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# Complex Semantic Processing in Old Age: Does It Stay or Does It Go?

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Old adults' ($N$ = 24) and young adults' ($N$ = 24) speed of producing exemplars of semantic categories (i.e., semantic fluency) varying in difficulty was assessed both in a standard condition and in a "set-switching" condition where exemplars had to be produced from 2 categories in an alternating manner. "Retrieval-position function" parameters were used to assess speed of semantic access independent of nonsemantic factors. Results suggested age effects in nonsemantic components but not in semantic retrieval per se. Also, age deficits in set switching were relatively subtle. Findings are discussed with relation to issues of domain specificity of age effects as well as of the role of executive control during semantic retrieval and age differences therein.

The main goal of this work was to clarify an open issue about the nature of age differences in retrieval from semantic memory. That semantic memory is less affected by age-related decline than most other cognitive domains is one of the least disputed tenets of cognitive aging research (e.g., Burke & Peters, 1986; Horn & Cattell, 1967; Lima, Hale, & Myerson, 1991); how to interpret the remaining age differences in tasks assessing semantic processing is however an open issue. These age differences may be either due to semantic processes per se or due to other, nonsemantic components specific to the tasks in the context of which semantic functions are studied (e.g., Light, 1992). To answer the question whether age differences in semantic retrieval are due to semantic or nonsemantic components we introduce a new analytic procedure that allows one to extract indicators of these two components from semantic fluency data.

## Does Semantic Memory Decline With Age?

The proposition that access to semantic knowledge is not impaired in old age is based on results of unspeeded assessments of semantic knowledge via vocabulary tasks. Here, positive trends can very often be observed up to the late 60s (e.g., Horn & Cattell, 1967). This, however, leaves the possibility that negative age differences in semantic memory may not emerge when the final product is evaluated—as typically done in vocabulary tasks—but only when the temporal processing characteristics are examined.

One measure that seems to promise direct information about semantic activation processes is semantic priming. The critical dependent variable is the facilitation observed when in a lexical decision task or in a word-naming task, the target word is preceded by a semantically related word relative to a neutral or unrelated word. Across a number of studies, semantic priming has been shown to be constant across age groups (e.g., Bowles & Poon, 1985; Burke, White, & Diaz, 1987; Burke & Yee, 1984; Howard, Shaw, & Heisey, 1986; see Light, 1992, for a review). In other studies, however (e.g., Balota & Duchek, 1988), and in particular when taking a broader view via meta-analytic integrations across age-differential studies on semantic priming (Laver & Burke, 1993; Myerson, Ferraro, Hale, & Lima, 1992), old adults were usually found to have increased priming effects. Larger priming effects could be interpreted in terms of an age-related slowing of semantic processing, which in turn would allow larger savings when related context is provided. However, currently there is no consensus on whether or not this is the correct interpretation of age effects in semantic priming (Laver & Burke, 1993; Lima et al., 1991; Madden, Pierce, & Allen, 1993).

One of the reasons why it may actually be difficult to clarify the issue of age decrements in semantic memory through age comparisons of semantic priming effects is that these effects very likely are not pure reflections of semantic processing. For example, young adults show larger priming when target words are visually degraded (Stanovich & West, 1983). This suggests that even if nonsemantic processes are slowed, semantic activation seems to have more time to accumulate and, thus, to produce larger semantic priming effects. Interestingly, age effects on semantic priming have also been shown to be larger for visually degraded targets than for undegraded targets (Madden, 1988). Thus, it is plausible to assume that an age-related slowing in nonsemantic processes may indirectly produce an age-related increase in semantic priming (Laver & Burke, 1993; Light, 1992). Given this ambiguity associated with age effects in semantic priming, it seems worthwhile to look for alternative indicators of semantic processing.

A different way of assessing semantic processing is via the examination of semantic fluency. In semantic fluency tasks, participants are asked to retrieve members of a specified semantic category as fast as possible. There are two related arguments why semantic fluency tasks may be an interesting paradigm for assess-

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ing age differences in semantic processing. First, much more so than in semantic priming where the influence of top–down, attentional factors is relatively small, semantic fluency tasks involve active search and retrieval from semantic memory (e.g., Rosen & Engle, 1997). Thus, semantic fluency performance may provide a particularly sensitive measure of age effects in semantic memory processes and, thus, also a conservative test of the notion that semantic processing is age insensitive. Second, compared with semantic priming effect sizes, the times required to retrieve exemplars are long (usually in the range of seconds) and should reflect, to a substantial portion, semantic processing. Thus, semantic retrieval times hold the promise for a more robust representation of semantic processing efficiency than is possible with the relatively small semantic priming effects and their documented low reliability (e.g., Madden et al., 1993).

With some notable exceptions (e.g., Fitzgerald, 1983), psychometric and experimental assessments of verbal fluency have usually revealed moderate but reliable age differences (e.g., Bäckman & Nilsson, 1996; Obler & Albert, 1985; Schaie & Parham, 1977; Troyer, Moscovitch, & Winocur, 1997). One interpretation of age differences in semantic fluency is that the lower scores of old adults could be indicative of an actual slowing of semantic memory processes. However, it is, again, possible that age effects observed in fluency tasks reflect age decrements in nonsemantic processes. For example, nonsemantic problems may be related to peripheral components such as speech rate. However, these components play only a minor role in the overall time demands, and age differences therein are very small (Birren, Riegel, & Robbin, 1962; Mysak & Hanley, 1958). Probably more important are executive control processes, such as stopping the last search process and initiating the next one. In fact, neuropsychological research revealed two different brain sites being involved in semantic fluency. First, there seems to be a temporal-lobe involvement that may be related to semantic activation processes (e.g., Corcoran & Upton, 1993; Klein, Milner, Zatorre, Meyer, & Evans, 1995; R. C. Martin, Loring, Meador, & Lee, 1990). Second, there is evidence for frontal-lobe involvement (e.g., Frith, Friston, Liddle, & Franckowiak, 1991; Moscovitch, 1994; Rosen & Engle, 1997; Troyer et al., 1997) that probably reflects executive processes, an issue we return to in the final section of the Introduction. Also, there is strong evidence indicating that executive processes are disproportionately affected by aging (e.g., Mayr & Kliegl, 1993; Mayr, Kliegl, & Krampe, 1996; Moscovitch & Winocur, 1992; Verhaeghen, Kliegl, & Mayr, 1997). Thus, it is a plausible hypothesis that age differences in semantic memory retrieval are due to age deficits in executive control while the semantic component itself may be age invariant.

What seems to be clear from this short review is that assessing semantic processing via semantic fluency tasks entails problems similar to those encountered in assessing semantic processing via semantic priming. In both cases it seems to be difficult to specify the degree to which "pure" semantic processes, in contrast to other components, determine overall performance in fluency tasks and to what degree these components may be differentially affected by aging. However, as we propose in the following section, for semantic fluency tasks there may be a way of dissociating semantic and nonsemantic components.

## Dissociating Semantic and Nonsemantic Processes in Semantic Fluency Tasks

Our attempt to dissociate semantic and nonsemantic, executive processes is based on a very simple model of the interplay between executive control and retrieval in semantic fluency tasks. In short, we believe that control operations need to be executed to initiate and set the parameters for each retrieval process. However, the retrieval itself then runs off in a highly autonomous manner.

A central variable in our attempt to make this simple model empirically tractable is the position of a word within the recall sequence. We propose that recall position provides a relatively pure manipulation of semantic processing difficulty. There are two reasons for this assumption. First, retrieval across recall positions is very likely nonrandom in nature. Specifically, words closely associated with a particular category should be retrieved before words less closely associated with a category. Second, the probability of resampling already used words should increase with recall position so that additional semantic activation is needed to find remaining words. In other words, we claim that demands on semantic processing proper increase as a function of recall position. In contrast, demands on executive processes should stay constant across recall positions. We propose that the main role of executive processes is to initiate and update a retrieval set for each specific semantic search process. For example, this involves marking the last produced word as "taken" or the decision whether or not a particular semantic subcategory is exhausted and needs to be changed. We believe that this component operates in roughly the same manner after each retrieval process (for a similar argument, see Cools, van der Bercken, Horstinck, van Spaendonck, & Berger, 1984) and therefore is relatively invariant across retrieval positions.

As simple as these assumptions are, they are far from trivial or uncontroversial. Specifically, the claim that executive control should not become more important as a function of retrieval position needs further explication. After all, one could argue that with increasing number of words retrieved, there is a larger number of words that needs to be prevented from being perseverated. In fact, Rosen and Engle (1997) argued that avoiding perseverations is an executive monitoring and suppression process in the course of semantic category recall that, for example, is less efficient in people with low than in those with high working memory capacity. In this context, however, we believe that it is important to make a distinction between the process of "marking" a word as already used (or suppressing it) and a process of recognizing it as already used once it is being resampled during retrieval. The first process is one critical function of the executive component, and it should become necessary after each act of retrieval. The recognition component, however, need not be a resource-demanding executive control process. In fact, there is evidence that perseveration detection during fluency production is a highly automatized process. For example, Indow and Takada (1981) showed that reaction times (RTs) for recognition judgments on whether or not a word has been already produced during the recall process are not affected by the number of words produced (i.e., a "pop-out" effect). Thus, even though prevention of perseverations may be a critical problem during semantic fluency performance, there is no evidence that this problem becomes more severe with increasing recall position.

From the simple model outlined above, three core assumptions can be derived that translate into a formal representation of the times between successively produced words as a function of the word position in the recall sequence. First, the time interval between retrieving word $n-1$ and word $n$ is dissociable into a nonsemantic component (consisting mainly of executive processes) and the actual semantic search component. Second, the nonsemantic (executive) component is constant across variations of semantic processing demands, whereas the time requirements of the semantic component increase with semantic processing demands. Third, semantic processing demands increase with retrieval position. We add to this last assumption one final specification, namely that the increase in time demands associated with every additional word in the recall sequence is constant.

These assumptions translate directly into a simple linear model of the time $t_n$ between recall of word $n-1$ and word $n$:

$$t_n = c + s*n. \tag{1}$$

This we will call the retrieval-position function. The slope $s$ of this function, that is, the time increment with every additional word recalled, represents processes directly related to semantic memory retrieval. For example, it could reflect transmission speed of activation through the semantic network (e.g., Burke, MacKay, Worthley, & Wade, 1991) or the sampling rate of cues leading to new words (Walker & Kintsch, 1985). Parameter $c$ represents the component that is stable across the number of words recalled and, thus, is not affected by semantic processing demands. It proposedly reflects mainly executive components that support semantic retrieval. Thus, through a combined consideration of both constant and slope of the retrieval-position function, we can assess to what degree age-related differences in fluency tasks are related to semantic processing per se or to executive control processes. Of course, there was no a priori reason for assuming that a simple linear function would adequately represent the relationship between accumulated words and the time between successive words. However, we decided to start with this most simple representation and, as the results show, found it to provide a satisfactory account of our data.

In this context, it is also important to note that our general approach of modeling fluency-production data deviates from the traditional procedure. Typically, the accumulated number of words is represented as a function of production time and a two-parameter hyperbolic function is most commonly used to model such data (e.g., Fitzgerald, 1983; Graesser & Mandler, 1978; Grunewald & Lockhead, 1980; Rubin & Olson, 1980). The reason why we looked for a different representation was that the hyperbola does not allow an additive decomposition of retrieval times into a semantic and a nonsemantic component. The form of this function is jointly determined by the asymptote (i.e., the limited pool of possible words) and the rate of search both of which are characteristics of semantic memory proper. Also, in the Results section we show that, at least for the current experimental paradigm, our representation actually seemed to provide a better account of the data than the traditionally used representation via a hyperbolic function.

To assess retrieval-position functions and age differences therein, we had young and old adults produce the first 10 exemplars they could think of to a given semantic category. By looking at the first 10 exemplars only, we restricted the analysis to a smaller recall segment than the one typically used in the study of semantic retrieval (e.g., Fitzgerald, 1983; Graesser & Mandler, 1978; Grunewald & Lockhead, 1980; Rubin & Olson, 1980; Walker & Kintsch, 1985). We compensated the limited number of observations from within one category by using a large variety of different categories (i.e., $N$ = 24) sampled from three levels of semantic category difficulty. The purpose of the manipulation of category difficulty was twofold. On the one hand, it allowed us to generalize our test of age differences in semantic processing across a large spectrum of semantic difficulty. On the other hand, with this manipulation we can validate our assumption that the slope of the retrieval-position function reflects semantic processing demands. The way semantic difficulty is used here, it is a heterogeneous construct that can refer to the degree of semantic organization within a category, to the average word-frequency of category exemplars, or to the strength of mutual associations between category exemplars. Our assumption is that each of these variables affects the rate of searching semantic memory and, thus, the retrieval-position slope. In contrast, the constant should remain largely unaffected by manipulations of semantic difficulty.

## On the Role of Switching During Semantic Fluency Performance

Currently, there is an increasing interest in the costs of switching cognitive sets as a potential indicator of executive control (e.g., Meiran, 1996; Rogers & Monsell, 1995; but see Allport, Styles, & Hsieh, 1994). Furthermore, Troyer et al. (1997) recently argued that frontal-lobe based executive processes in the context of semantic fluency play a specific role when people need to switch semantic subclusters. In support of this notion, those authors reported that old adults exhibited a smaller number of switches between semantic clusters than young adults during a fixed production interval but the same number of within-cluster transitions (but see also, Fitzgerald, 1983; Mayr, 1998). To explicitly test the role of switching during semantic fluency performance, we contrasted a standard semantic fluency condition with one in which words had to be produced from two categories in an alternating manner (e.g., Downes, Sharp, Costall, Sagar, & Howe, 1993). On the basis of the Troyer et al. model one would expect that age differences are particularly pronounced in a category-switching condition. The alternative view we propose here is that executive processes are relevant for every single act of retrieval. On the basis of such a view one would expect that age differences arise even when switching demands are low, whereas no marked, additional age-related effects should be associated with the switch manipulation.

## Calibration Study

In preparation for the main experiment, we conducted a study in which we tested old adults selected for having participated in higher education ($N$ = 22, $M$ = 67.7 years, $SD$ = 3.1; 11 female) and young students of the University of Potsdam ($N$ = 20, $M$ = 23.4 years, $SD$ = 4.8; 16 female) in terms of their performance in a standard assessment of semantic fluency. This study was supposed to provide us with information about the age differences within our population when using the traditional testing procedure. More importantly, by assessing performance in 44

Table 1
*Latency Per Word, Word Length, Rate of a Word's Occurrence in the Entire Group in Percentage (Normativity), and Category Typicality as a Function of Age and Difficulty Level*

| Difficulty level | Latency | | Length | | Normativity | | Typicality | |
|---|---|---|---|---|---|---|---|---|
| | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* |
| Young adults | | | | | | | | |
| Easy | 4.03 | 0.69 | 6.40 | 0.50 | 57.02 | 4.36 | 6.11 | 0.15 |
| Medium | 5.57 | 1.06 | 7.75 | 0.64 | 38.10 | 4.04 | 5.80 | 0.20 |
| Difficult | 6.68 | 1.00 | 9.25 | 0.64 | 36.02 | 3.03 | 5.47 | 0.24 |
| Old adults | | | | | | | | |
| Easy | 5.62 | 1.28 | 6.32 | 0.48 | 58.59 | 3.61 | 6.07 | 0.19 |
| Medium | 7.29 | 1.88 | 7.41 | 0.59 | 40.03 | 3.03 | 5.79 | 0.14 |
| Difficult | 9.74 | 2.72 | 9.09 | 0.73 | 38.37 | 3.41 | 5.43 | 0.28 |

*Note.* The latter three parameters were computed for the first six words produced in the recall sequence.

different categories sampled for a large variability in terms of difficulty, we wanted to gain independent information about semantic category difficulty for the manipulation of this variable in the main experiment.

Testing occurred in age-mixed group sessions. Participants worked through booklets with one category label and 40 lines on each page. The sequence of categories within the booklet was randomized across participants. The instruction was to produce as many words as possible corresponding to the category while avoiding complete and close repetitions (e.g., same word in singular and plural). An experimenter guided participants through the booklet by giving start signals for turning the page to the next category and stop signals. The time allowed to work through each category was 60 s.

Words for each category were counted (excluding repetitions and errors) and transformed into time-per-word "latency" scores. As expected, the range in terms of semantic complexity was large with a time per word of around 4 s for the easiest categories and around 8 s for the most difficult categories. Across all categories, there was a highly significant age effect with young adults requiring 5.15 s per word ($SD = 0.71$; corresponding to 11.7 words within 60 s) and old adults 7.09 s ($SD = 1.61$; corresponding to 8.46 words within 60 s), $t(40) = 4.95$, $p < .01$, which amounts to an old–young ratio of 1.38. Thus, in a standard assessment of semantic fluency, we replicated the general finding in the literature of a negative age effect that is of moderate size compared with age effects typically found in nonsemantic tasks.

In the next step we selected 24 categories for the main experiment that had to meet the following constraints. There should be eight categories for each of three different difficulty levels (simple, medium, difficult). Also, in order to meet the design requirements of the main experiment where we wanted to present half of the categories in a "no-switch" situation and the other half in a "switch" situation, we needed these eight categories to be divisible into two sets of four such that mean difficulty between the two sets should be minimal within each age group. An analysis of variance (ANOVA) with Age as between-subjects factor and Difficulty and Set as within-subject factors revealed an age effect, $F(1, 40) = 22.41$, $MSE = 12.39$, $p < .01$, a difficulty effect, $F(2, 80) = 168.54$, $MSE = 1.38$, $p < .01$, and an Age × Difficulty interaction, $F(2, 80) = 8.89$, $MSE = 1.38$, $p < .01$, but no effect involving the Set factor, all $Fs < 1.2$, all $p > .3$.

Table 1 shows the latency scores as a function of age group and difficulty level. In order to provide some additional information on this purely empirically based difficulty dimension, we also report three descriptive scores for the words produced by the two age groups at each level of difficulty. To avoid confounds with number of words produced across difficulty levels and age groups we computed these indicators for the first six words of each recall sequence only. The first score, word length, a simple letter count of each word produced, showed a highly significant difficulty effect, $F(2, 80) = 275.51$, $MSE = 0.30$, $p < .01$, but neither an age effect, $F(1, 40) = 2.15$, $MSE = 0.55$, $p > .15$, nor an age × difficulty interaction, $F(2, 80) = 0.61$, $MSE = 0.30$, $p > .5$. Very likely, word length captures a conglomerate of lexical and also semantic retrieval difficulty. It is, thus, not surprising that words from more difficult categories are on average longer than words from less difficult categories.

The second score, "normativity," indicates how often a particular word was produced for a particular category in the entire sample of participants. Presumably, a high degree of normativity for a given category reflects within-category associations that are relatively often encountered within a particular culture and, thus, should also support fluent retrieval. Accordingly, we found large difficulty differences in this score, $F(2, 80) = 622.05$, $MSE = 8.75$, $p < .01$. This score seemed most sensitive for the difference between easy and medium difficult categories; however, even the difference between medium and difficult categories was highly significant. There also was a small main effect for age here with old adults producing slightly more normative responses than young adults, $F(1, 40) = 5.53$, $MSE = 21.47$, $p < .05$. The age × difficulty interaction was far from significant, $F(2, 80) = 0.18$, $MSE = 8.75$, $p > .8$. The small age difference in the normativity of fluency production could be interpreted in terms of old adults' longer exposure to cultural knowledge. At the same time, it needs to be acknowledged that others have failed to find age differences in normativity (Burke & Peters, 1986; Light, 1992).

Finally, for the third score, each word produced at least once within the entire sample ($N = 2,258$) was evaluated by seven young raters (students of the University of Potsdam) with respect to its category typicality. Words were presented one at a time and drawn randomly across all categories on a computer screen together with the corresponding category. Raters answered the question "How typical is this word for the given category?" by pressing a number between 1 and 7, with 1 representing "very untypical" and 7 representing "highly typical." The scores from the seven raters were averaged to serve as a "typicality" scale. The resulting Cronbach's Alpha of .89 for the entire set of words was satisfactory. As expected, there was a substantial difficulty effect on typicality ratings, $F(2, 80) = 115.09$, $MSE = 0.04$, $p < .01$, but neither an age main effect, $F(1, 40) = 0.38$, $MSE = 0.05$, $p > .5$, nor an age $\times$ difficulty interaction, $F(2, 80) = 0.11$, $MSE = 0.04$, $p > .8$.

Taken together, the empirically derived manipulation of semantic category difficulty produced meaningful effects on three different scores. There may be some questions concerning the nature of the word-length score; however, at least the latter two scores can be assumed to reflect semantic difficulty in a relatively unambiguous manner.

Finally, aside from establishing a reference for constructing a semantic difficulty manipulation, this study showed that, within our population of participants, moderate age effects in fluency tasks can be obtained when using a standard assessment. Also, an Age $\times$ Difficulty interaction was found that possibly indicates an age deficit in terms of semantic processing. However, as outlined earlier, only more detailed analyses of processing characteristics will allow inferences about sources of age effects in standard fluency scores. The goal of the main experiment was to obtain such detailed processing information.

## Method

### Participants

New samples of 24 old adults ($M = 69.0$ years, $SD = 4.3$; 21 female) and 24 young adults ($M = 23.6$, $SD = 4.2$; 16 female) participated in this experiment. Young adults were students at the University of Potsdam. Old adults were selected for having participated in higher education (years of education are not comparable given the changes in educational systems due to historical changes in Germany). In a vocabulary test (modified after Wechsler, 1964), young adults showed superior performance compared with old adults (Old: $M = 15.2$, $SD = 5.3$; Young: $M = 20.6$, $SD = 3.7$).[1] In the Digit Symbol Substitution test (Wechsler, 1964), which measures psychomotor speed, we found the usual pattern of young adults outperforming old adults (Old: $M = 43.5$, $SD = 9.3$; Young: $M = 62.1$, $SD = 9.2$). Participants received a compensation of DM 20 (about U.S. $15).

### Stimulus Material

On the basis of results of the calibration study, we selected 24 categories that could be grouped into three levels of difficulty and two sets of four categories within each difficulty level (see Appendix for a list of the categories used). For each participant, one of the two sets per difficulty level was assigned to the no-switch condition and the other set was assigned to the switch condition. This assignment was counterbalanced across participants. The four categories within each set were further subdivided into two category pairs. In the switch condition, these pairs were always presented together, and in the no-switch condition they were also presented successively.

### Task and Procedure

Testing occurred in individual sessions of about 90 min. After attaining general information about participants and conducting psychometric tests, the actual experiment started. The assessment was guided and supervised by an experimenter while presentation of categories was controlled by a computer. The experimenter started each trial after making sure the participant was ready. At the beginning of the trial, the relevant category name or the two names in the switching condition appeared on the screen together with a warning tone. The experimenter read the category names aloud. Participants could start producing exemplars immediately afterward. After 3 s in the no-switch condition and 6 s in the switch condition, the screen turned blank. A trial lasted until either 10 exemplars were produced for each category or after 3 min in the no-switch condition and 6 min in the switch condition.

Participants practiced this procedure with two no-switch trials and two switch trials using categories that were not part of actual testing. For switch trials participants were asked to produce a word for Category A, then a word for Category B, then again for A, and so forth until the end of the trial (i.e., 10 words per category or 6 min). The practice trials were used to ascertain that every participant understood this procedure. During testing, trials were presented in sets of same difficulty. Order of difficulty was counterbalanced across participants. Within sets of same difficulty, one switch trial alternated with two successive no-switch trials. Order of switch versus no-switch trials was counterbalanced. Finally, also within each of the category pairs constructed to be presented together in the switch condition, order of presentation in the no-switch condition was counterbalanced.

### Scoring

The entire session was tape-recorded for later scoring and timing. Each trial was scored and timed in separate steps. During scoring, each word was classified (a) as correct, (b) as a within-category word perseveration (i.e., saying "dog" two times when the category is "four-legged animal"), (c) as a category perseveration (i.e., producing a word to the other possible, but currently irrelevant, category in the switch condition), (d) as a cross-category intrusion (i.e., words that would have been correct for categories used earlier), and (e) as an overgeneralization (i.e., words that were semantically related to the category but extended the category boundaries such as "bird" for the category "four-legged animals"). A final category was time-out errors that occurred when the time limit was reached before 10 words per category were produced.

Utterances were timed in the following way: The coder listened to the tape via headphones and pressed a key on a computer keyboard at the beginning of each utterance. Key presses were timed relative to the last key press. Thus, for example, the first interword interval was timed between the first and the second word. Every utterance of a word (whether correct or not) was timed. Only comments (which were very rare) were not coded. To avoid false alarms, coders listened to each trial once before actually going through the coding sequence. Also, coding could be repeated when an error occurred. The coder was blind toward the hypotheses of this study.

For analyses of retrieval times only latencies for words coded as correct were used. However, incorrect words were treated like correct words for the determination of both the interword intervals and the recall-sequence

[1] The low performance of old adults in the vocabulary task is surprising, and we can explain it only in terms of a sampling error. In typical cognitive aging studies, such an age difference in the vocabulary score would be unfortunate and potentially damaging to substantive inferences drawn from the results. However, in this particular case the age difference in the vocabulary score actually allows for a conservative test of our hypothesis that there are no age differences in semantic processing per se. We also redid the analyses reported in the Results section using subsamples with age equivalence in the vocabulary score (i.e., after eliminating the eight lowest scoring old adults and the eight highest scoring young adults). In all aspects, the subsample results conformed to those obtained in the total sample.

Table 2
*Error Percentage Per To-Be-Produced Word as a Function of Age, Switch/No-Switch, and Error Category*

| | Young | | | | Old | | | |
|---|---|---|---|---|---|---|---|---|
| | No-switch | | Switch | | No-switch | | Switch | |
| Error category | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* |
| Within-category perseverations | 0.83 | 0.95 | 1.30 | 1.16 | 1.39 | 1.03 | 3.50 | 2.36 |
| Category perseverations | — | — | 0.18 | 0.49 | — | — | 0.69 | 1.24 |
| Intrusions | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.42 | 1.50 |
| Overgeneralizations | 0.38 | 0.99 | 0.52 | 1.35 | 0.66 | 1.28 | 0.66 | 1.01 |
| Time-outs | 0.59 | 1.19 | 0.66 | 1.61 | 1.24 | 2.07 | 1.64 | 2.1 |

position of all following words. In the case of a time-out before 10 words per category were produced, the words recalled before the time-out were retained for the analysis.

## Results

### Error Analyses

Before we turn to the analysis of interword times (IWTs) it is useful to examine to what degree time-based results may need to be qualified by the pattern of errors. Basically all errors (99.9%) could be classified in terms of our coding schema. Table 2 contains error percentages from all categories as a function of young and old adults and the switch/no-switch factor. Given the overall small frequency of errors, we collapsed across difficulty levels and recall position here.

As can be seen, errors were generally rare. Most frequent were within-category perseverations. Here, we also found highly significant effects of the switch/no-switch factor, $F(1, 46) = 22.86$, $MSE = 1.75$, $p < .001$, of age, $F(1, 46) = 17.03$, $MSE = 2.69$, $p < .001$, and an Age $\times$ Switch/No-Switch interaction, $F(1, 46) = 9.31$, $MSE = 1.75$, $p < .01$. Separate analyses for no-switch and switch conditions showed that age differences in the no-switch condition just failed to reach the significance level, $t(46) = 1.94$, $p > .05$, whereas the age difference in the switch condition was highly reliable, $t(46) = 4.11$, $p < .001$. In the switch condition old adults exhibited about three times as many word perseverations as in the no-switch condition and as young adults in the switch condition. Overall, however, even for old adults, and in particular in the no-switch condition, perseverations were relatively rare events. In the switch condition, old adults also showed a tendency for a higher rate of failures to switch categories, $t(46) = 1.88$, $p < .07$.

The only other age-related effect we found was in terms of time-out errors. Old adults ran out of time significantly more often than did young adults, $F(1, 46) = 4.62$, $MSE = 3.42$, $p < .05$. Naturally, time-out errors occurred toward the end of the recall sequence. For example, in the difficult categories old adults were not able to produce the last word in 13% of the cases for the no-switch and in 16% for the switch condition. For young adults, the corresponding values were much lower, namely 1% and 3%. Such large differences in time-outs could qualify the interpretation of retrieval-position functions. Fortunately, however, the age difference in time-outs were mostly limited to the last positions of the difficult semantic categories. For example, up to Position 6, time-outs never occurred for young adults and only in 0.5% of the cases for old adults. Therefore, we complement our analysis of the entire recall sequence with analyses of Positions 1 to 6, which were not biased by age differences in time-outs.

### Retrieval-Position Functions

*Function fits.* As a first step, we determined (a) to what degree our representation of the recall dynamics in terms of a two-parameter linear model yielded an adequate fit and (b) how it fared compared with the traditional representation via a two-parameter hyperbolic function. Direct comparison of these functions is hindered by the fact that they operate on different levels of integration: the one models IWTs as a function of position in the retrieval sequence, whereas the other models the cumulation of words across time. We therefore used the first derivative of the inverse hyperbola, which, as the linear retrieval-position function, allows modeling IWTs as a function of word position in the recall sequence. IWTs were averaged for each participant within-category retrieval position, difficulty level, and the no-switch versus the switch condition. Table 3 shows the relevant parameters and fit statistics for each of the two functions. As can be seen, the linear retrieval-position model produced very satisfactory fits with all $R^2$s above .90. In contrast, the mathematical equivalent of the hyperbola to model IWTs as a function of word position produced $R^2$s below .90 in 6 of 12 cases. In 11 out of 12 cases, the linear function provided a numerically better fit than the equivalent of the hyperbola, a difference that is highly significant in a sign test, $\chi^2 = 8.3$, $p < .01$.

Given the nature of the fluency recall process, individual recall protocols showed a high degree of variability that is not in the main focus of our interest (but see the section *Distribution of IWTs*). Therefore, we believe that fitting data at the level of group means yields an adequate representation of the retrieval-position function. However, in order to statistically evaluate age and condition effects in function parameters, retrieval-position functions need to be fitted at an individual level. For this purpose, we aggregated within individuals across the four recall sequences per condition and fitted a linear retrieval-position function for each condition and participant. Naturally, the resulting fits were lower here but, with $R^2$s between .5 and .6, were of an acceptable size. Also, the averaged individual function parameters were, with the exception of minor differences, very similar to those obtained on the group level of aggregation.[2] The good fit of the retrieval-position model to the data as well as the close correspondence of parameter values at the individual and the group level is justification for the next step, the analysis of retrieval-position function parameters in relationship to age and experimental conditions.

*General effects.* Figures 1 and 2 present IWTs and corresponding linear retrieval-position functions based on the group data. Table 4 presents the results of two ANOVAs with function slopes and constant parameters (i.e., the constant) as dependent variables and with Age as between-subject factor as well as Difficulty and Switch/No-Switch as within-subject factors.[3] Arguably, for the examination of semantic fluency performance, the traditionally used no-switch situation is more appropriate than one in which additional demands come into play (i.e., the switch condition). Therefore, we present results in Table 4 not only for the full design but also separately for the no-switch and the switch conditions.

If, as we propose, the slope of the search function is an indicator of semantic processing efficiency, this parameter should be affected by the manipulation of semantic category difficulty. As Figures 1 and 2 show, this is the case. Search-function slopes increased monotonically with semantic category difficulty within all conditions and age groups. Consistent with this observation, there is a highly significant effect of category difficulty on the slope parameter.

If semantic difficulty increases demands on only semantic processes it should affect the slope parameter but not the constant. Inconsistent with this prediction, Table 4 shows that there was a difficulty effect on the constant parameter, which, however, was

Table 3
*Parameters and Fit Statistics of the Linear Retrieval-Position Model and the First Derivative of the Inverse Hyperbola for Each Age Group and Experimental Condition*

| Difficulty level | Retrieval-position model $c$ | $s$ | $R^2$ | First derivative of inverse hyperbola $a$ | $b$ | $R^2$ |
|---|---|---|---|---|---|---|
| Young | | | | | | |
| No-switch | | | | | | |
| Easy | 0.35 | 0.32 | .96 | 18.42 | 16.87 | .95 |
| Medium | 0.16 | 0.68 | .91 | 17.63 | 28.49 | .85 |
| Difficult | −0.08 | 1.00 | .97 | 16.83 | 35.62 | .92 |
| Switch | | | | | | |
| Easy | 1.43 | 0.54 | .97 | 22.06 | 51.00 | .92 |
| Medium | 1.81 | 0.94 | .94 | 21.11 | 74.41 | .86 |
| Difficult | 2.49 | 1.12 | .94 | 21.55 | 96.04 | .88 |
| Old | | | | | | |
| No-switch | | | | | | |
| Easy | 0.69 | 0.39 | .94 | 20.06 | 27.29 | .92 |
| Medium | 0.59 | 0.70 | .91 | 17.09 | 30.08 | .98 |
| Difficult | 1.40 | 0.96 | .95 | 20.03 | 64.04 | .88 |
| Switch | | | | | | |
| Easy | 1.33 | 0.72 | .97 | 20.59 | 53.80 | .92 |
| Medium | 2.10 | 0.99 | .94 | 21.74 | 85.28 | .86 |
| Difficult | 2.94 | 1.46 | .93 | 21.83 | 127.71 | .82 |

*Note.* The two-parameter hyperbola has the following form: $n = at/(b + t)$, where $n$ is the number of words, $t$ is cumulative time, $a$ is the asymptotic number of words, and $b$ is the search parameter. The first derivative of the inverse hyperbola is $\Delta t = b*(1/(a - n) + n/(a - n)^2)$.

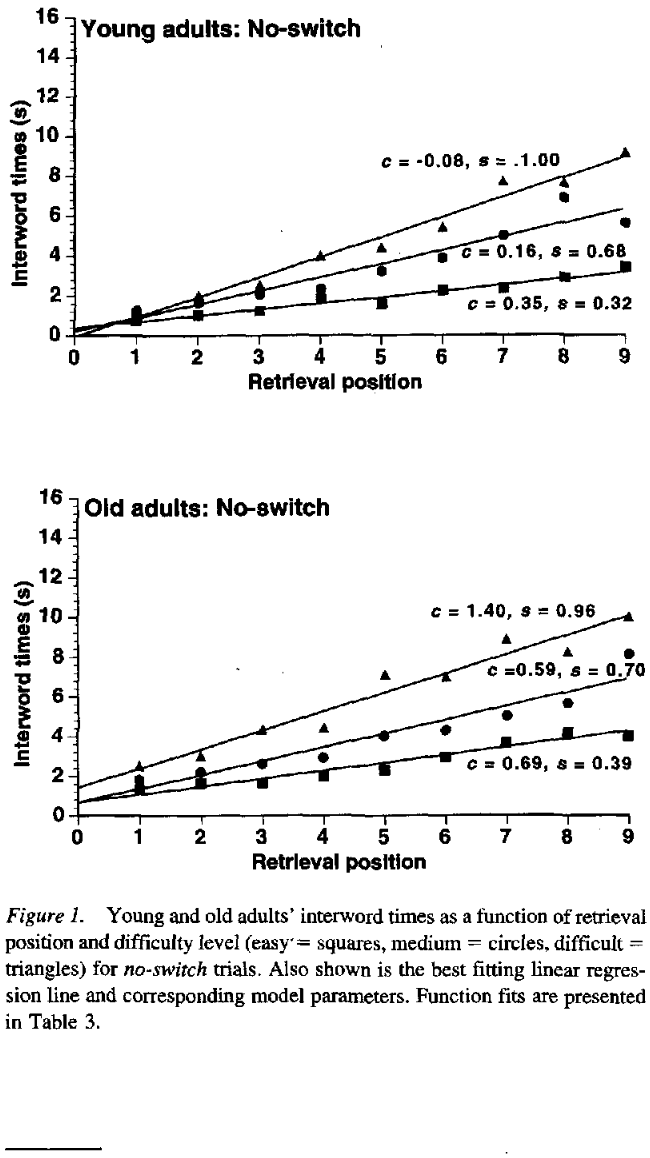


*Figure 1.* Young and old adults' interword times as a function of retrieval position and difficulty level (easy = squares, medium = circles, difficult = triangles) for *no-switch* trials. Also shown is the best fitting linear regression line and corresponding model parameters. Function fits are presented in Table 3.

[2] Ordered by the no-switch/switch contrast and levels of difficulty, young adults' averaged individual slope parameters for this function were 0.32, 0.68, 1.00, 0.54, 0.94, and 1.12. The corresponding parameters for old adults were 0.39, 0.70, 0.88, 0.73, 1.01, and 1.40. Young adults' constant parameters were 0.35, 0.16, −0.08, 1.43, 1.82, and 2.50; those for old adults were 0.69, 0.59, 1.63, 1.31, 2.04, and 3.13. Averaged $R^2$s for the linear model were for young adults .54, .61, .55, .61, .53, and .54 and for old adults .55, .62, .51, .62, .48, and .51. Averaged $R^2$s for the hyperbola were 58, .59, .55, .58, .55, and .52 for young adults and .54, .61, .55, .59, .45, and .48 for old adults. Quality of fit did not differ across age groups, all $F$s $< 0.33$. In comparing fits for the linear model and the hyperbola, no differences were obtained for the no-switch conditions, $F(1, 46) = 0.86$, $MSE = 0.01$, $p > .3$; however, a significant advantage for the linear model was found for the switch conditions, $F(1, 46) = 8.3$, $MSE = 0.00$, $p < .01$.

[3] A more traditional way of analyzing these data would be an ANOVA of retrieval times with the factors Age, Difficulty, Switch, and Retrieval Position. Effects associated with a linear contrast for the Retrieval-Position factor would correspond to effects on the search-function slope, whereas the age effects not associated with the retrieval position would roughly correspond to age effects in the constant parameter. This analysis yielded the same pattern of results as the analyses reported here.

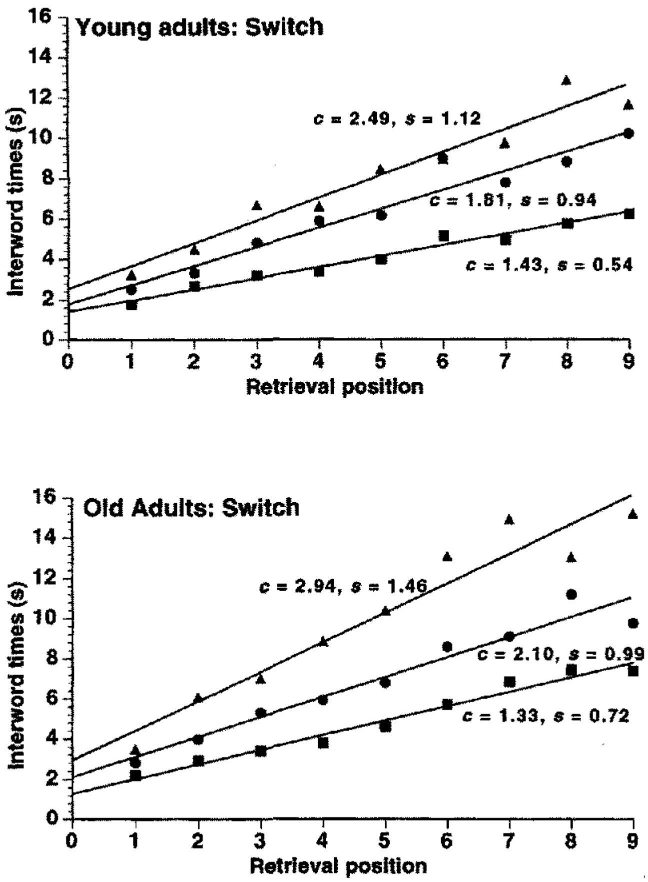


*Figure 2.* Young and old adults' interword times as a function of retrieval position and difficulty level (easy = squares, medium = circles, difficult = triangles) for *switch* trials. Also shown is the best fitting linear regression line and corresponding model parameters. Function fits are presented in Table 3.

qualified through a Difficulty × Switch interaction. When looking at the difficulty effects on the constant parameter separately in switch and no-switch conditions, a large effect is revealed for the switch condition, $F(2, 92) = 6.57, MSE = 3.89, \eta^2 = .12, p < .01$, but there was no general effect in the no-switch situation. Judging from Figure 1, for young adults in the no-switch condition there clearly was no increase in the constant parameter as a function of category difficulty—if anything, there was a nonsignificant effect in the reverse direction, $F(2, 46) = 0.71$. For old adults, however, the difficulty insensitivity of the constant parameter was limited to the easy-to-medium comparison, whereas the medium-to-difficult comparison shows a clear increase in the constant parameter. Accordingly, Table 4 shows an Age × Difficulty interaction for the constant parameter. This effect disappeared completely, when analyzing the easy and moderate conditions only, $F(1, 46) = 0.05$, $MSE = 0.28, \eta^2 = .001, p > .8$. Thus, there may be aspects to the semantic difficulty manipulation that under particular circumstances produce processing constraints not related to semantic search per se—and these aspects may also be sensitive to aging. However, at least for the easy-to-medium comparison the clear dissociation between constant and slope in terms of nonsemantic and semantic aspects seemed to have worked as intended even for old adults. Finally, Figures 1 and 2 show that increases in executive demands (i.e., switch/no-switch) affected both the constant and the slopes of the depth functions. This is reflected in a strong main effect for the switch/no-switch contrast and a corresponding interaction with retrieval position. Averaged across age groups, the constant amount of time per search step was 0.52 s in the no-switch condition and 2.01 s in the switch condition. This could be taken as evidence for a "switch operation." Note, however, that the constant "switch" duration is strongly affected by difficulty level for both young and old adults. It is not immediately obvious why a switch operation should be affected by difficulty of the semantic category, an aspect we come back to in the Discussion section. Finally, the steeper search slopes in the switch condition may reflect increased search or working memory demands in this condition.

*Age effects.* Our main interest was in the pattern of age differences. As the slope parameters clearly show, there was no difference between young and old adults in the no-switch condition. Aggregating across difficulty levels in the no-switch condition, young adults required 0.69 s more time with every additional word, whereas the corresponding value for old adults was 0.68 s. There was, however, a difference favoring young adults in the constant parameter. Young adults required a constant amount of 0.12 s for each word, whereas old adults required 0.89 s. Thus, under conditions of relatively low executive demands, we found no age effects in those processes that vary as a function of retrieval position. Accordingly, inspection of Table 4 shows age invariance of the slope parameter in the analysis both of the full design and of the no-switch conditions. In contrast, substantial age effects were obtained for the constant parameter, at least in the no-switch conditions. This pattern is compatible with the assumption of no age effects in semantic processing (i.e., the slope parameter) but age sensitivity in nonsemantic, executive processes.

The switch/no-switch comparison is critical for the evaluation of the switching-deficit hypothesis (e.g., Troyer et al., 1997). On the basis of this hypothesis, one would have expected an Age × Switch interaction on the constant parameter reflecting larger general switch costs for old than for young adults. Interestingly, if anything the reverse is true. There is a tendency for an Age × Switch interaction (see Table 4), which, however, is due to slightly smaller switch costs for old than for young adults. Note also that when looking at the switch condition separately there is no significant age effect for the constant parameter (see Table 4). Thus, these data certainly are not consistent with the idea of a general, age-related switching deficit. However, as shown in the Age × Switch × Depth interaction there was a modest age-related increase in search slopes in the switch condition. Averaged across difficulty levels, young adults required 0.87 s more time with every additional word, whereas old adults required 1.06 s more time in switch trials. This rather subtle effect, which was not significant for the switch-only analyses, could be interpreted in terms of age decrements in semantic processing that emerge under high selection demands. However, there are also other possible explanations for this very subtle age difference in switching to which we return in the Discussion.

*Analysis of Positions 1 to 6.* An important result of the foregoing analysis is that the retrieval-position slope is not affected by age across difficulty levels as long as executive demands are low.

Table 4
*Analysis of Variance of Retrieval-Position Function Parameters With the Factors Age, Difficulty, and Switch*

| Analysis and source of variation | *df* | *MSE* | $\eta^2$ | *F* | *p* |
|---|---|---|---|---|---|
| Complete design | | | | | |
| Slope | | | | | |
| Difficulty | 2, 92 | 0.22 | .47 | 40.64 | .00*** |
| Switch | 1 46 | 0.11 | .56 | 57.88 | .00*** |
| Switch × Difficulty | 2, 92 | 0.16 | .00 | 0.05 | .95 |
| Age | 1, 46 | 0.58 | .02 | 0.89 | .35 |
| Age × Difficulty | 2, 92 | 0.22 | .00 | 0.19 | .89 |
| Age × Switch | 1, 46 | 0.11 | .11 | 5.80 | .02* |
| Age × Switch × Difficulty | 2, 92 | 0.16 | .03 | 1.27 | .28 |
| Constant | | | | | |
| Difficulty | 2, 92 | 3.17 | .11 | 5.96 | .00** |
| Switch | 1, 46 | 1.72 | .66 | 91.55 | .00*** |
| Switch × Difficulty | 2, 92 | 2.38 | .07 | 3.62 | .03* |
| Age | 1, 46 | 3.33 | .12 | 6.17 | .02* |
| Age × Difficulty | 2, 92 | 2.92 | .05 | 2.38 | .10 |
| Age × Switch | 1, 46 | 3.33 | .07 | 3.55 | .07 |
| Age × Switch × Difficulty | 2, 92 | 2.38 | .01 | 0.52 | .60 |
| No-switch only | | | | | |
| Slope | | | | | |
| Difficulty | 2, 92 | 0.12 | .43 | 35.18 | .00*** |
| Age | 1, 46 | 0.29 | .00 | 0.01 | .93 |
| Age × Difficulty | 2, 92 | 0.12 | .02 | 0.96 | .39 |
| Constant | | | | | |
| Difficulty | 1, 92 | 1.66 | .03 | 1.20 | .31 |
| Age | 1, 46 | 1.27 | .30 | 19.3 | .00** |
| Age × Difficulty | 2, 92 | 1.66 | .03 | 4.27 | .02* |
| Switch Only | | | | | |
| Slope | | | | | |
| Difficulty | 2, 92 | 0.26 | .28 | 17.95 | .00*** |
| Age | 1, 46 | 0.40 | .06 | 2.84 | .10 |
| Age × Difficulty | 2, 92 | 0.26 | .01 | 0.51 | .60 |
| Constant | | | | | |
| Difficulty | 2, 92 | 3.89 | .12 | 6.57 | .00** |
| Age | 1, 46 | 3.78 | .01 | 0.56 | .46 |
| Age × Difficulty | 2, 92 | 3.89 | .01 | 0.43 | .65 |

$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

However, as has been shown in the error analyses, the pattern of time-outs (i.e., instances where the time for a trial ended before 10 words per category were produced) may compromise this result to some degree because old adults encountered time-outs more often than young adults. Such factors may have produced underestimates of true search slopes for old adults. Therefore, we repeated the analysis of IWTs as a function of age and experimental conditions while restricting retrieval position to Positions 1 to 6. As reported above, time-outs before Position 7 were extremely rare so that this analysis should eliminate any biases that may have been present for the entire sequence. In this analysis, the same pattern of effects emerged as in the analysis of the entire recall sequence, except for two exceptions. First, the Age × Switch effect for the slope was not significant here, $F(2, 92) = 0.74$, $MSE = 0.51$, $\eta^2 = .02$, $p < .4$, suggesting that the corresponding effect for the entire recall sequence was largely due to Positions 7–9. Second, there was an Age × Difficulty effect for the slope parameter, $F(2, 92) = 3.84$, $MSE = 0.36$, $\eta^2 = .08$, $p < .03$, suggesting a small "semantic" age effect for difficult categories. However, both inspection of Figure 1 and of the retrieval-position slopes for Positions 1 to 6 indicates that this effect was mainly due to the switch conditions.[4] Given that for the question of age effects in semantic processing, the no-switch condition is most critical, we, again, repeated the analysis of Positions 1 to 6 while dropping the switch condition. For the slope parameter neither the age main effect, $F(1, 46) = 0.02$, $MSE = 0.12$, $\eta^2 = .001$, $p > .8$, nor the interaction between age and difficulty were significant here, $F(1, 46) = 0.02$, $MSE = 0.06$, $\eta^2 = .00$, $p > .9$. However, for the constant parameter, the main effect for age was highly significant, $F(1, 46) = 8.80$, $MSE = 1.75$, $\eta^2 = .82$, $p < .01$, not, however, the interaction between age and difficulty, $F(2, 92) = 0.88$, $MSE = 4.69$, $\eta^2 = .02$, $p > .4$. Thus, at least for no-switch trials,

[4] Ordered by the no-switch/switch contrast and levels of difficulty, young adults' slope parameters for this function were 0.28, 0.52, 0.83, 0.60, 1.09, and 1.16. The corresponding parameters for old adults were 0.30, 0.52, 0.99, 0.66, 1.08, and 1.79. Young adults' constant parameters were 0.47, 0.58, 0.37, 1.26, 1.19, and 2.37; those for old adults were 0.93, 1.16, 1.25, 1.48, 1.79, and 1.90.

a pattern of no age effects in the semantic search slopes emerged in this analysis where the age-related time-out differences should have played much less of a role than in the analysis of the entire recall sequence. This strengthens the interpretation that for no-switch conditions, there was little evidence for a genuine age-related semantic deficit in these data.

### *Distribution of IWTs*

Fine-grained analyses of the recall process in semantic fluency tasks have revealed that words are typically produced in terms of semantically related clusters (e.g., Fitzgerald, 1983; Graesser & Mandler, 1978; Grunewald & Lockhead, 1980; Rubin & Olson, 1980; Walker & Kintsch, 1985). IWTs between clusters tend to be much longer than within-cluster IWTs, a fact that has been attributed to a specific process of switching between semantic clusters (e.g., Rosen & Engle, 1997; Troyer et al., 1997). Moreover, Troyer et al. (1997) recently argued that age effects in semantic fluency are the consequence of selective impairment of the switch component. Therefore, it would be interesting to see to what degree the pattern of effects we found with the retrieval-position function is representative of all IWTs, or whether it is the result of a small portion of long switch IWTs. With our short recall sequence of only 10 words, it is difficult to distinguish between-cluster IWTs and within-cluster IWTs. However, what we can look at is to what degree the effects we found with the retrieval-position analysis hold across the entire distribution of IWTs. Specifically, this allows us to examine whether or not age effects are limited to long IWTs, probably representing between-cluster switches. Therefore, we sorted the nine IWTs per individual recall sequence according to their size and then averaged them for each condition, age group, as well as each of the nine positions in the size rank order. The corresponding values are shown in Figure 3. In an Age × Switch × Difficulty × Rank ANOVA of IWTs there was a significant main effect for age, $F(1, 46) = 4.87$, $MSE = 174.00$, $\eta^2 = .10$, $p < .05$, and a significant Age × Difficulty interaction, $F(2, 92) = 3.89$, $MSE = 26.40$, $\eta^2 = .08$, $p < .05$, which mirrored the two main age-specific effects found in the constant parameter of the retrieval-position function (see Table 4). However, none of the other age-specific effects were significant, all $F$s $< 2.0$, $\eta^2 < 4.1$. For very long IWTs, there are sporadic indications of an increase of age differences that possibly could be detected with greater statistical power. However, the dominant pattern both in Figure 3 and in the statistical analysis is one of constant age effects across the IWT distribution. Moreover, as suggested by the insets in Figure 3, age effects were present even at the lowest end of the distribution. This impression was confirmed in a separate ANOVA of IWTs in the shortest category. As in the preceding analyses, there was a significant age effect here, $F(1, 46) = 12.13$, $MSE = 1.84$, $\eta^2 = .21$, $p < .01$, and an Age × Difficulty interaction, $F(1, 46) = 4.11$, $MSE = 0.44$, $\eta^2 = .08$, $p < .05$. No other age-related effects were reliable. The Age × Difficulty interaction, again, could be attributed to the most difficult condition, and it disappeared when this condition was omitted, $F(1, 46) = 0.46$, $MSE = 0.10$, $\eta^2 = .01$, $p > .4$. Taken together, the analysis of IWTs strongly suggests that age differences in semantic fluency cannot be attributed to the demands of switching between semantic clusters. Rather, they seem to affect every act of retrieval in a nearly uniform manner.

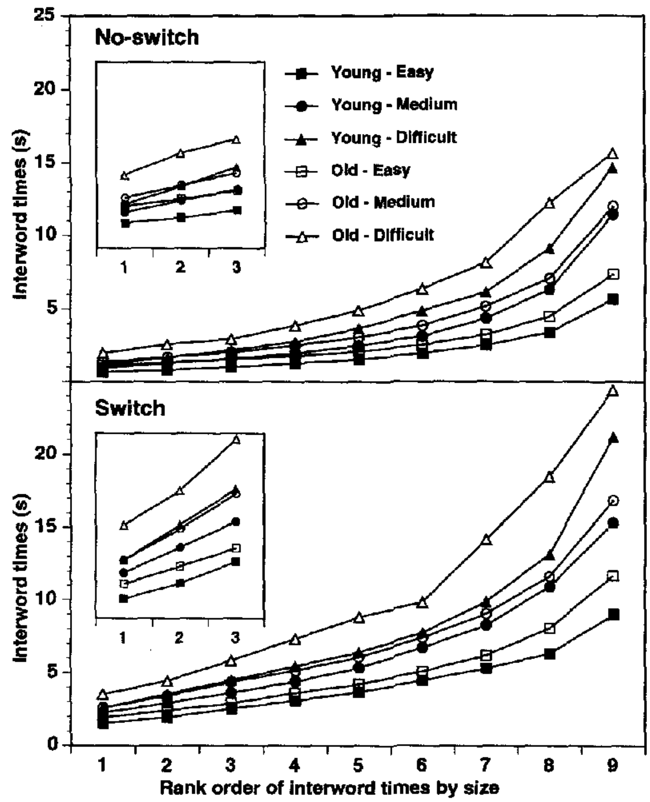


*Figure 3.* Old and young adults' interword times as a function of switch condition, difficulty level, and rank order. Inserted figures show Positions 1 to 3; the *y*-axis of the inserted figure for no-switch conditions is scaled from 0 to 5 s and for switch conditions from 1 to 6 s.

## Discussion

The main question we wanted to answer in this study was whether age differences in semantic fluency tasks reflect age differences in semantic processing proper or in other, nonsemantic components. Our main dependent variable for answering this question was the slope of the retrieval-position function. As we claim this parameter reflects semantic processing in a rather pure way. Interestingly, we found no evidence for age differences in the slope parameter, at least as long as executive demands were low. In contrast, we did find age differences that were relatively constant across retrieval position (i.e., in the constant of the retrieval-position function) and across the distribution of retrieval latencies. We interpret this as an age-sensitive, nonsemantic process. It most likely represents an executive component that regulates each retrieval act but that is itself relatively insensitive to the semantic difficulty of the retrieval process itself.

The results of this study add to a number of empirical demonstrations of no or only very small age differences in semantic processing (e.g., Fitzgerald, 1983; Laver & Burke, 1993; Madden et al., 1993; Verhaeghen et al., 1997). In the initial sections of the Discussion we focus on some open issues and implications associated with the finding of no age differences in semantic processing. In the final section, we try to complement the picture by discussing both substantive and methodological issues related to the potential role of executive control during semantic retrieval and age differences therein.

### Open Issues

Our conclusions rest on the validity of the assumption that the constant of the retrieval-position function represents nonsemantic processes whereas the slope represents semantic processing efficiency. In order to check these assumptions, we had included in our design a manipulation of semantic processing demands via semantic category difficulty. As expected, semantic difficulty did have a very strong effect on the steepness of the retrieval-position function, thus validating our claim that the slope actually does represent semantic activation processes. The picture was somewhat more complicated for the constant parameter, which should have been unaffected by the category-difficulty manipulation. For young adults this actually was the case. However, for old adults this was true for the easy and the medium difficult category, whereas there seemed to be a larger constant for the difficult category. We submit that whatever the reason for this exception from the otherwise consistent dissociation pattern, it does not affect our central conclusion that there is at least one component of semantic processing (reflected by the search slope) that seems to be largely age invariant. Currently we cannot say whether the age difference for the most difficult categories reflects an additional aspect of semantic processing that is age sensitive or some other, nonsemantic aspect that comes into play in this condition. For example, retrieval of difficult-category words could pose higher demands in terms of maintaining a clear representation of the current search criterion, and old adults may be impaired in such an executive, maintenance process.

Another aspect that needs to be discussed is the fact not only that search slopes were generally larger in the switch than in the no-switch condition but also that this effect showed a small but reliable interaction with age. This could be interpreted in terms of generally larger "semantic selection demands" and the emergence of age differences in "pure" semantic processing in situations of such high selection demands. We believe, however, that another interpretation, based on the assumption of increased memory demands in the switch condition, is just as plausible: While searching within one category, the other category as well as earlier produced words associated with that category need to remain accessible until the switch back to that category occurs. Moreover, with increasing retrieval position, and, thus, a longer search within each category, this maintenance-of-information problem becomes more severe so that an increase in IWTs as a function of retrieval position could be a natural consequence. Old adults typically exhibit difficulties in conditions with high working memory demands so that it is not surprising to see a larger switch effect on the search slope for old than for young adults. In line with this interpretation is the finding that in the switch condition, old adults showed a numerically small, but highly reliable, increase in the number of within-category perseverations, suggesting that in this situation it was more difficult for old adults to remember which words they already had produced. Finally, the discussion of possible reasons for the age effect in the switch-condition search slope (and the increased perseveration rate) should not divert attention from the fact that this age-specific deficit is subtle, both when compared with overall switch costs and when compared with typical effects in nonsemantic, speeded tasks (e.g., Cerella, 1990) and, in particular, when compared with coordinatively demanding tasks (Mayr & Kliegl, 1993). Thus, the bigger picture is one of relative age resilience of complex selection processes in semantic memory.

A further limitation arises from our focus on semantic fluency tasks. Interestingly, there are reports suggesting a complete absence of age differences in assessing phonemic fluency where participants are required to generate words with a particular initial letter (e.g., Troyer et al., 1997). This finding poses a challenge to the view that age differences in semantic fluency are due to a nonsemantic component. After all, there is no obvious reason why the constant age effect that we found in our data and that we attributed to a nonsemantic control deficit should not also play a role in phonemic fluency tasks. It is important to note, though, that there are studies that do report age differences in phonemic fluency (e.g., Parkin & Walker, 1991). Also, basically all relevant studies in the literature report overall performance scores instead of more fine-grained analyses. We, thus, believe that the final word on a potential phonemic–semantic distinction regarding age differences in fluency tasks needs to await detailed comparisons of age differences in both semantic and phonemic fluency protocols.

Finally, one should be cautious with generalizing the results of this study beyond the age range we had examined. It is possible that decrements in semantic memory would arise in very old age. Indeed, decline in crystallized abilities has been observed in studies that had included not only old but also very old adults (e.g., Lindenberger, Mayr, & Kliegl, 1993). The fact that in very old age, these effects can also be found for unspeeded vocabulary tests could point to a genuine semantic memory deficit. However, to make more definite inferences about late-life age effects in semantic processing proper, it would be of interest to look at the retrieval-position function for these age ranges.

### Age × Complexity Effects

One of the most dominant patterns in cognitive aging research is the approximately proportional Age × Complexity effect (e.g., Cerella, 1990; Salthouse, 1996). In particular, age differences in nonsemantic response-time tasks seem to be well described by a proportional factor relating young adults' RTs to old adults' RTs. This proportional slowing has been attributed to a decrement in a very general resource such as mental speed. The Age × Complexity effect currently has the status of a new null-hypothesis against which specific effects (or the absence of age effects) need to be tested (e.g., Kliegl & Mayr, 1992). For semantic processing a "reduced variant" of this proportional slowing has been observed in one meta-analysis of lexical decision tasks (e.g., Lima et al., 1991; Myerson et al., 1992), a finding that would be compatible with the notion that semantic processing is impaired, although less so than nonsemantic processing.

In contrast to these results, we found no evidence for a slowing of semantic processes (in the absence of switching demands). This was the case even though judged by estimated processing times, task complexity was much higher than in typical lexical or semantic RT tasks. Interestingly, our finding of a no-age-difference pattern in the depth-function slope accompanied by an age effect in the constant implies additive slowing instead of proportional slowing (e.g., Lima et al., 1991; Myerson et al., 1992). Additive slowing was also reported by other researchers on the basis of meta-analytic results (Laver & Burke, 1993) and has been interpreted in terms of age deficits in nonsemantic aspects. The current results, thus, not only are consistent with earlier demonstrations of age invariance in semantic processing but also extend these findings to relatively time-demanding search processes in semantic memory.

We believe that the main reason for the divergence of results in the literature lies in the fact that semantic and nonsemantic components are often not clearly separable in "typical semantic" tasks so that unambiguous inferences about age differences in semantic processing are impossible. Age differences in such tasks may simply reflect nonsemantic components. This probably is the case for standard assessments of semantic fluency. Very likely, the confounding of semantic and nonsemantic processes also occurs for other, "semantic" indicators such as lexical decision RTs. As outlined in the Introduction section, even the size of semantic priming effects may be contaminated by nonsemantic aspects (e.g., Laver & Burke, 1993; Stanovich & West, 1983).

Thus, a conclusion from the current work and related studies (e.g., Laver & Burke, 1993) is that if the goal is to study age differences in genuine semantic processing, one should be cautious with interpreting overall performance scores derived from "semantic" tasks (e.g., psychometric assessments of fluency) or indicators that are known to be sensitive to nonsemantic aspects (e.g., semantic priming effects); and one should be even more cautious with inferences based on meta-analytic integrations of such measures (e.g., Lima et al., 1991; Myerson et al., 1992). Instead, strong efforts are necessary to derive indicators that can be assumed to reflect "pure" semantic processing both on theoretical and empirical grounds. Any kind of sloppiness in this respect is likely to increase the probability of attaining a result in accord with the "new null-hypothesis" in cognitive aging, the Age × Complexity effect.

### *Why Does Semantic Memory Stay?*

If one accepts the validity of the current results for the age range studied, the question arises what the reason for the relative age invariance in semantic processing is. We see three possibilities, which are not mutually exclusive.

First, neuroanatomical structures underlying semantic memory may simply be less affected by age-related biological changes than other structures. There is some evidence that not all brain areas are affected uniformly by biological aging. Specifically frontal lobes seem to show more biological loss than posterior brain regions (e.g., Moscovitch & Winocur, 1992; West, 1996), and decrements in these regions could be associated with the age effect in the nonsemantic fluency component (e.g., Troyer et al., 1997). In contrast, temporal regions, often associated with semantic processing (e.g., Moscovitch, 1994), may be relatively spared in old age. Converging evidence for such an explanation of the observed pattern of age differences could be attained by comparing frontal patients and temporal-lobe patients in parameters of the retrieval-position function. We would expect frontal-lobe patients to exhibit selective increase in the constant parameter, whereas temporal-lobe patients should exhibit selective increase in the search slope.

Second, there could be just as much "biological" decline in semantic memory as in other functions. However, life-long learning may counteract biological decrements. Direct empirical support for the thesis that life-long practice of specific cognitive components can help maintain high levels of functioning despite biological loss comes from studies on aging expert pianists or chess players (Charness, Krampe, & Mayr, 1996; Krampe & Ericsson, 1996). However, these studies also showed that only extensive, "deliberate practice" counteracted age-related decline. Given that people rarely "deliberately practice" semantic knowledge one may have some doubts whether or not the life-long experience account can explain the absence of age differences in semantic memory. This is particularly true when considering the fact that the power law of practice (Newell & Rosenbloom, 1981) predicts that buildup and stabilization of semantic facts proceed fast early in life, but once established, further improvement via mere exposure should become increasingly difficult. Thus, it is an open question whether or not the small, residual improvement predicted by the power law of practice would be sufficient to eliminate slowing effects in the magnitude of 50 to 100% often found in nonsemantic domains.

A third account was proposed by Burke et al. (1991) and is based on the idea that the organization of semantic knowledge is highly redundant and, thus, may be more resilient to biological decrements than other domains. If memory access via one route is impaired because of age-related loss there are still many routes that could be followed. Weakening of links would become observable only for one-to-one connections such as between lexical nodes and phonological nodes. Extending this argument, problems may arise also in cases where connections between semantic nodes are sparse or very indirect. Thus, it is possible that different patterns of age effects than obtained in this study would emerge if tasks were used in which participants need to produce or verify distant semantic relationships. In fact, the difficult semantic categories used in this study where we found large age differences even in the intercept of the retrieval-position function may constitute such a condition.

On the basis of current knowledge neither can we confirm one of the possible explanations for the age resilience of semantic memory, nor can we rule out that some age deficits in semantic processing may show up in further experimentation. However, the method we have introduced may be useful for further, detailed explorations of this matter. In any case, the current demonstration of a complete absence of age differences in at least some aspects of semantic memory along with similar findings from other authors (e.g., Laver & Burke, 1993) imposes strong constraints on general theories of age-related cognitive decline.

### *Executive Control*

In this study, the issue of executive control is relevant in two different ways. First, we suggest that the constant age effect we found across positions of the recall sequence, and also across much of the IWT distribution, is due to a deficit in executive control processes that support retrieval from semantic memory. On a general level, this is consistent with the two-component view of memory retrieval proposed by Moscovitch and colleagues that specified both a frontal-lobe, executive component and a purely associative, temporal-lobe component (e.g., Moscovitch & Winocur, 1992). Recently, Troyer et al. (1997) made the additional argument that the executive component becomes particularly relevant during switches between semantic clusters. The results we report in this article are not compatible with this version of the two-component view: We found a relatively constant age difference across the entire distribution of IWTs, and even in the explicit switching condition there was little to no evidence in favor of a specific switching deficit. We therefore suggest that executive control processes that accompany every single act of memory retrieval are implied by an age-related deficit rather than processes that are specific to switching. For example, this could imply the updating and maintenance of the current search probe. Such processes are necessary to initiate every new retrieval act and may not differ in any critical (or easily detectable) way between no-switch and switch transitions.

These considerations lead directly to the second point related to executive control. We did find a relatively large and age-invariant switch component when contrasting no-switch and switch conditions (i.e., the 1.5-s switch effect on the constant). If the view developed so far is correct, what processes are reflected by this component? A seemingly straightforward interpretation of switch costs would hold that they represent, at least in part, domain-unspecific executive control processes (e.g., Mayr & Keele, in press; Rogers & Monsell, 1995; Shallice, 1994). However, two aspects of our results are difficult to reconcile with such a notion. First, given the known age differences not only in executive control (e.g., Kliegl, Mayr, & Krampe, 1994; Mayr & Kliegl, 1993; Verhaeghen et al., 1997) but also in most nonsemantic processes (e.g., Cerella, 1990), one would have expected age differences in switch costs—if these actually do reflect a domain-unspecific (i.e., nonsemantic) processing component. Second, the switch effect on the constant parameter increased monotonically with semantic difficulty. This should not have occurred if switch costs reflect only a domain-independent set-switching operation. Instead, this finding suggests that the dominant process reflected both by no-switch IWTs and by switch costs alike is nothing more and nothing less than search in semantic memory. Just as search for an exemplar within a category depends on category difficulty, also establishment of the next semantic category itself may require search, which in turn should be affected by category difficulty (i.e., its "remoteness" within the semantic network). Of course, this does not imply that no domain-unspecific control component is involved when switching semantic categories. However, such a component may do little more than setting and resetting top-level goals (e.g., search criteria), which computationally may be a rather trivial and fast process. In contrast, the actually critical process in terms of time demands may be very similar whether or not a search criterion has changed, only that in the switch condition, more of the same process is required than in the no-switch condition. Interestingly, our view is compatible with results obtained when comparing normal controls and Parkinson patients who presumably have a specific set-switching deficit (Downes et al., 1993). When switching between semantic categories or between phonemic categories, patients showed no impairment (see also Gurd & Ward, 1989). Only when switches had to be made between a phonemic and a semantic category did a specific deficit arise. Presumably, only the latter required a change in the processing algorithm, whereas within-domain switches simply required more of the same type of search process than in the no-switch condition.

We recognize that our inferences concerning the role of executive control are indirect. In future work, more direct experimental control over processes such as set maintenance or updating should be attempted. For example, the difficulty of the set maintenance process could be manipulated by specifying a set of category exemplars that are supposed to be excluded from the sample of "legal" exemplars (e.g., Rosen & Engle, 1997). Similarly, updating difficulty may be increased by requiring shifts not only in content type (as when switching semantic categories) but also in algorithmic aspects of search process (as when switching between semantic and phonemic search criteria; e.g., Downes et al., 1993). We should expect that such manipulations interact with age in the constant of the search function but leave the slope unaffected.

In conclusion, the data presented here provide a relatively clear picture concerning age differences in semantic processing proper. Specifically, the rate of searching semantic memory seems to be unaffected by age, at least in the no-switch condition and up to age 70. In contrast, with respect to the issue of age differences in executive control in the context of semantic memory processing, the present work raises as many questions as it answers. At the very least, however, our results concerning executive control raise the possibility that particular aspects of control over complex selection processes may be much more tied to domain-specific constraints than the notion of a *central* executive (e.g., Baddeley, 1986; Shallice, 1994) would imply.

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## Appendix

List of Categories Used in Main Experiment Ordered by Difficulty and Switch/No-Switch Sets

| | Difficulty | | |
|---|---|---|---|
| Set | Easy | Medium | Difficult |
| A | Body parts | Building materials | Traffic signs |
| | Four-legged animals | Vegetables | Writing utensils |
| | Colors | Weather phenomena | Communication means |
| | Vehicles | Spices | Insects |
| B | Birds | Kitchen utensils | Fabrics |
| | Clothes | Nonalcoholic beverages | Sciences |
| | Musical instruments | Fish | Fluids |
| | Food items | Flowers | Criminal acts |

*Note.* For switch trials, the first two categories and the second two categories within a set were combined.

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