INTERNATIONAL JOURNAL OF BEHAVIORAL DEVELOPMENT, 1998, *22* (4), 813–845

Differential Age Effects on Semantic and Syntactic Priming

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Adult age differences in the processing of semantic and syntactic information during language comprehension were investigated in a lexical decision task in which the target word was preceded by a sentence fragment. Sentence fragment and target were presented visually and made up either a correct or an incorrect sentence containing either a semantic violation (selectional restriction violation) or a syntactic violation (subcategorisation violation). Experiment 1 revealed a differential age effect for the processing of syntactic,

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The present research was supported by the Alfried Krupp von Bohlen und Halbach Prize awarded to the first author and by the Berlin-Brandenburgische Akademie der Wissenschaften. The research reported in Experiment 3 was conducted within the context of the Berlin Aging Study (BASE). The study is directed by a Steering Committee consisting of P.B. Baltes, psychology, H. Helmchen, psychiatry, K.U. Mayer, sociology, and E. Steinhagen-Thiessen, internal medicine and geriatrics. BASE is a project of the Committee on Aging and Societal Development in collaboration with institutes and research centres associated with the Psychiatric Clinic of the Free University of Berlin, the Virchow Clinic of the Humboldt University of Berlin, and the Max-Planck-Institute for Human Development and Education where the study is co-ordinated. The Committee on Aging and Societal Development, initiated in 1987 by the former Academy of Sciences and Technology in Berlin, has been sponsored by the Berlin-Brandenburg Academy of Sciences since 1994. From 1989 to 1991, BASE was financially supported by the Federal Ministry of Research and Technology. Since 1992, financial support has been awarded by the Federal Ministry of Family Affairs, Senior Citizens, Women, and Youth (313–1722–102/9 + 314–17222–102/9a). We thank Janet Nicol and two anonymous reviewers for comments on the manuscript.

but not for the processing of semantic violations. Experiment 2, using visually degraded targets, demonstrated that this differential effect was independent of peripheral processing aspects, such as visual encoding. Experiment 3 including a neutral baseline condition revealed that the differential age effect on syntactic processing was due to controlled rather than to automatic aspects of priming, as it was observed for the cost component, but not for the benefit component. Experiment 4 revealed that this effect was independent of the timing parameters used for stimulus presentation. It appears that age can have differential effects on specific cognitive domains, such as syntax and semantics. This may be attributable to the amount of controlled processes involved in syntactic and semantic priming.

One of the issues still discussed in the field of aging research is the question whether cognitive aging affects language processes. A number of studies investigating lexical-*semantic* aspects (e.g. Balota & Duchek, 1988; Bowles & Poon, 1985, 1988; Burke, White, & Diaz, 1987; Burke & Yee, 1984; Howard, 1983; Madden, 1986, 1988, 1989) found no particular age-related changes concerning these aspects of language processing. But what about other aspects of language processing involved in sentence comprehension, such as *syntactic* aspects?

Although the identification of lexical elements is a necessary condition for language processing, it is certainly not sufficient for sentence understanding. In order to identify the grammatical relation between lexical elements, syntactic structures must be recognised. The syntactic information in a language is conveyed by word order, function words, and inflectional elements, but also by syntactic information encoded in lexical elements, such as, for example, syntactic category information (e.g. information of whether a lexical element is a noun, a verb, a preposition, etc.), and, in the case of verbs, argument structure information (e.g. information about how many and which arguments a verb can take). Although there is an ongoing discussion in the psycholinguistic literature of whether verb argument structure information is used to guide the initial syntactic parse (Ferreira & Henderson, 1990; Shapiro, Nagel, & Levine, 1993), there is no dispute that this information must be available when thematic role assignment takes place.

The few studies that have investigated syntactic aspects of langauge processing in aging seem to suggest that these processes might change with age. This suggestion comes from experiments that have used production as well as off-line comprehension tasks (Emery, 1985; Kemper, 1987, 1992; Norman, Kemper, Kynette, Cheung, & Anagnopoulis, 1991). Only recently, one study has assessed syntactic aspects of language comprehension in the elderly with an on-line task (Zurif, Swinney, Prather, Wingfield, & Brownell, 1995). This study showed a difference between younger participants and elderly participants when processing sentences in which lexical elements

were displaced from their canonical position.[1] The authors attributed this age-related difference to a difference in the memory capacity of young and elderly adults. To our knowledge, however, no study has undertaken a direct comparison between semantic and syntactic processes. The data available in the literature rather stem from different studies using different types of tasks: Whereas semantic aspects have usually been examined using semantic priming tasks, syntactic aspects have mostly been investigated in off-line comprehension or production tasks. The present paper will report data from a series of experiments using a sentence priming task to examine both semantic and syntactic aspects of language processing in old age.

SEMANTIC AND SYNTACTIC PRIMING

In the following, we will briefly review the results from semantic and syntactic priming studies in young adults as well as from semantic priming studies in the elderly before turning to the present study. *Semantic priming* refers to the finding that subjects in a lexical decision or naming task typically show faster responses to targets preceded by a semantically related prime-word or a prime-sentence than to targets preceded by an unrelated prime. This effect is attributed to two components contributing to the semantic priming effect: the automatic one and the attentional one. The *automatic* component is assumed to reflect spreading of activation through the semantic network, increasing the level of activation for those words that are semantically related to the prime (Keefe & Neely, 1990; Neely, 1977; Posner & Snyder, 1975; Stanovich & West, 1983). The *attentional* component is taken to reflect an expectancy mechanism that induces an expectation for a particular item that will follow. Both mechanisms, the automatic and the attentional one, raise the activation level for words being semantically related to the prime. They are the basis for the benefit in recognition times observed for words preceded by a semantically related versus a neutral prime. The observed cost in recognition time for words preceded by a semantically unrelated versus a neutral prime is taken to represent "the process of overcoming the inhibition of semantically unrelated prime information" (Madden, Pierce, & Allen, 1993, p. 491). Although there are quite a number of studies on semantic priming during sentence processing in young adults (for a review see Zwitserlood, 1989), only some of them investigate the particular aspect of cost and benefit (e.g. Stanovich & West, 1983).

A similar picture emerges for *syntactic priming*. Only a few studies focus on the nature of cost and benefit in this domain (Deutsch & Bentin, 1994;

[1] More specifically, they showed that elderly participants in contrast to younger participants did not reactivate a filler in filler-gap constructions when the distance between filler and gap was large.

Friederici & Schriefers, 1994; O'Seaghdha, 1989; West & Stanovich, 1986). Those studies, however, suggest that the syntactic priming effect is composed of a benefit and a cost component.[2] Whether the benefit can be viewed as being due to an automatic and an attentional component, similar to the benefit component observed for semantic priming, cannot be decided on the basis of the available data. In principle, both components are possible contributors: A given structural element (e.g. a gender-marked article) could either reduce the number of possible nouns by activating all nouns whose gender matches the prime article by means of an automatic spreading activation process, or it could build up more attentionally based expectations for possible nouns to come, namely, those that match in gender. It has been argued, however, that the existence of a syntactically organised lexical network has no convincing support from empirical evidence or independent theoretical considerations. The mechanism of spreading activation, therefore, is not considered to be a likely candidate for the source of facilitation in syntactic priming (Deutsch & Bentin, 1994). Whether the observed facilitation in syntactic priming is indeed due to attentionally based processes is open for discussion. The cost component observed for syntactic priming has received a less straightforward interpretation than the cost component for semantic priming. The assumption that the cost component for syntactic priming might be due to strategic influences is supported by the finding of Deutsch and Bentin (1994) that manipulation of attention-related strategies affected the magnitude of the inhibition effect, but not the facilitation effect. Thus, in syntactic priming both the benefit and the cost component might be due to the formation of context-based expectations, although attentional processes may be more heavily involved in the latter component.

Studies investigating *semantic priming in old age* indicate that this aspect of semantic processing as reflected by priming is basically unaffected by age (Balota & Duchek, 1988; Bowles & Poon, 1985, 1988; Burke, White, & Diaz, 1987; Burke & Yee, 1984; Howard, 1983; Howard, McAndrews, & Lasaga, 1981; Madden, 1986, 1988, 1989). In a series of experiments, Madden, Pierce, and Allen (1993) found that this holds for both the benefit and the cost component. If anything, it is the benefit component that is affected by age but only when the stimulus input is degraded. Following Stanovich and West (1983), who had used degraded visual stimuli in a priming study with young adults, Madden (1988) showed age-related changes for the benefit component. This result, however, was attributed to an age-related slowing of

[2] The syntactic facilitation effect constituting the benefit component, however, seems somewhat less reliable across experiments than the inhibition effect constituting the cost component (e.g. Bates, Devescovi, Hernandez, & Pizzamiglio, 1996; Grosjean, Dommergues, Cornu, Guillelmon, & Besson, 1994).

feature extraction during early stages of processing and not to lexical or post-lexical processes. These are assumed to be unaffected as the cost component in semantic priming is not subject to age-related changes. Thus, semantic processes, in general, seem quite resistant against age-related changes. What is observed, however, in old age is a slowing in the participant's reaction times in cognitive and perceptual tasks (e.g. Hertzog, 1991; Salthouse, 1985). According to the general slowing hypothesis, this phenomenon is caused by a general decrease in processing rate with age. Recent evidence, however, suggests that the magnitude of age differences in old age may vary systematically as a function of task domain and task complexity (Lima, Hale, & Myerson, 1991; Mary & Kliegl, 1993). Based on metaanalyses involving a total of 225 experimental conditions from 26 different studies, Lima et al. (1991) concluded that response slowing was less pronounced in the lexical processing domain, regardless of whether naming, relatedness judgements, or category membership judgements were required, than in the nonlexical domain. Specifically, lexical decisions were slowed by a factor of about 1.5, whereas nonlexical decisions were found to be slowed by a factor of about 2 when the same linear equation was used. In a subsequent metaanalysis Myerson and colleagues (Myerson, Ferraro, Hale, & Lima, 1992) found the age differences in the absolute magnitude of semantic priming effects to be completely consistent with the notion that older adults' response times in the lexical domain are slowed by a factor of about 1.5, whereas Laver and Burke (1993) described the relationship between age and semantic priming effects as a function with a positive intercept and a slope of 1.0. Of course, one may try to reconcile Laver and Burke's findings as well as other results documenting the domain-dependent nature of age differences in latencies with the general slowing hypothesis by adding the assumption that slowing, as a general mechanism, can be attenuated or modulated by domain-specific factors. On the other hand, one could also argue that slowing itself may be process-specific, and may qualify as a phenomenon to be explained rather than as an explanation of cognitive changes (Molenaar & van der Molen, 1994). An empirical discrimination between these alternatives is beyond the scope of this article. Rather, for the remainder of this paper, we accept response slowing as an empirical (i.e. descriptive) regularity, and focus on the question whether or not the slowing observed for lexical-semantic processes generalises to the syntactic domain.

Semantic and syntactic processes also differ functionally with respect to their underlying brain mechanisms. At the functional level, semantic and syntactic processes differ with respect to their degree of dependency on fixed rules. Syntactic processes are strictly rule-governed, whereas semantic processes are to a lesser degree as they must guarantee the processing of new semantic associations.

Moreover, neuropsychological data (e.g. Caramazza & Zurif, 1976; Friederici, 1983a; Zurif, Swinney, Prather, Solomon, & Bushell, 1993) as well as neurophysiological data (e.g. Friederici, Hahne, & Mecklinger, 1996; Friederici, Pfeifer, & Hahne, 1993; Kutas & Hillyard, 1983; Neville, Mills, & Lawson, 1992) suggest that semantic and syntactic processes involve different brain systems. Given the functional neuropsychological differences between semantic and syntactic processing, this paper discusses whether aging affects the two aspects of language processing in similar or different ways.

THE PRESENT STUDY

The goal of this paper is to investigate if and to what extent cognitive aging affects semantic and syntactic priming differently with respect to the cost and benefit components. Similar to research evaluating semantic priming (Burke & Yee, 1984; Madden, 1988, 1989), we used a sentence priming technique in which subjects read a sentence fragment and make a lexical decision about a visual target presented immediately at the offset of the sentence prime. In contrast to earlier aging studies, focusing exclusively on the semantic relationship between the sentence prime and the target, the present study also varied their syntactic relationship. In Experiment 1 we establish an age-related difference between semantic and syntactic priming. Experiment 2 tests whether this difference is due to peripheral aspects of processing, and Experiment 3 evaluates the contribution of the benefit and cost components to the observed priming effects by introducing a neutral baseline. Experiment 4, finally, shows that the age-related difference between semantic and syntactic priming is independent of the timing parameters used for stimulus presentation.

The types of syntactic and semantic information covered in this paper concerned subcategorisation constraints and selectional restrictions of verbs. Both types of information are associated with a verb's lexical entry in the mental lexicon, but are assumed to concern different processing domains. Selectional restrictions specify the semantic aspects of the nouns that can fill a verb's argument roles (e.g. the agent role of the English verb "die" requires an animate noun). This type of information is related to the domain of lexical semantics. Subcategorisation constraints, by contrast, specify the argument structure of a given verb (e.g. the verb "die" cannot take a direct object, as it is an intransitive verb; see Shapiro, Zurif, & Grimshaw, 1987, for a detailed discussion of the processing of the argument structure of verbs). Using German as the test language, we focused on the recognition of a verb in sentence final position and the impact of contextual

information concerning the verb's subcategorisation and selectional restriction requirements.[3]

In the present study, critical conditions contained a sentence fragment prime consisting of Article + Noun + Auxiliary, followed by a past participle form as the target word. The sentence fragment and the target word either formed a correct or incorrect sentence. In incorrect sentences, the target word was either semantically or syntactically incompatible with the beginning of the sentence. Choosing these constructions we were able to keep the underlying sentence structure as comparable as possible in the incorrect semantic condition (e.g. Der Apfel wurde gelesen/The apple was read) and the incorrect syntactic condition (e.g. Der Mann wurde gelacht/ The man was laughed). The sentence fragments did not contain specific selectional restriction and subcategorisation information associated with a particular verb. They could, however, set up some more general expectations on particular classes of verbs as the auxiliary "wurde"/"was" asks for transitive main verbs and the noun "Mann"/"man" plus the auxiliary requires a verb that has the selectional restriction for animate nouns in the patient role.

When the beginning of the sentence and the target form a correct sentence we expect a benefit based on automatic activation of lexical elements and/or the build-up of expectations. When the beginning of the sentence and the target mismatch we may observe a cost. For the semantic domain this cost component has been taken to reflect the processes of overcoming the inhibition or deactivation of semantically unrelated words. For the syntactic domain the cost component has not yet been specified. We will leave the more detailed specification of this component to the General Discussion, not, however, without formulating the general expectation that semantic and syntactic priming may differ with respect to this component. This expectation is based on the consideration that syntactic processes are more strictly rule-governed, and therefore the process of overcoming a syntactic mismatch between sentence beginning and target may be more costly.

As an additional aspect of the present material we have to consider that priming processes usually tested run forward unidirectionally from the prime to the target: for example, from the noun prime (doctor) to the noun target (nurse) in a word-word priming paradigm or from the verb prime (write) to a noun target (letter) in a sentence priming paradigm (He wrote the letter). These processes could be considered to involve aspects of automatic speading activation as well as attentional expectancies. In the

[3] Similar sentences were used in an electrophysiological study indicating that these two types of information are processed by different brain systems (Rösler, Friederici, Pütz, & Hahne, 1993).

present German material, priming processes may be bidirectional as they run forward from the noun (letter) to the target verb (the letter was written), and in addition backward, that is, from the sentence final verb (written) to the preceding noun (letter). This latter process could be considered as a post-access check whether the information carried by the already received noun matches the target verb's selectional restrictions or whether the information carried by the already perceived auxiliary matches the verb's subcategorisation constraints. Such a checking mechanism would have particular effects whenever the outcome of the checking process is negative, but the required lexical decision response on the target is positive. In this case, the system has to overcome the negative result of the checking process in order to give the required positive lexical decision.

In summary, we have several potential influences on the lexical decision latencies for the material under investigation. First, there are forward processes, such as automatic activation and the building up of expectations, and there are automatic backward post-access checking processes, which in case of a positive outcome, should lead to a benefit in the required positive lexical decision latencies (yes-responses). Second, if the outcome of the checking processes is negative, additional processes are necessary to overcome the mismatch between prime and target in order to give the required positive lexical decision response. These additional processes should lead to a cost in lexical decision latencies.

THE EXPERIMENTS

We will report four experiments exploring the age-related effects on the different processes involved in semantic and syntactic processes, all using similar materials and similar procedures. We will first describe those methodological aspects that are identical for the experiments, before turning to the individual experiments. Experiments 1 and 2 used the same materials but different presentation modes. Experiment 1 used a nondegraded visual presentation, whereas in Experiment 2 the target words were presented in a degraded form. A comparison between these two experiments should allow testing the potential influence of changes in peripheral visual encoding on semantic and syntactic processes. Experiments 2 and 3 both used the degraded visual presentation mode, but the latter experiment included a neutral baseline condition to identify benefit and cost components in semantic and syntactic priming. As the timing of presentation of primes and targets differed for young and elderly adults in Experiment 3, Experiment 4 was conducted to make sure that possible processing differences between the two age groups are independent of these different timing parameters. Experiment 4 was a replication of

Experiment 3 with young adults only, using the presentation times that had been used for the elderly adults in Experiment 3.

Materials

In the first two experiments the critical trials consisted of a short sentence fragment followed by a past participle form (hereafter called the target). The sentence fragments were of the form ART + N + AUX (e.g. Der Apfel wurde/The apple was). The targets were verbs (e.g. GELESEN/READ). The targets were always presented in upper case, whereas the primes were presented in lower case with the sentence beginning and the first letter of the noun being presented in upper case (as required by the rules of German orthography). The stimuli were presented in black on a white background. Each target occurred twice, once in a correct combination with a prime, and once in an incorrect combination with a prime.

For semantically incorrect trials, the selection restrictions of the target verb were violated by the noun in the sentence fragment (e.g. Der Apfel wurde GELESEN/The apple was READ). The corresponding correct trials combined the same verb with a different noun in the beginning of the sentence (e.g. Das Buch wurde GELESEN/The book was READ). Altogether, there were 10 such pairs of correct versus semantically incorrect sentences. In the resulting 20 sentences, 10 different nouns were used in the sentence beginnings such that each noun occurred once in a correct sentence and once in a semantically incorrect sentence such that each target served as its own control. In 5 of the 10 correct sentences the auxiliary, wurde/was, was used, and in the remaining 5 sentences the auxiliary, ist/is. The same holds for the 10 semantically incorrect sentences. All target verbs were transitive.

For the syntactically correct sentences the beginning of the sentence consisted of an article, a noun, and the auxiliary, hat/has or ist/is. The target was the past participle of the intransitive verb (e.g. correct: Der Mann hat GELACHT/The man has laughed). For the corresponding syntactically incorrect trials the sentence contained a violation of the target verb's subcategorisation constraint. This was achieved by changing the auxiliary of the correct beginning of the sentence, from hat/has or ist/is to wurde/was. Wurde/was is the auxiliary to be used in German verbal passive (e.g. incorrect: Der Mann wurde GELACHT/The man was LAUGHED). There were 10 different target verbs yielding 10 syntactically correct sentences. In 5 of these correct sentences the auxiliary, hat/has, was used, in the remaining 5 the auxiliary, ist/is. The 10 incorrect sentences differed from the correct sentences only with respect to the auxiliary. Thus, as for the semantic condition, each target verb served as its own control (see the Appendix for a listing of the materials used in Experiments 1 and 2).

All verb targets were verbs with unprefixed stems preceded by the morphological element, ge-, signalling the past participle.[4] Targets in the semantic and the syntactic condition were matched for length with a mean of 8.1 letters in the semantic condition (range: 6–11) and in syntactic condition (range: 7–10).

Owing to the within-condition constraints (strong semantic relatedness between noun and verb in the semantic condition and no semantic relatedness between noun and verb combined with clear transitivity), as well as the cross-condition constraints (unprefixed stems and word length), frequency could only be approximately controlled for. Mean frequency for targets in the semantic condition was 24.5 per million and for targets in the syntactic condition, 12.5 per million. The possible difference in reaction time in the two conditions was taken into consideration by using the identical targets in the correct and incorrect condition arguing on the basis of difference scores.

Twenty nonword trials were derived from the critical trials in the following way. Ten sentences from the correct versus semantically incorrect sentences were selected. Half of these sentences had the auxiliary, ist/is, and half the auxiliary, wurde/was. Furthermore, half of the sentences were from the correct condition and half from the semantically incorrect condition. For each of these 10 sentences, the target word was converted into a nonword by changing one letter. For three targets, this letter was in the first third of the word, for four targets it was in the second third of the word, and for the three remaining targets it was in the last third of the word. Letter changes were only made in the words' stems, not in the prefixes and suffixes indicating the past participle. Another 10 sentences were selected from the correct versus syntactically incorrect sentences. Again, half of these sentences were from the correct and half from the syntactically incorrect condition. Three of these sentences had the auxiliary, hat/has, four the auxiliary, wurde/was, and three the auxiliary, ist/is. Nonwords were derived from the corresponding 10 past participles in the same way as described earlier. Sentences were presented in a quasi-randomised order, counterbalancing for the appearance of targets in the correct and incorrect condition and for the distribution of word and nonword target across the experiment.

The sentence material of Experiments 3 and 4, which included a neutral baseline condition, consisted of only eight semantically correct versus incorrect sentence pairs, and eight syntactically correct versus incorrect sentence pairs. For each of these sentence pairs, a corresponding neutral baseline sentence was constructed (e.g. Jetzt sehen sie TARGET/Now you will see TARGET) (for details see later). Fifteen practice trials were

[4] Note that German has a large number of prefixed verbs (e.g. *aufstehen*, *to stand up*) whose past participle form takes *ge-* as an infix (e.g. *aufgestanden*, *stood up*).

constructed in which all critical conditions were presented. The proportion of word versus nonword targets, as well as the proportion of the different auxiliaries, were approximately the same as for the critical trials. None of the practice trials contained a noun or past participle from the critical trials.

EXPERIMENT 1

Procedure

The time course of a trial for the young adults was as follows. First, a fixation cross appeared for 200msec in the centre of a MULTISYNCH monitor. This was followed by a blank period of 100msec. Then the beginning of the sentence appeared in the centre of the screen for 750msec. Next, the target was presented in the centre of the screen for 1500msec. With the presentation of the target the reaction time measurement began. By pressing one of two keys, the participant gave a word/nonword decision and reaction time measurement ceased. If the participant did not react within 2000msec after target onset, the response was recorded as incorrect. The next trial started 2500msec after offset of the target with the presentation of the fixation cross.

For the old adults some of these time parameters were adjusted, as pre-tests had shown that the time parameters chosen for the young participants were not applicable for the entire age range in the old adult group.[5] The fixation cross appeared for 200msec, followed by a blank period of 300msec. Then the beginning of the sentence appeared for 1200msec. After this, the target was presented at the centre of the screen for 3000msec. If the participants did not react after 3000msec, the response was recorded as incorrect. The next trial started 2000msec after the offset of the target with the presentation of the fixation cross.

Participants

Thirty-five old adults (mean age: 71; range: 63–81) participated in the experiment. Their mean score on the digit symbol test (Wechsler, 1955) was 42.94, SD = 9.89. They were paid DM20 for participating in the experimental session and were all native speakers of German. They had normal or corrected-to-normal vision. The participants were recruited by a newspaper advertisement and tested at the Max-Planck-Institut für

[5] Pre-tests were run with unselected old adults between the ages of 60 and 90, with the timing parameters used for the young adults. With these timing parameters number of time outs (i.e. missing data) were too large to be able to conduct statistical analyses. We therefore decided to adjust the timing parameter for the old adult group accordingly. As we are expecting a differential effect for semantic and syntactic processes, this general change in the time parameters in the old age group should not affect the expected pattern. If anything, it might have a general effect on both the semantic and syntactic priming.

Bildungsforschung in Berlin. Each participant reacted to 10 trials in each of the four critical conditions.

In addition, 42 young adults (mean age: 24; range 19–28) participated in the experiment. They were all native speakers of German, and had normal or corrected-to-normal vision. They were students at the Free University of Berlin and participated for course credit or were paid DM10. Both young and old participants reported to be in good health.

Results

Extreme reaction times (more than 2 SDs from a subject's or an item's mean) and errors were substituted within age groups by estimates following the procedure proposed by Winer (1971). The percentages of extreme reaction times were 1.9% for young adults and 0.6% for old adults. Table 1 gives the mean reaction times, their standard deviations, and the percentage of errors for each of the four conditions in each of the two age groups, as well as the priming effect (i.e. the difference between the correct and incorrect condition).

Young and old adults differ in their grand mean, with faster reaction times for the young than for the old adults. Furthermore, at a descriptive level it seems that semantic and syntactic aspects of processing are differentially affected by age. Age seems to affect the variation between the correct and the incorrect sentences more for the syntactic condition than for the semantic condition (see Table 1). That is, in the subcategorisation condition, the difference between correct and incorrect sentences for old adults is almost four times greater than for young adults. By contrast, in the selection restriction condition, the corresponding difference for old adults is only slightly more than twice as great.

The results were analysed in two ways. First, ANOVAs were performed on the original reaction times. However, as we pointed out earlier, an interaction of correctness by age group on the original reaction times could simply be due to proportional slowing (i.e. due to the fact that every subprocess contributing to the reaction times is slowed by some proportion in elderly subjects as compared to young subjects; Lima, Hale; & Myerson, 1991; Meyerson et al., 1992). Therefore, in a second analysis we introduced a correction for proportional slowing by taking the logarithm to the base of 10 of the reaction times and submitted these transformed values to an ANOVA.[6] As the targets for syntactic and semantic conditions were not

[6] For this analysis, we first converted all individual reaction times to the corresponding logarithmic values. An alternative procedure would be to take first the mean of the individual reaction times of all trials of a given subject in a given condition, and then to convert these means to logarithmic values. With this second procedure we obtained the same results as in the present analysis.

TABLE 1
Experiment 1: Mean Lexical Decision Times (RTs), Standard Deviations (SDs), Percentage of Errors, and Priming Effects (i.e. Difference between the Correct and Incorrect Condition, Δ)

	Semantic Condition: Selectional Restriction	*Syntactic Condition: Subcategorisation Constraint*
Young adults		
Correct		
RT (msec)	677	690
(SD)	(90)	(101)
Error (%)	1.5	2.1
Δ (msec)	93	63
Incorrect		
RT (msec)	770	753
(SD)	(117)	(113)
Error (%)	4.5	5.5
Old adults		
Correct		
RT (msec)	1061	1171
(SD)	(213)	(234)
Error (%)	0.6	5.7
Δ (msec)	198	235
Incorrect		
RT (msec)	1259	1406
(SD)	(269)	(266)
Error (%)	2.6	12.0

identical, separate ANOVAs were carried out for the syntactic and semantic condition with the factors Age (Young vs. Old) and Correctness (Correct vs. Incorrect).

The critical questions were the following: First, do we obtain an Age by Correctness interaction for the syntactic condition but not for the semantic condition? Second, if so, does the pattern occur for the untransformed and the transformed data, or can this pattern only be substantiated if proportional slowing is taken into account by transforming the data?

The ANOVA for the untransformed data for the semantic condition revealed significant main effects of Age [$F(1,75) = 126.7$, $P < .005$, $MSe = 114824$] and Correctness [$F(1,75) = 102.1$, $P < .005$, $MSe = 15772$]. The Age by Correctness interaction was also significant [$F(1,75) = 13.2$, $P < .005$, $MSe = 15772$]. The corresponding ANOVA of the untransformed data for the syntactic condition yielded significant main effects of Age [$F(1,75) = 194.1$, $P < .005$, $MSe = 126491$] and Correctness [$F(1,75) = 140.1$, $P < .005$, $MSe = 12158$]. The interaction of the two factors was also significant [$F(1,75) = 46.8$, $P < .005$, $MSe = 12158$].

The ANOVA for the transformed data in the semantic condition showed a significant main effect of Age [$F(1,75) = 139.3$, $P < .001$, $MSe = 0.0103$] and Correctness [$F(1,75) = 124.9$, $P < .001$, $MSe = 0.0012$], but no significant interaction [$F(1,75) = 2.2$, $P = .135$, $MSe = 0.0012$]. The corresponding ANOVA for the syntactic condition yielded significant main effects of Age [$F(1,75) = 208.7$, $P < .001$, $MSe = 0.0103$] and Correctness [$F(1,75) = 140.2$, $P < .001$, $MSe = 0.0009$], and a significant Age by Correctness interaction [$F(1,75) = 18.6$, $P < .01$, $MSe = 0.0009$].

This pattern of results on the transformed data is further confirmed by an ANOVA on the difference scores of the untransformed reaction times between the incorrect and the correct condition with the factors, Age and Condition (semantic vs. syntactic). This analysis reveals a significant effect of Age [$F(1,75) = 36.2$, $P < .05$, $MSe = 20286$], and a significant interaction between Age and Condition [$F(1,75) = 5.8$, $P < .05$, $MSe = 7662$]. The effect of condition was not significant [$F(1,75) < 1$].

An analysis of the errors showed that the incorrect condition had significantly higher error rates than the incorrect condition. This was the case for the young and old adults in the semantic as well as in the syntactic condition. No other differences in error rates reached significance.

Discussion

The results reveal a differential effect of age on semantic and syntactic priming. The difference in lexical decision times between correct and incorrect sentences was larger for old adults than for young adults. Furthermore, the increase of this correctness effect with age was more pronounced in the subcategorisation condition than in the selection restriction condition. This descriptive pattern was confirmed by the statistical analyses on the transformed data. The descriptive increase of the correctness effect in the semantic condition with age turned out to be insignificant, as indicated by the absence of a correctness by age interaction. By contrast, the corresponding analysis for the syntactic condition, the increase of the correctness effect with age was significant, as indicated by the significant correctness by age interaction.

How can one account for this differential effect of age in the semantic and the syntactic processing domain, that is, in the selection restriction and subcategorisation conditions? A close look at the processes required during the present lexical decision task may help to give a tentative answer to this question. After reading the beginning of the sentence, the verb target will be read. The present correctness effects may reflect the following subprocesses. The reader automatically and mandatorily tries to match the target verb on to the information given by the sentence beginning, attempting to integrate this element with the preceding prime to a full sentence. When integration

does not succeed, the inhibition of the unexpected target must be overcome, probably by controlled processes, in order to give the required yes response in the lexical decision task, thereby yielding longer lexical decision latencies for targets in incorrect than in correct sentences. In order to be able to explain the observed differential effects between the semantic and the syntactic condition, we would have to assume, furthermore, that overcoming an unexpected target is more difficult in the subcategorisation condition than in the selectional restriction condition in old adults, though not in young adults. A possible explanation for why this should be more difficult in the subcategorisation condition is based on the fact that syntactic subcategorisation information is represented as a fixed rule which once automatic is difficult to overcome. Overcoming an unexpected target in the semantic condition may be easier as a new combination of two lexical elements (e.g. noun and verb) is generally possible or even necessary when communicating about nonreal worlds. It is the overcoming of fixed syntactic knowledge as in the syntactic condition which appears to be more difficult in the elderly than in younger individuals.

To evaluate further this tentative explanation, additional experiments were conducted. Experiment 2 was designed to demonstrate that the observed effect is not due to slowing during peripheral processes, such as stimulus encoding, but is indeed due to central processes of lexical integration. Therefore, Experiment 2 used the same stimulus materials as Experiment 1, but the targets were presented in a visually degraded way. If the observed effect is indeed due to processes at a central stage of processing, degradation of the stimulus should not affect the general pattern of performance. Experiments 3 and 4 were designed to clarify whether the observed differential priming effect in old adults is indeed due to the amount of controlled processes involved in semantic and syntactic priming. This was evaluated by introducing a neutral baseline condition, allowing us to identify the cost and benefit components in semantic and syntactic priming and thereby the relative contributions of controlled processes in the different domains.

EXPERIMENT 2

Experiment 2 used the same materials as in Experiment 1, but a slightly different procedure. Following Madden (1988), we presented the visual target words with asterisks between the letters (e.g. L*E*T*T*E*R). Madden (1988) had demonstrated an age effect on priming by semantic sentential context when the targets were presented in such a degraded form. Although this effect was accounted for in a meta-analysis by a general slowing factor of about 1.5 (Myerson et al., 1992), it is still likely that degradation of the target will enhance potential age effects. However, as the

differential age effect found for syntactically incorrect sentences was attributed to central integration processes, it should be independent of the peripheral processes, such as stimulus encoding.

Materials and Procedure

The sentence material was the same as in Experiment 1. However, unlike Experiment 1, targets were presented in capital letters with asterisks between letters. The procedure was the same as in Experiment 1.

Participants

Forty old adults (mean age: 70; range 63–88) participated in the experiment. Their mean score on the digit symbol test (Wechsler, 1955) was 43.43, SD = 9.07. The participants were all native speakers of German, and had normal or corrected-to-normal vision. They were recruited by a newspaper advertisement, and tested at the Max-Planck-Institut für Bildungsforschung in Berlin. They were paid DM20 for their participation.

In addition, 40 young adults (mean age: 25; range: 20–28) participated in this experiment. They were all native speakers of German, and had corrected-to-normal vision. They were students of the Free University of Berlin and participated for course credit or were paid DM10. Both the young and old adults reported themselves to be in good health.

Results

Extreme reaction times (more than two SDs from a subject's and an item's mean) and errors were substituted, as in Experiment 1. The percentages of extreme reaction times were 2.1% for young adults and 0.2% for old adults.

Table 2 gives the mean lexical decision times, their standard deviations, and the corresponding percentages of errors for old and young adults in the four critical conditions, as well as the priming effects. The data were analysed in the same way as in Experiment 1.

The ANOVA of the untransformed data for the semantic condition showed significant main effects of Age [$F(1,78) = 114.4$, $P < .005$, $MSe = 149285$] and Correctness [$F(1,78) = 118.5$, $P < .005$, $MSe = 15043$]. The Age by Correctness interaction was also significant [$F(1,78) = 15.4$, $P < .005$, $MSe = 15043$]. The corresponding ANOVA for the syntactic condition also revealed significant main effects of Age [$F(1,78) = 169.6$, $P < .005$, $MSe = 171074$], Correctness [$F(1,78) = 180.9$, $P < .005$, $MSe = 13317$], and a significant interaction [$F(1,75) = 44.8$, $P < .005$, $MSe = 13317$].

The ANOVA of the transformed data for the semantic condition revealed significant main effects of Age [$F(1,78) = 120.5$, $P < .001$, $MSe = 0.0106$],

TABLE 2
Experiment 2: Mean Lexical Decision Times (RTs), Standard Deviations (SDs), Percentage of Errors, and Priming Effects (i.e. Difference between the Correct and Incorrect Condition, Δ)

	Semantic Condition: Selectional Restriction	*Syntactic Condition: Subcategorisation Constraint*
Young adults		
Correct		
RT (msec)	794	825
(SD)	(112)	(126)
Error (%)	3.0	2.0
Incorrect		
RT (msec)	889	913
(SD)	(132)	(123)
Error (%)	7.3	8.3
Δ (msec)	95	88
Old adults		
Correct		
RT (msec)	1202	1341
(SD)	(235)	(270)
Error (%)	0.3	4.9
Incorrect		
RT (msec)	1405	1601
(SD)	(281)	(284)
Error (%)	4.0	8.6
Δ (msec)	203	260

and Correctness [$F(1,78) = 131.8$, $P < .05$, $MSe = 0.001$], but no Age by Correctness interaction [$F(1,78) = 3.7$, $P = .10$, $MSe = 0.0012$]. For the syntactic condition, there was a significant main effect of Age [$F(1,78) = 174.2$, $P < .001$, $MSe = 0.0107$], Correctness [$F(1,78) = 178.1$, $P < .001$, $MSe = 0.0038$], and a significant Age by Correctness interaction [$F(1,78) = 12.2$, $P < .01$, $MSe = 0.0007$].

As for Experiment 1, this pattern of results on the transformed data is further confirmed by an analysis of variance on the difference scores of the untransformed reaction times between the incorrect and the correct condition with the factors, Age and Condition (semantic vs. syntactic). This analysis reveals a significant effect of Age [$F(1,78) = 55.4$, $P < .05$, $MSe = 14197$] and a marginally significant interaction between Age and Condition [$F(1,78) = 3.2$, $P < .06$, $MSe = 14181$]. The effect of condition was not significant [$F(1,78) = 1.6$, $P < .20$].

An analysis of the errors showed the same pattern as in Experiment 1. The incorrect condition had significantly higher error rates than the correct condition. Again, no other differences in error rates reached significance.

Discussion

The results of Experiment 2, using degraded visual presentation of the stimuli, replicate the findings of Experiment 1 although with an overall increase of the reaction times. For the transformed data, there is an age by correctness interaction in the syntactic condition, but not in the semantic condition. The differential age effect in the semantic and syntactic conditions was independent of the degrading of the target, as the comparison between Experiment 1 and 2 shows. Earlier, it was argued that a mismatch between the sentence final verb and the preceding sentence fragment is harder to overcome by old adults in the case of a syntactic mismatch than in case of a semantic mismatch. To overcome the syntactic mismatch, the processing system has to disregard a fixed syntactic knowledge in order to perform the required lexical decision. This process of disregarding a fixed syntactic rule may ask for more controlled processes than overcoming a semantic mismatch. New relations between a noun and a verb may be used to describe possible worlds, whereas new relations between an auxiliary and a past participle are not licensed by the syntax. We will return to this issue in the General Discussion.

EXPERIMENT 3

Experiment 3 evaluates whether the controlled aspects of syntactic processing, most probably attributable to the cost component of the priming effect, are responsible for the observed age-related changes.

The investigation of cost and benefit components is operationalised by the introduction of a so-called neutral baseline (see Stanovich & West, 1983).

Materials and Procedure

The critical variation in Experiment 3 compared to Experiment 2 was the inclusion of a neutral baseline. Although there is some discussion of what constitutes a neutral baseline in word–word and sentence priming the sentence fragment, "Das nächste Wort ist/The next word is", is taken to represent a good approach (Stanovich & West, 1983). As the experiment with the old adults was part of a larger study in Berlin (BASE, the Berlin Aging Study; for details see Baltes, Mayer, Helmchen, & Steinhagen-Thiessen, 1993), there were severe time constraints for each experimental session which was set to a maximum of 9 minutes. This time constraint had two consequences. First, in order to be able to include the neutral baseline, we had to reduce the number of targets within the semantic and the syntactic condition to eight targets per condition, resulting in eight correct, eight incorrect, and eight baseline sentences in each condition. The 24 sentences in each condition ending in a real word (past participle) were combined with 12 structurally similar sentences ending in a nonword. Second, as the 36

sentences of the semantic condition and the 36 sentences of the syntactic condition could not be presented together within the time limits given, we were forced to conduct the experiment as a between-subject design, with one group of elderly subjects assigned to the semantic condition and the other group assigned to the syntactic condition.

The procedure was similar to that of Experiment 2 (i.e. target items were presented in a visually degraded form). Slight adjustments in the timing parameters were introduced for the old adults. The sentence beginnings were presented for 1500msec and the target was presented for 10,000msec to avoid missing data due to time-outs (see also footnote 5). For the young adults, the same presentation times as for the young adults in Experiment 2 were used.

Participants

A total of 131 old adults participated in this experiment: 70 were assigned to the syntactic condition and 61 to the semantic condition. The mean age of the syntactic group was 80.4 (range: 70.1–100.5; SD = 6.85) and the mean age of the semantic group was 78.6 (range: 69.7–95.9; SD = 6.92). The mean score on the digit symbol test (Wechsler, 1955) was 31.0, SD = 9.76, for the syntactic group, and 31.8, SD = 7.76, for the semantic group.

These old adults were part of the Berlin Aging Study. They were tested in the context of the intensive data collection protocol of BASE, which comprises a total of 14 sessions covering four different disciplines (i.e. internal medicine, psychiatry, psychology, and sociology; cf. Baltes et al., 1993). The priming task was administered individually at the end of the cognitive session (see Lindenberger, Mayr, & Kliegl, 1993, for a description of the cognitive battery).

A total of 24 young adults (mean age: 24.4; range: 19–35) participated in the experiment. They were all native speakers of German, and had normal or corrected-to-normal vision. They were students at the Free University of Berlin and participated for course credit or were paid DM10.

The young adults participated in the semantic and the syntactic condition in two sessions separated by approximately one week. Half of the young adults participated first in the semantic and then in the syntactic condition, for the other half of the participants, the order of the two sessions was reversed.

Results

Extreme reaction times (more than two SDs from the subject's or the item's mean) and errors were substituted by estimates following the procedure proposed by Winer (1971). The percentages of extreme reaction times were 1.9% for young and 1.7% for old adults. Tables 3 and 4 give the mean

reaction times and their standard deviations, and the percentage of errors for each of the four conditions, as well as the priming effects for the young adults (Table 3) and the old adults (Table 4).

At a descriptive level it appears that there are particular differences in how age affects the benefit and the cost component in semantic and syntactic priming. Age seems to affect primarily the cost component in the syntactic priming condition. Although the cost and the benefit components are comparable in size for young adults (cost 32msec, and benefit 40msec), this is not the case for old adults (cost 225msec, and benefit 112msec). By contrast, in the semantic priming condition, cost and benefit components are of approximately equal size in both, the young adults (cost 32msec, and benefit 29msec) and the old adults (cost 117msec, and benefit 143msec).

We will first report the results of the ANOVAs for the young adults in the semantic and the syntactic condition with the factors Correctness (Correct vs. Neutral vs. Incorrect) and Order of Testing (syntax first vs. semantic first). For the semantic condition, there was a significant main effect of Correctness [$F(2,44) = 7.6$, $P < .01$, $MSe = 2958$], but no main effect of Order of Testing [$F(1,22) < 1$], nor an interaction of these two factors [$F(2,44) < 1$]. For the syntactic condition, the same pattern was obtained: Significant main effect of Correctness [$F(2,44) = 13.4$, $P < .001$, $MSe = 2335$], no main effect of Order of Testing [$F(1,22) < 1$], and no interaction [$F(2,44) = 1.68$, $P = .20$, $MSe = 2335$]. On the basis of this analysis, revealing no effect of the order in which the semantic and the

TABLE 3
Experiment 3 (Young Adults): Mean Lexical Decision Times (RTs), Standard Deviations (SDs), Percentage of Errors, and Cost (i.e. Difference between the Neutral and Incorrect Condition, and Benefit, i.e. Difference between the Neutral and Correct Condition (Δ)

	Semantic Condition: Selectional Restriction	*Syntactic Condition: Subcategorisation Constraint*
Correct		
RT (msec)	762	771
(SD)	(154)	(125)
Error (%)	2.6	7.8
Benefit (Δ, msec)	29	40
Neutral		
RT (msec)	791	811
(SD)	(156)	(153)
Error (%)	4.2	5.2
Cost (Δ, msec)	32	32
Incorrect		
RT (msec)	823	843
(SD)	(155)	(150)
Error (%)	4.7	6.2

TABLE 4
Experiment 3 (Old Adults): Mean Lexical Decision Times (RTs), Standard Deviations (SDs), Percentage of Errors, and Cost (i.e. Difference between the Neutral and Incorrect Condition, and Benefit, i.e. Difference between the Neutral and Correct Condition (Δ)

	Semantic Condition: Selectional Restriction	*Syntactic Condition: Subcategorisation Constraint*
Correct		
RT (msec)	1624	1829
(SD)	(499)	(680)
Error (%)	3.5	2.5
Benefit (Δ, msec)	143	112
Neutral		
RT (msec)	1767	1941
(SD)	(564)	(743)
Error (%)	6.4	7.0
Cost (Δ, msec)	117	225
Incorrect		
RT (msec)	1884	2166
(SD)	(633)	(890)
Error (%)	8.6	10.9

syntactic conditions were presented, we pooled the two order-of-testing groups.

The descriptive data strongly suggest that we obtain a differential age effect for the syntactic condition primarily in the cost component (incorrect vs. neutral), but not in the benefit component (correct vs. neutral). As a statistical test of this descriptive pattern we conducted separate analyses on the benefit and cost scores. As our design provides us with a neutral baseline for each critical target item for each participant, we can compute benefit and cost scores for each adult as the differences between the correct and the neutral condition or between the incorrect and the neutral condition, respectively (see Fig. 1). These scores were submitted to separate ANOVAs, one for the benefit scores and one for the cost scores with the factor, Experimental Group, on four levels, namely, young-semantic, young-syntax, old-semantic, and old-syntax. These ANOVAs were first performed on untransformed data.

The ANOVA for the benefit scores yielded a significant main effect of the factor, Experimental Group [$F(3,175) = 3.6$, $P < .05$, $MSe = 30533$]. A *post-hoc* test (Duncan $P < .05$) showed that the benefit score of the old-semantic and the old-syntax group did not differ, and the same was true for the young-semantic and young-syntax group.

The analysis of the cost scores, however, yielded a different picture. There was also a significant main effect of the factor Experimental Group [$F(3,175) = 4.13$, $P < .01$, $MSe = 70787$]. However, *post-hoc* tests (Duncan

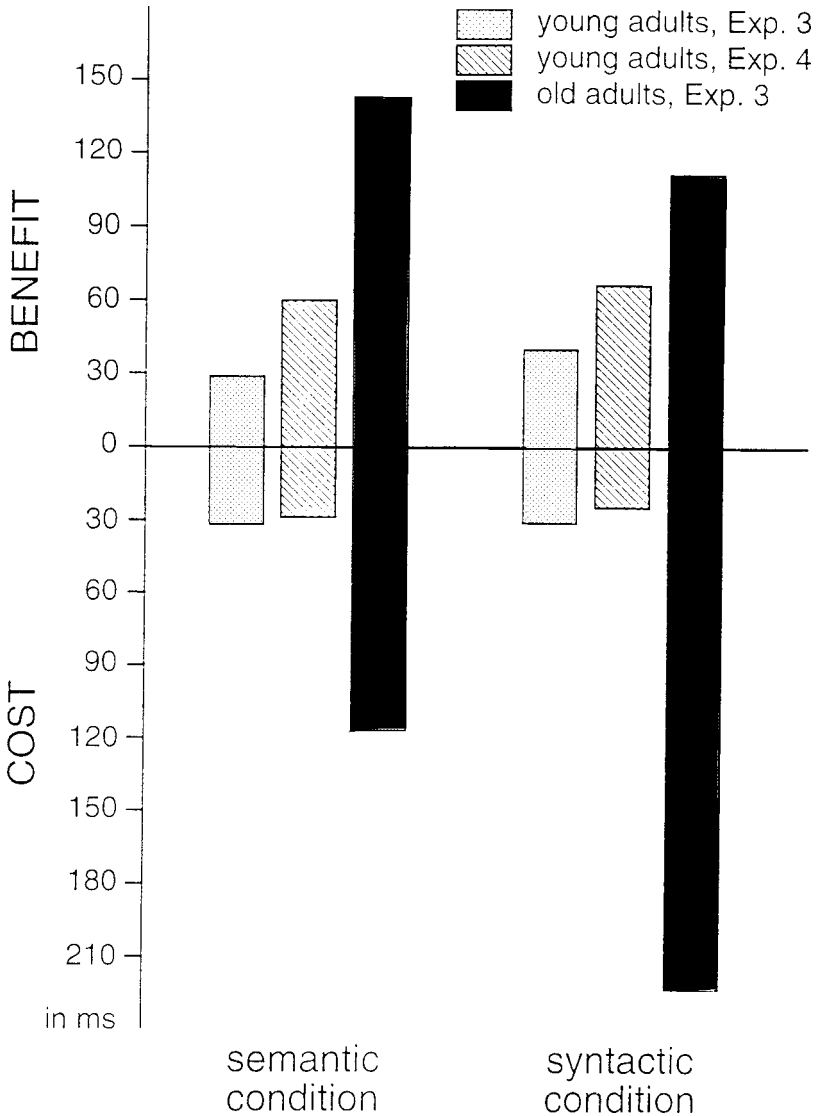

FIG. 1. Cost and benefits (in msec) for old adults in Experiment 3, and for young adults in Experiments 3 and 4 in the semantic condition (selectional restriction), and the syntactic condition (subcategorisation constraint).

$P < .05$) revealed a different pattern for the young and old adults. Cost scores for the young adults did not differ significantly between the young-semantic and the young-syntax group. They did, however, differ significantly for the old adults. Cost scores for the old-syntax group were significantly greater than for the old-semantic group.

An analysis of errors shows a significant increase of error rates from the correct condition over the neutral condition to the incorrect condition for old adults. Corresponding analyses for the young adults did not reveal any significant differences in error rates.

Discussion

The results of Experiment 3 revealed that old adults are particularly affected in the processing of syntactically incorrect sentences. Age did not affect semantic processes, neither the benefit nor the cost component. However, age did influence syntactic processes, in particular those underlying the cost component. These were defined as processes of disregarding fixed syntactic knowledge, presumably involving mainly controlled processing.

Before turning to the General Discussion we will have to consider an objection that could be raised with respect to Experiment 3. It might be that the difference in presentation times for the old and young adults may have contributed to the observed processing differences. Age-related changes in semantic priming, for example, have been observed for attention-guided expectancy effects as tested in a paradigm using different stimulus onset asynchronies between a prime word and a prime target under the condition that the prime was only available for 200msec, leaving an interstimulus interval of up to more than 3 seconds (Balota, Black, & Cheney, 1992).

From our pilot experiments with the old adults (see also footnote 5), it was clear that the time parameters for the old adults could not be shortened to the time parameters that we used with the young adults without losing too many data points. Therefore, we decided to replicate Experiment 3 for the young adults using the same parameters that were used for the old adults in Experiment 3. The data of this new group of young adults in Experiment 4 were then compared to the results of the old adults in the same way as in Experiment 3.

EXPERIMENT 4

Participants

A total of 26 young adults (mean age: 26.2; range: 18–36) participated in Experiment 4. None had participated in any of the preceding experiments. Most participants were students at the Free University, Berlin. They received DM10 for their participation. As in Experiment 3, half the subjects participated first in the semantic condition and then in the syntactic condition. For the other half, the order of conditions was reversed.

Materials and Procedure

Materials and procedure were identical to Experiment 3, with only the timing parameters for presentation of the stimuli being identical to the timing parameters used for the old adults in Experiment 3.

Results

Extreme reaction times (0.7%) and errors were treated in the same way as in Experiment 3. Table 5 gives the mean reaction times, their standard deviations, and the percentage of errors for the experimental conditions, as well as the priming effects.

As in Experiment 3, we first analysed the results for the young adults in the semantic and the syntactic condition by ANOVAs with the factors, Correctness (correct, neutral, incorrect) and Order of Testing (syntactic condition first or semantic condition first). For the semantic condition, there was a significant main effect of Correctness [$F(2,48) = 9.9$, $P < .005$, $MSe = 5312$]. Neither the main effect of Order of Testing nor its interaction with correctness reached significance (Fs < 1). The same pattern was obtained for the syntactic condition. Only the main effect of Correctness was significant [$F(2,48) = 11.2$, $P < .005$, $MSe = 5206$]. Neither the effect of Order of Testing nor its interaction with correctness reached significance (Fs < 1). Therefore, as in Experiment 3, we pooled the two order of testing groups.

TABLE 5
Experiment 5 (Young Adults): Mean Reaction Times (RTs), Standard Deviations (SDs), Percentage of Errors, and Cost (i.e. Difference between the Neutral and Incorrect Condition, and Benefit, i.e. Difference between the Neutral and Correct Condition (Δ)

	Semantic Condition: Selectional Restriction	*Syntactic Condition: Subcategorisation Constraint*
Correct		
RT (msec)	915	986
(SD)	(269)	(259)
Error (%)	1.0	4.3
Benefit (Δ, msec)	60	66
Neutral		
RT (msec)	975	1052
(SD)	(274)	(248)
Error (%)	0.5	1.9
Cost (Δ, msec)	29	25
Incorrect		
RT (msec)	1004	1077
(SD)	(291)	(227)
Error (%)	1.4	6.2

At a descriptive level, there are two important deviations from the results of the young adults in Experiment 3. First, overall reaction times are slower. Second, the benefit scores in the correct condition (as compared to the neutral condition) are somewhat larger than in Experiment 3 (Experiment 3: 29 and 40msec for the semantic and syntactic conditions, respectively; Experiment 4: 60 and 66msec for the semantic and syntactic conditions, respectively). This is presumably due to the slower presentation times in Experiment 4 which leads to an overall slowing in response speed and perhaps also to a strategy by which participants try to actively predict the target on the basis of the prime fragment. The cost scores remain more or less constant between Experiments 3 and 4 (32msec for both the semantic and the syntactic condition in Experiment 3, and 29 and 25msec in the semantic and the syntactic condition, respectively, in Experiment 4).

The descriptive comparison of the present data for young adults with the results from the old adults in Experiment 3, similar to the comparison within Experiment 3, strongly suggests that we obtain a differential age effect for the syntactic condition which is primarily due to the cost component (incorrect vs. neutral), and not present in the benefit component (correct vs. neutral).

For the statistical test, we combined the results of the present experiment with the results of the old adults from Experiment 3 and analysed them in the same way as the within-experiment comparison in Experiment 3.

The ANOVA for the benefit scores yielded a marginally significant effect of Experimental Group [$F(3,179) = 2.4$, $P = .07$, $MSe = 31343$]. A Duncan test revealed that this marginally significant difference was owing to the fact that the benefit scores for the old adults were systematically larger than for the young adults. As in Experiment 3, the benefit scores of the old-semantic and old-syntax group did not differ, and the same was true for the young-semantic and young-syntax group.

The ANOVA of the cost scores also showed a significant main effect of Experimental Group [$F(3,179) = 4.7$, $P < .05$, $MSe = 69725$]. A Duncan test showed the same pattern of differences as the one obtained for the cost scores of Experiment 3. For young adults, the cost scores in the semantic and the syntax conditions did not differ significantly. By contrast, for the old adults, the cost score in the syntax condition was significantly greater than for the semantic condition. In summary, Experiment 4 shows that the differential age effect in cost scores that was observed in Experiment 3, is also obtained when old and young adults are tested with the same timing of stimulus presentation.

The cost and benefit analyses just reported primarily aim at demonstrating that dividing the difference between the correct and incorrect condition by the neutral baseline is not the same across both age groups and both conditions (semantic vs. syntactic). Indeed, the analyses show that this

dividing the correct-incorrect difference is different for the old adults in the syntactic conditions from the remaining three comparisons. This conclusion can also be corroborated by corresponding analyses on log-transformed data. ANOVAs contrasting the correct condition and the neutral baseline condition of the age groups in the semantic condition shows a main effect of Age [$F(1,85) = 74.4$, $P < .005$, $MSe = 0.0279$] and of Condition [correct vs. neutral: $F(1,85) = 37.2$, $P < .005$, $MSe = 0.0279$], but no interaction between these two factors [$F(1,85) = 1.3$, $P < .20$, $MSe = 0.0009$]. A corresponding analysis for the syntactic condition reveals basically the same results [Age: $F(1,85) = 60.3$, $P < .005$, $MSe = 0.0389$; Condition (correct vs. neutral): $F(1,85) = 27.3$, $P < .005$, $MSe = 0.0389$; interaction: $F(1,85) < 1$]. However, corresponding analyses contrasting the neutral and the incorrect condition yield a different picture which is parallel to the one obtained in Experiments 1 and 2. For the syntactic condition, the analysis reveals a significant main effect of Age [$F(1,94) = 59.6$, $P < .005$, $MSe = 0.0437$] and Condition (incorrect vs. neutral: $F(1,94) = 27.7$, $P < .005$, $MSe = 0.0437$], as well as a significant interaction of these two factors [$F(1,94) = 7.04$, $P < .01$, $MSe = 0.0012$]. By contrast, the corresponding analysis for the semantic condition only shows two main effects [Age: $F(1,94) = 78.9$, $P < .005$, $MSe = 0.0313$; Condition (incorrect vs. neutral): $F(1,94) = 22.9$, $P < .005$, $MSe = 0.0313$], but no interaction between these factors [$F(1,94) = 2.0$, $P > .15$, $MSe = 0.0009$].

As for Experiment 3, an analysis of error rates for the young adults did not reveal any systematic differences between the different experimental conditions.

GENERAL DISCUSSION

The present results suggest that semantic and syntactic aspects of language processing are differentially affected by age. *Semantic* aspects of language processing in old adults are similar to those in young adults. This finding proved to be independent of a peripheral variable, namely, stimulus degradation. Moreover, it appears that cost and benefit components in semantic processing are not differentially affected by age. These findings are in general agreement with earlier studies on semantic priming (Burke & Yee, 1984; Lima et al., 1991; Myerson et al., 1992).

Specific age-related differences in language processing, however, were found for *syntactic* integration processes. The age-related difference was evidenced in a larger priming effect for old adults than for young adults. This specific effect was shown to be independent of peripheral variables, such as stimulus degradation. The evaluation of the cost and benefit components revealed that age had its specific effect on the cost component in the

syntactic condition. The present data demonstate that the processing of violations within the domain of syntactic rule-based knowledge was more affected by age than the processing of anomalies in the domain of lexical-semantic knowledge. A tentative explanation for this finding will have to consider at least two aspects: first, the difference between semantic and syntactic processes as modelled by psycholinguistic theory; and second, the degree to which automatic and controlled processes are assumed to be involved in the cost and benefit components of semantic and syntactic priming.

Psycholinguistic models typically distinguish different subcomponents in language processing. According to these models, the semantic component has to work in concert with other components, such as phonology and syntax, to reach the ultimate goal of producing or understanding sentences. These different components have been shown to develop at different phases during early development with syntactic rules being acquired later than word meanings (Chomsky, 1969; Flores d'Arcais, 1981; Friederici, 1983b), to break down differentially as a result of central brain lesions with syntactic aspects to be particularly vulnerable to brain damage (Bradley, Garrett, & Zurif, 1980; Friederici, 1985; Friederici & Saddy, 1993; Rosenberg, Zurif, Brownell, Garrett, & Bradley, 1985), and to show differential electrophysiological patterns in the intact adult brain (Friederici, Pfeifer, & Hahne, 1993; Neville, Mills, & Lawson, 1993; Van Petten & Kutas, 1991). This may not be surprising given that these different components serve distinct functions. The lexical-semantic component's purpose is to represent the meaning of and the semantic relations between different words such as nouns, verbs, and adjectives. The syntactic component's function is to structure the incoming and outgoing information by a set of fixed rules, thereby providing the basis for correct grammatical assignment of thematic roles. As long as these components can work without disruption in the adult (i.e. when processing syntactically and semantically well-formed language material), both components seem to perform their job quite automatically and efficiently, independent of age, as revealed by the analysis of the benefit component in this and earlier studies (e.g. Madden et al., 1993). When, however, confronted with incoherent and incorrect language input, such as in the incorrect conditions of the present experiments, the old adult's and the young adult's processing systems seem to work differently, especially with respect to the syntactic information as revealed by the analysis of the cost component. The principal difference between the semantic and syntactic condition may be characterised in the following way. When lexical integration is required syntactic incorrectness (i.e. a violation of fixed syntactic knowledge may be harder to overcome than semantic incoherence). The establishment of new relations between different lexical elements such as nouns and verbs should, in principle, be possible in order to

be able to communicate about possible worlds. The establishment of new syntactic rules, in contrast, is impossible as they are not licensed by the syntax of a given language. This principal difference underlying syntactic incorrectness on the one hand and semantic incoherence on the other, may contribute to the differences between the processing of syntactic and semantic violations in old age.

The finding that the observed differential age effect is due to the cost component in the syntactic condition may be connected to the hypothesis that there is a general age-related deficit in the ability to inhibit irrelevant information (Hartman & Hasher, 1991; Hasher & Zacks, 1979; 1988). Cost components in general are viewed to reflect the costs necessary to process incoherent information. As the present experiments used a lexical decision task it may, moreover, reflect the costs necessary to overcome or inhibit the tendency to make an implicit no response associated with the incorrectness of the sentence in order to make the required yes response in case of word targets. The present data, however, constrain this general view about age-related inhibitory deficits by showing that this deficit could have a domain-specific effect. That is, old adults in contrast to young adults take much longer to overcome a syntactically incorrect context than a semantically incoherent context. It appears that for this age group, overcoming violations in the syntactic domain is particularly difficult.

This interpretation can be connected to the finding that colour-word interference effects are of a greater magnitude in older adults than in younger adults (Cohn, Dustman, & Bradford, 1984; Panek, Rush, & Slade, 1984), whereas the facilitation effect is similar for younger and older adults (Spieler, Balota, & Faust, 1996). West and Bell (1997) interpret this age-related increase in the interference effect as resulting from an inability to suppress the influence of incongruent information. Within this framework the age-related changes in syntactic as compared to semantic priming are a function of the processing costs necessary to inhibit information violating fixed knowledge in a highly automatic processing domain.

Manuscript received March 1997
Revised manuscript received September 1997

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APPENDIX

Sentence beginnings and target words in the semantic and syntactic conditions (English translations in parentheses)

Correct	*Incorrect*
Semantic condition	
Der Brief ist GESCHRIEBEN (The letter is WRITTEN)	Der Rock ist GESCHRIEBEN (The skirt is WRITTEN)
Der Rock ist GENÄHT (The skirt is SEWED)	Der Baum ist GENÄHT (The tree is SEWED)
Der Baum ist GEFÄLLT (The tree is HEWED)	Das Hemd ist GEFÄLLT (The skirt is HEWED)
Das Hemd ist GEBÜGELT (The shirt is IRONED)	Der Reis ist GEBÜGELT (The rice is IRONED)
Der Reiss ist GEKOCHT (The rice is COOKED)	Das Buch ist GEKOCHT (The book is COOKED)
Das Buch wurde GELESEN (The book was READ)	Der Apfel wurde GELESEN (The apple was READ)
Der Apfel wurde GEGESSEN (The apple was EATEN)	Der Text wurde GEGESSEN (The text was EATEN)
Der Text wurde GESPROCHEN (The text was SPOKEN)	Der Wein wurde GESPROCHEN (The wine was SPOKEN)
Der Wein wurde GETRUNKEN (The wine was DRUNK)	Der Teppich wurde GETRUNKEN (The carpet was DRUNK)
Der Teppich wurde GEKNÜPFT (The carpet was KNOTTED)	Der Brief wurde GEKNÜPFT (The letter was KNOTTED)
Syntactic condition	
Der Mann hat GELACHT (The man has LAUGHED)	Der Mann wurde GELACHT (The man was LAUGHED)
Die Mutter hat GEWEINT (The mother has CRIED)	Die Mutter wurde GEWEINT (The mother was CRIED)
Der Freund hat GEREDET (The friend has TALKED)	Der Freund wurde GEREDET (The friend was TALKED)
Der Gast hat GEZITTERT (The guest has TREMBLED)	Der Gast wurde GEZITTERT (The guest was TREMBLED)
Die Tochter hat GESCHLAFEN (The daughter has SLEPT)	Die Tochter wurde GESCHLAFEN (The daughter was SLEPT)
Der Vater ist ERBLAßT (The father is TURNED PALE)	Der Vater wurde ERBLAßT (The father was TURNED PALE)
Der Fremde ist GEFLOHEN (The stranger is RAN AWAY)	Der Fremde wurde GEFLOHEN (The stranger was RAN AWAY)

Correct	*Incorrect*
Der Arzt ist GEBLIEBEN (The doctor is STAYED)	Der Arzt wurde GEBLIEBEN (The doctor was STAYED)
Der Sohn ist GEWACHSEN (The son is GROWN)	Der Sohn wurde GEWACHSEN (The son was GROWN)
Die Frau ist ERKRANKT (The woman is TURNED ILL)	Die Frau wurde ERKRANKT (The woman was TURNED ILL)