit on time to identify the target. Summation of priming over multiple connections rapidly increases priming levels at target nodes near levels required for onset of the activation mechanism.

In contrast, transmission deficits impair mental operations that depend on activation of representational units with one-on-one connections. For example, within this model connections from a lexical node to phonological nodes representing word sounds are always one-on-one (see Burke et al., 1991; MacKay, 1987). A transmission deficit affecting this one-on-one connection will invariably impair performance and has been postulated as the cause of older adults' increasing word retrieval failures (Burke et al., 1991). In summary, the effects of age-related transmission deficits are not constant for all mental operations but rather vary depending on the architecture of the system involved.

There are other factors within the model that would contribute to the observed larger semantic priming effects. First, it seems likely that there are more connections among related words in older adults' memory because of their greater and more diverse experience during 60 or more years of language use compared with 18-year-old adults. Another relevant factor that varies with age is the time to respond: Older adults almost always take longer to respond, and this longer-time-to-respon provides a greater interval for the accumulation of priming compared with the faster-responding young adults (Howard, 1988). Time-to-respon is therefore an uncontrolled temporal variable that is independent of attempts to control the prime-target SOA. An important question for future research is whether age differences in priming remain when there are response deadlines requiring young and older adults to respond at the same interval after prime-target presentation (Laver, 1992).

**Conclusions**

Neely (1991) recently reviewed the core phenomena from the semantic priming paradigm and argued that they must be accounted for by models of word recognition. The present study establishes age-related increases in semantic priming effects as an additional phenomenon that such models must explain. Interactive activation models of priming can explain aging effects in the same way as they explain the effect of other variables that slow word recognition: Semantic context is a complementary source of activation and reduces the amount of sensory analysis that is required for recognition. Under this explanation, the speed of spreading activation is constant across age. Alternatively, the transmission deficit hypothesis suggests that transmission of priming is slowed in old age but that the architecture of the semantic system produces summation of priming that compensates for the transmission defect. Both our empirical and theoretical analyses suggest that models postulating general slowing of all verbal processes to the same degree are incompatible with age differences in semantic context effects on word recognition.

**References**


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