

Longitudinal Change in Language Production: Effects of Aging and Dementia on Grammatical Complexity and Propositional Content

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Mixed modeling was used to examine longitudinal changes in linguistic ability in healthy older adults and older adults with dementia. Language samples, vocabulary scores, and digit span scores were collected annually from healthy older adults and semiannually from older adults with dementia. The language samples were scored for grammatical complexity and propositional content. For the healthy group, age-related declines in grammatical complexity and propositional content were observed. The declines were most rapid in the mid 70s. For the group with dementia, grammatical complexity and propositional content also declined over time, regardless of age. Rates of decline were uniform across individuals. These analyses reveal how both grammatical complexity and propositional content are related to late-life changes in cognition in healthy older adults as well as those with dementia. Alzheimer's disease accelerates this decline, regardless of age.

Linguistic abilities in adulthood have been traditionally studied by testing older adults' vocabulary, usually by assessing their ability to define words (Wechsler, 1981). Across a wide range of tests both longitudinally and cross-sectionally, vocabulary has been shown to increase throughout the middle adult years but to decline in late adulthood (Albert, Heller, & Milberg, 1988; Arenberg, 1990; Botwinick & Siegler, 1980; Eisdorfer & Wilkie, 1973; Hultsch, Hertzog, Dixon, & Small, 1998; Schaie, 1983; Schaie & Willis, 1993; Zelinski & Burnight, 1997). In contrast, language sample analysis has been traditionally used to assess children's linguistic development (Stromswold, 1996). In a series of studies, Kemper and her colleagues used oral and written language samples to examine the effects of aging on linguistic ability (Kemper, 1992;

Kemper, Kynette, Rash, Sprott, & O'Brien, 1989; Kemper, Rash, Kynette, & Norman, 1990; Kynette & Kemper, 1986). The cross-sectional findings suggested that older adults' linguistic abilities are affected by working memory limitations on the production of complex syntactic constructions. For example, Kemper et al. (1989) reported that the mean number of clauses per utterance (MCU), a general measure of the complexity of adult language, is positively correlated with the adults' backward digit span using the Wechsler Adult Intelligence Scale—Revised (WAIS-R; Wechsler, 1981) subtest. Further, Kemper and Rash (1988) calculated Yngve depth (Yngve, 1960), a measure of the working memory demands of sentence production, and found that it was positively correlated with WAIS-R digit span as well as with MCU.

These language sample analyses showed that older adults favor coordinate or right-branching constructions (e.g., "She's awfully young to be running a nursery school for our church") over left-branching constructions (e.g., "The gal who runs a nursery school for our church is awfully young"). During the production of the left-branching constructions in which the embedded clause occurs to the left of the main clause, the form of the subject "the gal" must be retained and the grammatical form of the main clause verb "is" must be anticipated as the embedded clause "who runs a nursery school for our church" is being produced. Each clause is produced sequentially in the right-branching construction in which the embedded clause occurs to the right of the main clause. This asymmetry between left- and right-branching constructions has been assumed to reflect working memory limitations on the production of left-branching constructions (Gibson, 1988; Gibson, Pearlmutter, Conesco-Gonzalez, & Hickok, 1996; Gibson, Schutze, & Salomon, 1996).

Although the primary target for Alzheimer's disease is the memory system, it also affects linguistic ability. Kemper et al.

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(1993) and Lyons et al. (1994) documented the progressive decline in linguistic ability due to probable Alzheimer's disease. The pattern of decline characteristic of older persons suffering from dementia differs from the pattern of healthy older adults. Linguistic changes associated with Alzheimer's disease have an earlier onset, coincident with the onset of the disease, and a more precipitous decline than those associated with normal aging in healthy adults. Early linguistic changes in individuals with dementia of the Alzheimer's type reflect problems accessing semantic memory, or the organized system of knowledge, meanings, and attributes of world knowledge (Kemper & Lyons, 1994). Additionally, grammatical complexity declines although some aspects of grammar, such as basic subject-verb relations and morphology, are preserved. Hence, older adults with Alzheimer's disease typically use simple sentences with greatly reduced propositional content (Kemper et al., 1993; Lyons et al., 1994). As the dementia progresses, language is further reduced to short, familiar, repetitive phrases and sentence fragments; eventually adults with Alzheimer's disease become mute and nonresponsive (Hamilton, 1994).

A limitation of cross-sectional studies such as those of Kemper et al. (1989), Kemper and Rash (1988), Kemper et al. (1993), and Lyons et al. (1994) is that age-related and disease-related changes in linguistic ability were inferred from cross-sectional differences between younger and older adults, and causal relations among variables were inferred from correlational patterns. In contrast, longitudinal analyses directly investigate intraindividual change due to age or disease as well as interindividual change due to individual differences in cognitive abilities. We used two sets of language samples in the present longitudinal analyses of linguistic change. The first set consisted of language samples collected from a group of healthy older adults. The initial language samples were collected in 1983 and were described in the Kemper et al. (1989) article; many of these individuals participated in a series of laboratory experiments over the next 15 years, including studies reported in Kemper et al. (1990), Norman, Kemper, Kynette, Cheung, and Anagnopoulos (1991), Norman, Kemper, and Kynette (1992), Jackson and Kemper (1993), Kemper, Jackson, Cheung, and Anagnopoulos (1994), Kemper, Othick, Warren, Gubarchuk, and Gerhing (1996), and Kemper, Finter-Urczyk, Ferrell, Harden, and Billington (1998). After 5 years, a preliminary longitudinal investigation was reported by Kemper, Kynette, and Norman (1992). Language samples were also elicited from a group of older adults with dementia who participated in a preliminary study of referential communication (Kemper, Anagnopoulos, Lyons, & Heberlein, 1994) or in a study of metalinguistic judgments (Kemper, 1997); semiannual language samples were collected from many of these same individuals for 2 to 5 years.

Language samples can be analyzed by tallying the incidence of different types of linguistic constructions, such as left- versus right-branching clauses, or by computing a summary metric of linguistic complexity. Possible metrics include developmental level (D-Level; Cheung & Kemper, 1992; Rosenberg & Abbeduto, 1987), a measure of grammatical complexity, and propositional density (P-Density), a measure of how much information is conveyed.

D-Level is correlated with measures of working memory, including digit span and reading span (Kemper & Sumner, 2001). Working memory imposes limits on how many digits may be retained (forward digit span), reordered (backward digit span), and

how many words may be retained while other sentences are read (reading span). Working memory also imposes limits on how many sentence relations, particularly hierarchical relations, may be formulated at one time. Each embedded or subordinate clause increases the burden on working memory by imposing additional requirements, including subject-verb agreement, pronominal choice, linear ordering of adjectives, and other grammatical rules. Left-branching embeddings, in which the embedded clause precedes or interrupts the main clause, typically require that the grammatical form of the main clause be anticipated while the embedded clause is being produced, thus adding to the burden on working memory. Right-branching embeddings, in which the embedded clause follows the main clause, can be produced successively, thus reducing the burden on working memory. D-Level is computed by assigning points to sentences on the basis of their complexity and order of emergence in children's language. D-Level is sensitive to the amount of embedding and the type of embedding used to create complex sentences. Simple, one-clause sentences earn 0 points. Sentences containing infinitives, gerunds, relative clauses, and other forms of embedding earn 1 to 6 points; left-branching forms are assigned more points than right-branching forms. Sentences with multiple forms of embedding and subordination earn 7 points.

The second measure was P-Density (Kintsch & Keenan, 1973), a measure that assesses how much information is packed into a sentence, relative to the number of words. Previous studies have shown that P-Density is correlated with performance on vocabulary measures (Cheung & Kemper, 1992). A more recent study, Kemper and Sumner (2001), investigated the relationship of P-Density to vocabulary, working memory, and verbal fluency measures by using structural equation modeling. In this analysis, P-Density, although it loaded on a separate factor of processing efficiency along with measures of verbal fluency, reading rate, and sentence length in words, was also correlated with the vocabulary measures. Individuals who produced sentences low in P-Density also tended to use long sentences, to read slowly, and to perform poorly on verbal fluency tasks. Verbal fluency tasks, sometimes termed *generative naming*, require the person to generate as many words as possible meeting a list of criteria in a set amount of time. Verbal fluency has been shown to be particularly sensitive to the onset and progression of Alzheimer's disease (Bayles & Tomoeda, 1983; Benson, 1979; Borkowski, Benton, & Spreen, 1967). Processing efficiency, typically measured by speeded tasks such as verbal fluency, declines with advancing age and with poor health status (Earles & Salthouse, 1995; Earles, Connor, Smith, & Park, 1997; Hulstsch et al., 1998; Light, 1978; Salthouse, 1996). Hence, P-Density appears to be a measure of processing efficiency that assesses how efficiently individuals can express information.

D-Level and P-Density were used by Snowdon and his collaborators to investigate how linguistic ability affects risk for Alzheimer's disease and longevity. Snowdon et al. (1996) analyzed language samples from a group of nuns, members of the School Sisters of Notre Dame. The nuns produced autobiographical writing samples at the time they took their final religious vows, between 18 and 32 years of age. When the nuns were 75 to 93 years of age, they were given a battery of tests of cognition and memory designed to assess probable Alzheimer's dementia. Low linguistic ability in young adulthood, indicated by low D-Level (termed "grammatical complexity" by Snowdon et al., 1996) or

low P-Density (or "idea density") in these language samples, was associated with increased risk for poor performance on the cognitive and memory tests in late adulthood. Low P-Density in young adulthood was also associated with increased neuropathology characteristic of Alzheimer's disease for a small number of nuns who had died. In a follow-up study, Snowdon, Greiner, Kemper, Nanayakkara, and Mortimer (1999) linked low linguistic ability, measured by P-Density in young adulthood, to increased all-cause mortality among the nuns. Kemper, Greiner, Marquis, Prenovost, and Mitzner (2001) have traced these measures of linguistic ability over the life span, comparing the initial samples collected from the nuns to those elicited when they were in their 40s, 70s, and 80s. Further, they investigated how education and adult experiences affected initial linguistic ability and its decline. P-Density appears to be a general measure of cognitive and neurological development that is not related to grades in high school English or mathematics nor is it affected by adult experiences including obtained advanced educational degrees. Low P-Density in young adulthood may reflect suboptimal neurocognitive development, which, in turn, may increase susceptibility to age-related decline due to Alzheimer's or other diseases.

For both healthy older adults and those with dementia, cognitive aging processes are progressive and can be observed over repeated assessments of the same aging persons. Longitudinal data and models are more consistent with our research questions and belief systems about age- or dementia-related cognitive decline than are cross-sectional data and analyses. Sliwinski and Buschke (1999) discussed the different types of age effects as assessed in cross-sectional and longitudinal studies. They noted that the cross-sectional approach examines the relationship between the outcome variable and age differences among persons; these age differences are treated as fixed effects and do not allow assessment of differential change. In contrast, the longitudinal approach allows the assessment of age-related changes within persons and differences in those changes between persons. Age-related changes, which are within-person effects that describe the general or average pattern of change, are modeled as fixed effects. Differential change effects reflect individual differences in cognitive aging and are modeled as random effects. Both patterns of change and differential change effects are of interest in the present study.

The most useful statistical models for assessing longitudinal change in grammatical complexity and propositional content support the estimation of both within- and between-subject effects as discussed above. In addition, the statistical models need to handle the increased complexity present in longitudinal data; these complexities include correlated observations within any individual, varying numbers of observations between participants because of missed observations and dropout, and varying intervals between observations within and between participants. Traditional statistical methods based on the general linear model either do not allow for the above-mentioned complexities or else handle them in a very restrictive manner. However, the general linear *mixed model* (Laird & Ware, 1982) provides the flexibility and utility needed to model longitudinal data used in this study. Mixed models include models referred to as multilevel models, hierarchical linear models, and random coefficient models (respectively, see Goldstein, 1995; Bryk & Raudenbush, 1992; Laird & Ware, 1982). Mixed models have been used in studies of aging to assess change in various types of cognitive function (Jacqmin-Gadda, Fabrigoule,

Commenges, & Dartigues, 1997; Rasmusson, Carson, Brookmeyer, Kawas, & Brandt, 1996; Sliwinski & Buschke, 1999; Teri, Hughes, & Larson, 1990). In this study, we used mixed modeling to examine the level and pattern of change over time, or growth curves, in grammatical complexity and propositional content. The fixed effects describe these two aspects (level and pattern of age- or time-related changes) in the linguistic measures. They include a coefficient for the intercept, a coefficient for the linear slope for age, and, potentially, coefficients for higher order age terms (e.g., age² and age³). Random effects are required in the model to the extent that age-related changes vary among individuals. Specifically, the level (e.g., intercept) and the relationships (e.g., slopes) that describe the age- or time-related changes in the linguistic outcomes may vary across participants. Covariates can be added to the growth model to explain between-subject variance or covariance in intercept or slope. The specific analytic approach is described in more detail in the description of Study 1.

Using data extracted from spontaneously produced language samples, repeated observations of grammatical complexity and propositional content were collected at regular intervals from healthy older adults and older adults with Alzheimer's disease. Vocabulary and forward and backward digit spans were also assessed at the time each language sample was obtained. We hypothesized a priori that vocabulary or digit span might be appropriate covariates to explain individual differences in the intercepts or slope for grammatical complexity or propositional content as both were assumed to be measures of general verbal ability. Therefore, we also examined the effects of individual differences in initial vocabulary and composite digit span on growth curves for the two outcomes.¹

Study 1

In the first study, we examined language samples collected from a group of healthy older adults over a span of 7 to 15 years.

Method

Participants. The participants in this study were 30 older adults. They were 65 to 75 years of age at the first assessment. All were native speakers of English who were recruited by means of newspaper solicitations and personal referrals. Initially, the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) was used to screen for cognitive impairment; all participants in the group of healthy

¹ An alternative approach would be to treat the digit span and vocabulary covariates as time-varying covariates by using the contemporaneous measures in the analyses. The present approach investigates whether the initial status of the participants (in terms of span or vocabulary scores) accounts for the initial level of linguistic ability or rate of decline. The time-varying covariate approach investigates a different question. It asks whether the variables covary together over time. The time-varying covariate approach is open to several interpretations if the variables are found to covary together. One interpretation is that a common mechanism accounts for the rate in decline in, for example, digit span and grammatical complexity. Another is that one variable causes change in another. Both our present approach and the time-varying approach ask legitimate questions within the context of theories of cognitive aging; we feel that the question regarding initial status is simpler and logically prior to that regarding covariation.

adults were required to score 28–30 (maximum score = 30) to be included in the study.

The healthy older adults were screened for a variety of medical conditions, including a history of closed head injury, alcohol or drug dependence, current use of psychotropic or antidepressant medications, a history of stroke or heart attack, untreated hypertension, Parkinson's disease, cancer, liver disease, or kidney disease. Oral language samples were collected annually over a period of up to 15 years from the healthy older adults. Their participation was discontinued when any of the described medical conditions occurred or for other significant medical reasons ($n = 15$), the individuals entered a congregate living facility ($n = 2$), the individuals moved from the locale ($n = 7$), or when the individuals' performance on the annual MMSE was 27 or lower ($n = 1$).

Attrition. An analysis of attrition was conducted to assess whether there were initial differences in participants who completed the study and those who ceased participation after a number of assessments. Independent-samples t tests were conducted to detect any appreciable relationship between initial performance and attrition, and homogeneity of variances was not assumed. All 30 healthy older adults were evaluated annually for at least the first 7 years of the study, 25 participants for 10 years, 10 participants for 12 years, and 5 participants were evaluated for all 15 years of the study. Initial linguistic measures of the participants who remained for 11 or more years of the study were compared with those who remained in the study for less than 11 years. Initial mean differences between those who continued for 11 or more years ($n = 10$) and those who did not ($n = 20$) were not statistically significant for D-Level, $t(28) = 1.47$, $p = .161$, and for P-Density, $t(28) = 1.57$, $p = .136$. Participants who remained in the study for 11 or more years averaged 68.3 years of age at the initial observation, whereas those who completed less than 11 years were 73.5 years of age initially, $t(28) = -7.17$, $p < .001$. Initially the participants were 15 men and 15 women; by the 11th assessment, only women were participating in the study, precluding any assessment of gender differences.

Procedure. At each assessment, all participants were given the MMSE as well as the Digits Forward and Digits Backward tests from the WAIS-R and the WAIS-R Vocabulary test. Conventional procedures were used to score their responses. A composite digit span score was computed for each participant by summing their forward and backward spans.

An oral language sample was elicited from each participant in response to one of a number of elicitation questions. Elicitation questions were designed to require reflection; they included questions such as "Describe the person who most influenced your life," "Describe an unexpected event that happened to you," "Tell me about your wedding—did anything unexpected happen?" "Whom do you most admire and why?" Each participant received a different elicitation question on each occasion. A minimum of 50 utterances was elicited from each participant on each occasion.

The sample was analyzed following the procedures described by Kemper et al. (1989). The samples were transcribed and coded by first segmenting each into utterances. Utterances were segmented by discernible pauses in the participant's flow of speech or by conventional sentence boundaries; therefore, utterances correspond to grammatical sentences as well as interjections, fillers, and sentence fragments. *Fillers*, defined as speech serving to fill gaps in the speech flow, included both lexical and nonlexical fillers. Nonlexical fillers, such as "uh," "umm," "duh," and so on, were excluded from the transcript. Lexical fillers, such as "and," "you know," "yeah," "well," and so on, were retained in the transcript. Also excluded from the transcript were utterances that repeated or echoed those of the examiner.

Two measures were then obtained from each language sample (see Cheung & Kemper, 1992, for details). The first measure was the D-Level, an index of grammatical complexity based on a scale originally developed by Rosenberg and Abbeduto (1987). Grammatical complexity ranges from simple one-clause sentences to complex sentences with multiple forms of

embedding and subordination. Each complete sentence was scored, and the average D-Level for each language sample was then calculated. Note that this measure is based on complete, grammatical sentences; all fragments, fillers, and interjections are excluded from the calculation of D-Level. The second measure was P-Density, a measure of the propositional content of a passage. P-Density was calculated according to the procedures described by Turner and Greene (1977). Each utterance was decomposed into its constituent propositions, which represent concepts and relations between them. The P-Density for each language sample was defined as the average number of propositions per 10 words. P-Density, unlike D-Level, is based on complete sentences as well as fragments, interjections, and fillers. Two trained coders independently scored 10% of the language samples to establish reliability. Reliabilities were .94 and .91 for D-Level and P-Density, respectively.

Statistical analyses. There is no one widely accepted modeling approach for obtaining a statistical model including fixed and random effects. We found it useful to examine growth trajectories both by graphic models and by statistical models.

For graphic models, we used spaghetti plots to display individual growth curves of the participants in order to assist in developing initial hypotheses about the overall pattern of growth and the effects of vocabulary and digit span on those patterns. In this study, the plots indicated a decline in grammatical complexity. This decline appeared to be age related, occurring in most participants in the same age span, beginning sometime around 74 years of age, and it appeared to occur for most participants in the same period of time, a period of 2 to 4 years. Hence, effects of both age and time on the decline in grammatical complexity appear to cooccur during the 4-year period corresponding to ages 74 to 78. The spaghetti plots are also useful in suggesting a strategy for modeling the data in terms of the random effects. For example, in this study, individuals within a group displayed the same general pattern of change in linguistic ability over time, but the initial levels on the outcome measures and the rates of decline appeared to vary from person to person, suggesting the need for random intercepts and slopes. We then hypothesized that covariates for digit span or vocabulary might explain the between-subject variance or covariance in the random intercept and slope. Our statistical modeling approach examined random components separately from the fixed components by using restricted maximum-likelihood estimation. In selecting the fixed components, we retained the same random components (random intercept and slope) for all models while progressively evaluating the higher ordered fixed effects: linear, quadratic, cubic, and so on. Fixed effects were retained in the model if the F statistic for the effect was significant. Once the fixed effects were determined, the random components were examined. In selecting the random components for the model, we again used the forward selection approach of progressively adding the random effects for the higher order terms (random quadratic and cubic). The random effects were evaluated using the deviance statistic ($-2 \log$ likelihood) associated with each model. When the fixed effects are exactly the same in two nested models, differences in the deviance statistics are approximately chi-square distributed with degrees of freedom equal to the difference in the number of (random) parameters between the two nested models. A similar modeling strategy involving descriptive analyses followed by alternative evaluations for fixed and random effects components was recommended by Wallace and Green (in press). The SAS PROC MIXED program was used in this study to estimate the models of interest. For additional details on specifying and evaluating models using SAS PROC MIXED, see Singer (1998) and Littell, Milliken, Stroup, and Wolfinger (1996). Only the final models, as determined by using the statistical modeling strategy described previously, are reported in the tables. We do not report interim results of the modeling process nor do we report the statistics for comparing models.

Results

Descriptive statistics are presented first, followed by the models for grammatical complexity and propositional content.

Descriptive statistics for healthy older adults. The healthy older adults participated in the study from 7 to 15 years. Table 1 summarizes relevant data collected at Years 1, 5, 10, and 15. In addition to indicating the number of participants remaining in the study, these data include the means and standard deviations of age, D-Level, P-Density, digit span, and vocabulary. Spaghetti plots were created to examine growth curves for the two linguistic outcomes. Figure 1 depicts the relationship between age and D-Level in the top panel, whereas the relationship between age and P-Density are depicted in the bottom panel. Both graphs display a strong age effect. A cubic pattern of decline is strongly visible for D-Level and is suggested to a lesser extent for P-Density. The graphs show individual variability in initial levels and in patterns of change for both outcomes, supporting the need to estimate and interpret the between-subjects variability.

Statistical models of linguistic changes in healthy older adults. As observed in Figure 1, age-related declines in both linguistic outcomes were observed for the healthy older adults. For each outcome, several statistical models were evaluated to quantify this decline. First, a model was fitted to indicate the relationship between aging and the outcome. Both fixed effects and random effects were considered according to the procedure summarized in the *Method* section. To ease interpretation of the estimated coefficients, the age variable was centered at the mean initial age for the healthy older adults. Random between-subject variation in intercepts, slopes, or both was present; previously hypothesized subject-level covariates were evaluated for their ability to account for this variation. Parameter estimates and related test statistics for the D-Level and P-Density models are presented in Tables 2 and 3, respectively.

Grammatical complexity. An age-related decline in D-Level was hypothesized a priori, and the plot of age versus D-Level (Figure 1, top panel) suggested that higher order terms would be required in a statistical model to describe the inflections. Figure 1 depicts a marked decline in D-Level between ages 74 and 78, with more gradual declines before and after that interval. A cubic model best represented the relationship between advancing age and

D-Level (Table 2, Model 1). The intercept estimate, 6.270, is the predicted initial D-Level score for a person at the initial mean age. Fixed effects for the linear, quadratic, and cubic components of age were statistically significant ($p < .0001$). The random effects for the intercept and slope were also significant, indicating that there was substantial unexplained intercept and slope variability. This between-person variability was also clearly seen on the graph.

In separate models, vocabulary and digit span were added to the cubic age model (Table 2, Models 2 and 3, respectively) as covariates to explain the variability in slope and intercept among persons. The covariates consisted of the initial vocabulary and digit span scores for each person. Each person's covariate was centered at the highest score observed on that measure in the healthy older adults (66 for vocabulary and 16 for digit span) so that deviations from this centered score are interpretable as decline from their highest score. The fixed effect estimate for vocabulary and the interaction between age and vocabulary were not statistically significant, nor did they contribute significantly to explaining the slope and intercept variability between persons (Table 2, Model 2).

In contrast, initial digit span and the interaction between age and digit span were useful and statistically significant in predicting D-Level over advancing age (Table 2, Model 3). Initial digit span reduced but did not fully account for the between-subject variance in the intercept for initial D-Level. Healthy adults with higher initial digit span scores were also likely to have higher D-Level scores, accounting for the reduction in intercept variance when digit span is included as a covariate in the model (compare Models 1 and 3 in Table 2). Figure 2 illustrates the relationship between initial digit span scores and D-Level scores, in addition to aiding in the interpretation of the Age \times Digit Span interaction term. D-Level growth curves were generated for hypothetical participants having high, average, and low initial digit span scores using the fixed effects coefficients reported in Table 2, Model 3. Figure 2 (top panel) illustrates that differences in predicted D-Level scores for participants having high ($M = 16$), average ($M = 13$), and low ($M = 10$) initial digit span scores become smaller with advancing age. The sign of the estimate for the Age \times Digit Span interaction is negative, reflecting the fact that the positive relationship between D-Level and initial digit span weakens somewhat as people get older. Therefore, healthy adults with higher initial digit span scores declined in D-Level slightly more rapidly than those with lower initial digit span scores.

Propositional content. As observed in Figure 1 (bottom panel), an age-related decline was also observed on the P-Density measure for the healthy older adults. The pattern of decline was similar to that for D-Level, with the most pronounced decline occurring in the mid 70s. Again, a cubic model best represented the relationship between advancing age and P-Density (Table 3, Model 1). The intercept estimate, 7.485, reflects the predicted P-Density score for a person at the group mean age at the initial measurement time. Fixed effects for the linear, quadratic, and cubic components of age were statistically significant ($p < .0001$). Also significant were the variance components for the intercept and slope, as well as the covariance between the intercept and slope. Figure 1 (bottom panel) displays this variability in growth curves among individuals.

Table 1
Means (and Standard Deviations) of Linguistic Measures and Covariates for Healthy Older Adults

Variable	Time of measure and sample size			
	Initial ($n = 30$)	Year 5 ($n = 30$)	Year 10 ($n = 25$)	Year 15 ($n = 5$)
Age	71.76 (2.98)	75.84 (2.94)	80.42 (3.07)	80.83 (1.53)
Grammatical complexity	6.06 (0.43)	4.62 (1.38)	3.24 (1.30)	2.98 (0.98)
Propositional content	7.25 (0.72)	6.96 (0.97)	6.49 (0.75)	5.84 (0.37)
Digit span	13.07 (1.60)	10.23 (2.97)	7.12 (2.51)	6.80 (1.10)
Vocabulary	53.20 (5.89)	49.87 (5.80)	45.28 (4.76)	42.40 (2.61)

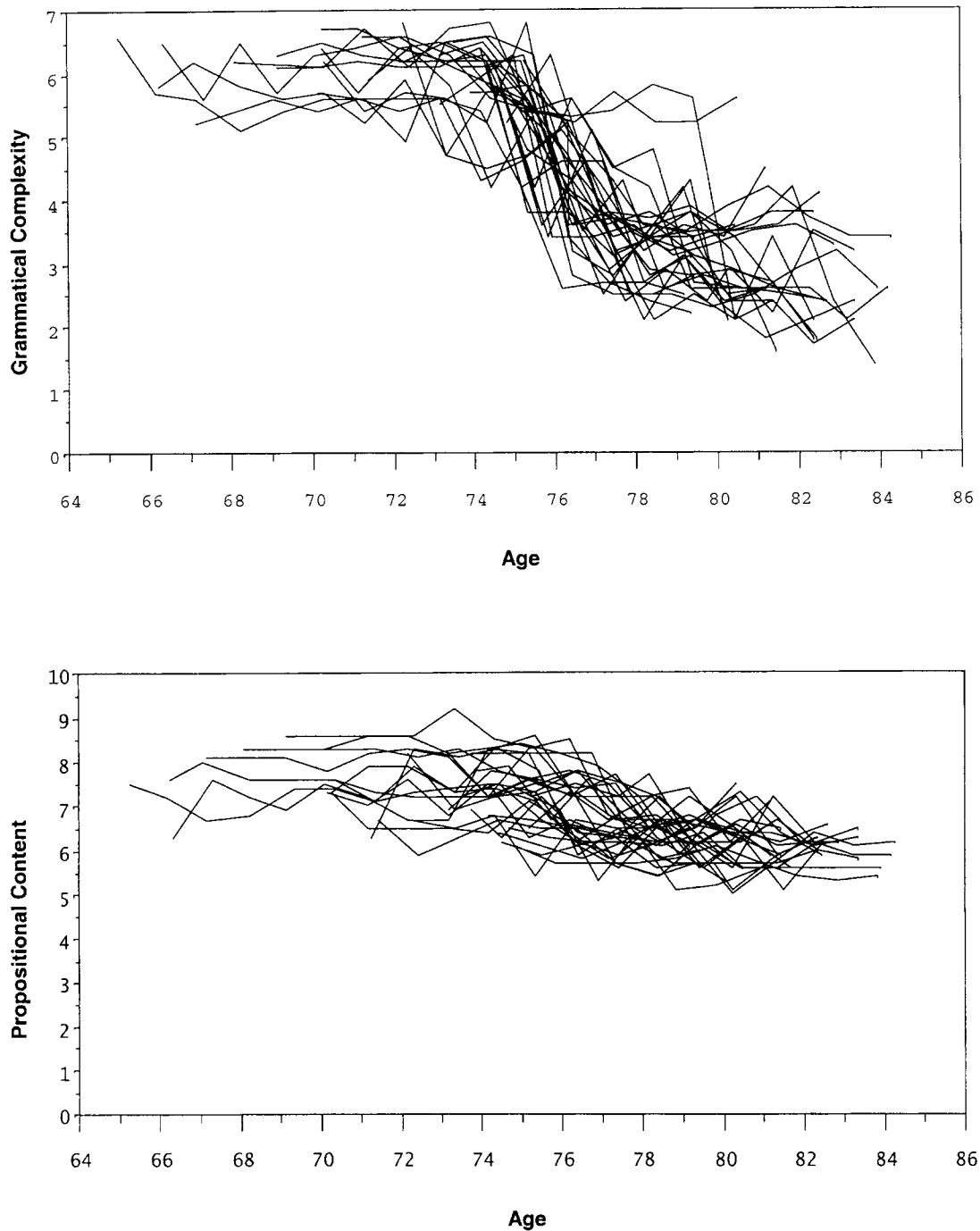


Figure 1. Longitudinal change in grammatical complexity (D-Level; top panel) and in propositional content (P-Density; bottom panel) for healthy older adults.

The between-subject variance in the initial level and linear component of the decline in P-Density was reduced, and their covariance was significantly reduced by inclusion of initial vocabulary as a covariate (Table 3, Model 2). Figure 2 (bottom panel) is helpful in understanding the estimates for the vocabulary covariate and the Age \times Vocabulary interaction term. P-Density growth curves were generated for hypothetical participants having high

($M = 66$), average ($M = 53$), and low ($M = 40$) initial vocabulary scores using the fixed effects coefficients reported in Table 3, Model 2. Healthy adults with higher initial vocabulary scores were also likely to have higher P-Density scores, accounting for the reduction in intercept variance when vocabulary is included as a covariate in the model (compare Models 1 and 2 in Table 3). Figure 2 (bottom panel) also shows that differences in predicted

Table 2
Grammatical Complexity Models for Healthy Older Adults, REML Estimates

Predictor	Model 1: Age effect				Model 2: Vocabulary as a covariate				Model 3: Digit span as a covariate			
	Estimate	SE	F	df	Estimate	SE	F	df	Estimate	SE	F	df
Fixed effects												
For base level												
Intercept	6.270	0.095			6.128	0.193			6.554	0.154		
Covariate					-0.013	0.016	0.64	1, 28	0.123	0.050	6.13*	1, 28
For linear effect												
Age	-0.241	0.024	97.53*	1, 294	-0.026	0.036	49.61*	1, 293	-0.284	0.033	74.42*	1, 293
Age × Covariate					-0.001	0.003	0.10	1, 293	-0.025	0.010	6.55*	1, 293
For quadratic effect												
Age ²	-0.049	0.005	86.52*	1, 294	-0.049	0.005	85.95*	1, 293	-0.052	0.005	98.25*	1, 293
For cubic effect												
Age ³	0.004	<0.001	70.74*	1, 294	0.004	<0.001	70.65*	1, 293	0.004	<0.001	75.51*	1, 293
Variance components												
Intercept	0.062*	0.043			0.064*	0.043			0.033*	0.044		
Linear slope	0.003*	0.001			0.003*	0.001			0.003*	0.002		
Residual	0.494	0.042			0.494	0.042			0.493	0.042		

Note. REML = restricted maximum-likelihood.
* *p* < .05.

P-Density scores for participants having high, average, and low initial vocabulary scores become smaller with advancing age. The sign of the estimate for the Age × Vocabulary interaction is negative, reflecting that the positive relationship between P-Density and initial vocabulary weakens as people get older. Further, the decrease in slope variance between participants (compare Models 1 and 2 in Table 3) is attributable to the inclusion of the Age × Vocabulary interaction term. Healthy adults with higher

initial vocabulary scores declined more rapidly in P-Density with advancing age than those with lower scores.

Digit span was evaluated as a potential covariate for the P-Density model (Table 3, Model 3). The fixed effects estimates for digit span and the interaction between age and digit span were not statistically significant. The random effects were not appreciably reduced, and overall fit statistics were not improved by inclusion of the digit span covariate.

Table 3
Propositional Content Models for Healthy Older Adults, REML Estimates

Predictor	Model 1: Age effect				Model 2: Vocabulary as a covariate				Model 3: Digit span as a covariate			
	Estimate	SE	F	df	Estimate	SE	F	df	Estimate	SE	F	df
Fixed effects												
For base level												
Intercept	7.485	0.149			8.789	0.122			7.927	0.290		
Covariate					0.112	0.010	122.76*	1, 28	0.153	0.089	3.01	1, 28
For linear effect												
Age	-0.072	0.025	8.38*	1, 294	-0.163	0.023	50.36*	1, 293	-0.104	0.036	8.36*	1, 293
Age × Covariate					-0.010	0.002	31.90*	1, 293	-0.012	0.010	1.38	1, 293
For quadratic effect												
Age ²	-0.022	0.004	30.18*	1, 294	-0.022	0.004	39.65*	1, 293	-0.022	0.004	30.48*	1, 293
For cubic effect												
Age ³	0.001	<0.001	19.82*	1, 294	0.001	<0.001	17.52*	1, 293	0.001	<0.001	20.01*	1, 293
Variance components												
Intercept	0.502*	0.166			0.017*	0.013			0.473*	0.157		
Linear slope	0.005*	0.002			0.001	<0.001			0.005*	0.002		
Intercept linear	-0.045*	0.018			<-0.001	—						
Residual	0.234	0.021			0.240	0.021			0.233	0.020		

Note. Dash indicates the standard error was not estimated. REML = restricted maximum-likelihood.
* *p* < .05.

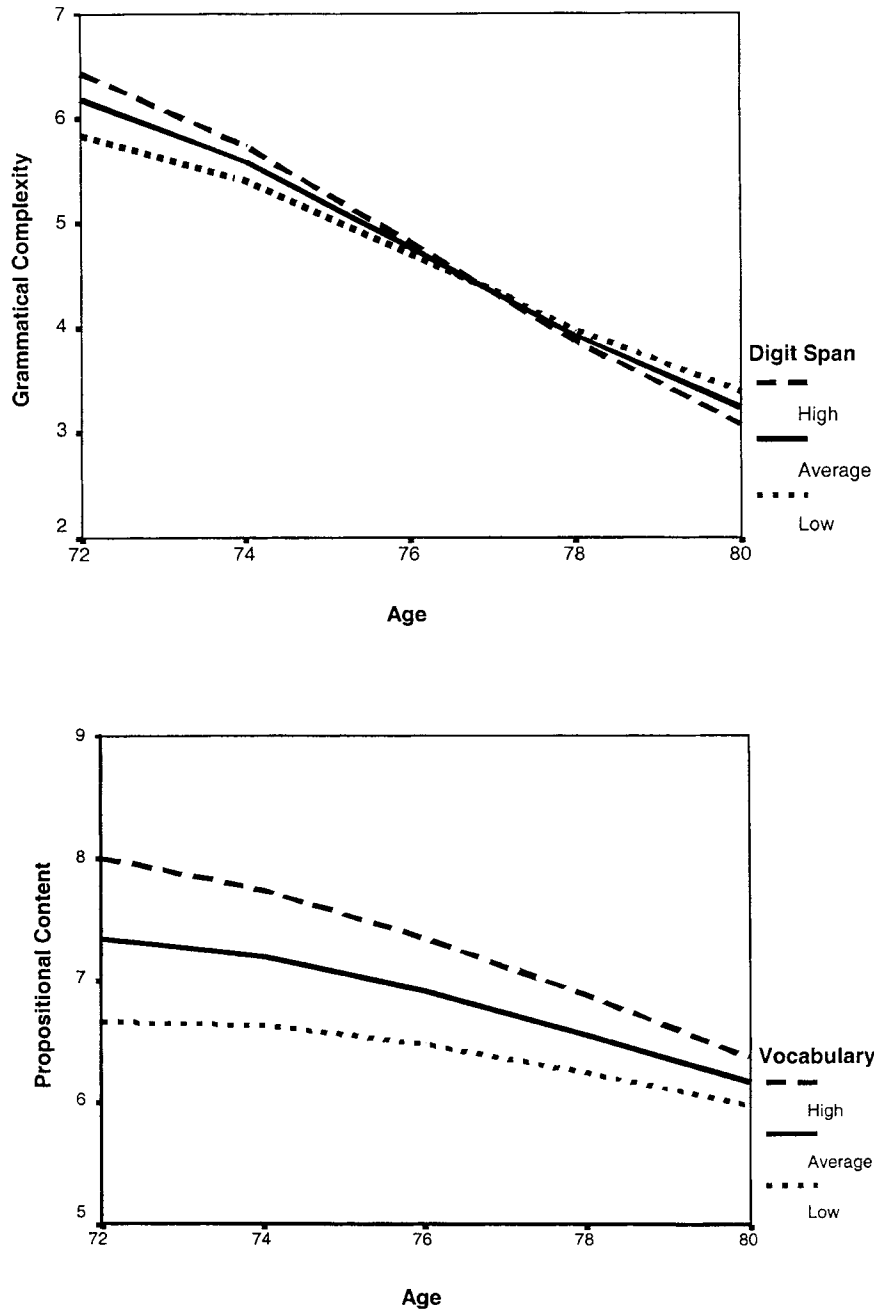


Figure 2. Illustration of digit span as a covariate in the Age × Grammatical Complexity model for the healthy older adults (Table 3, Model 3; top panel) and vocabulary as a covariate in the Age × Propositional Content model for the healthy older adults (Table 4, Model 2; bottom panel).

Study 2

Language samples were also analyzed for a group of older adults with dementia. In contrast to the preceding analyses, language samples were collected at 6-month intervals for up to 2.5 years.

Method

Participants. The older adults with dementia met Consortium to Establish a Registry for Alzheimer’s Disease (CERAD; McKhann et al.,

1984) criteria for diagnosis of probable Alzheimer’s disease; none had a history of stroke, ischemia, focal neurological deficit or lesions, depression, psychosis, alcoholism, or drug use. Of those participants who have died and for which information is available, Alzheimer’s disease has been confirmed in 92% of the cases (12 of 13 cases). Each was initially given the MMSE; all received scores of 23 or lower. Oral language samples were collected at 6-month intervals from the older adults with dementia for a period of up to 2.5 years. Their participation in the study was discontinued whenever they developed major medical conditions such as cancer or kidney or liver disease ($n = 1$), they entered an assisted living center ($n =$

5), they died ($n = 3$), they became uncooperative ($n = 3$) or mute and unresponsive ($n = 6$). Each began treatment with donepezil hydrochloride during the course of the study; the small sample size precluded detection of effects, if any, of this medication. All but 1 of the participants were women.

Attrition. Attrition occurred more quickly in the group of older adults with dementia: all 30 participants were present for the first two biannual assessments, 25 participants for three assessments, 19 participants for four assessments, and 12 participants for all five of the biannual assessments spanning 2.5 years. Independent-samples t tests were conducted to compare the initial cognitive function, linguistic measures, and ages of the participants with dementia who remained for four or five assessments with those who remained in the study for fewer than four assessments. Initial cognitive function, as measured by MMSE scores, was comparable among participants with dementia who continued through four or five assessments ($n = 11$) and those who contributed two or three assessments ($n = 19$), $t(28) = -0.04$, $p = .968$. These groups did not differ significantly on the initial D-Level outcome, $t(28) = 0.05$, $p = .961$, however, participants who remained in the study longer had somewhat higher initial measures on the P-Density outcome, $t(28) = 5.31$, $p < .001$. Participants who remained in the study for 2 or more years averaged 68.6 years of age at the initial observation, whereas those who participated for less than 2 years had an initial mean age of 74.0 years, $t(28) = -4.54$, $p < .001$.

Procedure. The language samples from the older adults with dementia were elicited, transcribed, and coded using the same procedures described above.

Approach to statistical modeling. The plots for the participants with dementia were quite different from those for the healthy older adults. The decline in grammatical complexity was much steeper, occurred over a shorter period of time, and did not appear to occur in any specific age span (see Figure 3). Thus, the time effects appear to be separate from the age effects, if any, in the group with dementia. One way to partially separate the age effects from the time effects is to use age-related deviation scores to represent time effects and to use a constant age variable, such as mean age or age at entry into the study, to represent the age effects in the model (Jacobs et al., 1999). To accomplish this separation of age and time effects in the group with dementia, we calculated each person's mean age over the course of their participation in the study. We also created a variable representing the time effect by subtracting the person's mean age from his or her age at each observation; these values represent the period of time elapsed between observations. The age-deviation scores by themselves are still confounded with age, but by including the mean age in the model, we controlled for age effects.

Results

Descriptive statistics for older adults with dementia. Older adults with dementia participated at 6-month intervals for 6 to 30 months. Table 4 reports relevant summary data collected from participants at each interval: 6, 12, 18, 24, and 30 months. The number of participants at each interval is indicated, along with means and standard deviations of age, D-Level, P-Density, digit span, vocabulary, and MMSE scores. Spaghetti plots were again generated to examine growth curves for the two linguistic outcomes. The relationships of age with D-Level and P-Density are shown in the top and bottom panels of Figure 3, respectively. Similar and rapid declines over time are apparent for all individuals in the older adults with dementia regardless of age. The declines are largely linear until the final observations, when a number of the participants register slight improvements on the two linguistic measures. This may be an effect of the pharmaceutical intervention because all participants were taken donepezil hydrochloride by the time of their final assessment. There is some evidence of individual variability in initial levels, but little vari-

ability in the apparent rate of decline. Figure 3 suggests that decline in the two outcomes should be modeled as a function of time rather than age for those persons diagnosed with dementia.

Statistical models of linguistic changes in older adults with dementia. In the first stage of the analyses, the relationship between time and the outcome was modeled. Fixed effects and random effects were again evaluated according to the procedure summarized in the *Method* section. Random between-subject variation in intercepts, slopes, or both was present for both outcomes, so pertinent subject-level covariates were added to assess the extent to which they could explain this variation. Parameter estimates and related test statistics are presented in Tables 5 and 6, respectively, for the D-Level and P-Density models.

Grammatical complexity. The relationship between time and D-Level was best described by a cubic model. Estimates for the time and age effect model are specified in Table 5, Model 1. Because of the centering procedure used to separate the time (within-person) and age (between-person) effects, the intercept estimate (-1.500) is meaningful only after it is adjusted by adding to it the product of the mean age coefficient (0.057) and the mean age (71.286). The expression ($-1.500 + 0.057 \times 71.286$) yields 2.563, an estimate of the mean D-Level score of the older adults with dementia at their mean age, without controlling for any other factors. Fixed effects for the linear, quadratic, and cubic components of time, as well as the mean age effect, were statistically significant ($p < .05$). The random effect for the intercept was also significant, indicating substantial unexplained intercept and slope variability. For the older adults with dementia, it is possible that the random intercept is a function of the length of time the person had been dementing prior to entering the study.

Vocabulary was also evaluated as a potential covariate for the D-Level model (Table 5, Model 2). The fixed effects estimates for vocabulary were not statistically significant. The random effects were not appreciably reduced; the linear, cubic, and quadratic effects for time remained, and overall model fit statistics were not improved by inclusion of the vocabulary covariate.

The initial digit span measure was evaluated as a potential covariate in the older adults with dementia. Digit span was centered at 11, the largest score observed in the older adults with dementia. Inclusion of initial digit span did not improve overall model fit nor did it reduce the random variability in the intercept and slope (Table 5, Model 3). Figure 4 (top panel) illustrates this relationship between D-Level and high ($M = 11$), medium ($M = 9$), and low ($M = 7$) digit span for the older adults with dementia. Initial digit span increased or decreased the level of grammatical complexity but did not alter the pattern of decline.

Propositional content. For the older adults with dementia, a linear model was most appropriate for describing the relationship between progressing time and P-Density. Model 1 in Table 6 reports details for the time effect model. The mean age effect was not significant for P-Density. The intercept estimate, 3.220, is the estimated mean P-Density score of all persons at their mean age. The linear effect for time reflects that for every year beyond the mean of the person-mean age, P-Density decreases by 1.535. The fixed effect for time was statistically significant ($p < .0001$). The random effects for the intercept and slope were statistically significant, reflecting unexplained intercept and slope variability.

Vocabulary was again used as a covariate. Vocabulary was centered at 41, the largest score observed in the older adults with

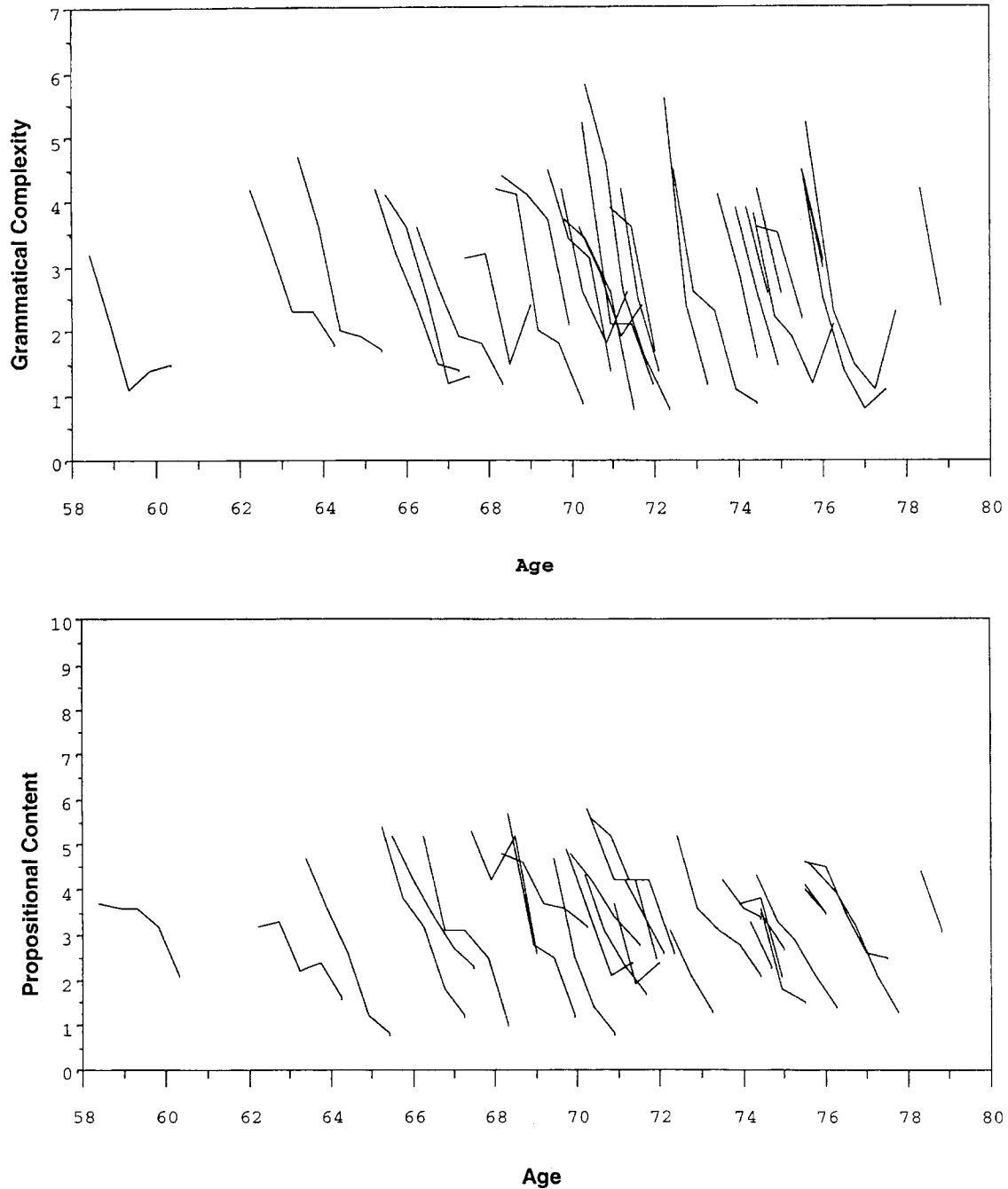


Figure 3. Longitudinal change in grammatical complexity (D-Level; top panel) and in propositional content (P-Density; bottom panel) for older adults with dementia.

dementia. Model 2 in Table 6 shows that inclusion of vocabulary as a covariate accounted for the random variability in the intercept and slope and improved model fit. The vocabulary fixed effects was statistically significant along with the time effect. Figure 4 (bottom panel) illustrates this relationship between P-Density and high ($M = 41$), medium ($M = 30$), and low ($M = 19$) vocabulary for the older adults with dementia.

Digit span was also evaluated as a potential covariate for the P-Density model (Table 6, Model 3). The fixed effects estimates

for digit span were not statistically significant, the random effects were not appreciably reduced, the linear effect for time remained, and overall model fit statistics were not improved by inclusion of the digit span covariate.

Discussion and Conclusions

Like vocabulary-based assessments of linguistic abilities, the present assessments, based on language sample analysis, indicate

Table 4
Means (and Standard Deviations) of Linguistic Measures and Covariates
for Older Adults With Dementia

Variable	Time of measure and sample size				
	Initial (n = 30)	6 months (n = 30)	12 months (n = 25)	18 months (n = 19)	24 months (n = 12)
Age	70.56 (4.57)	71.07 (4.58)	70.57 (4.31)	70.09 (4.46)	70.13 (5.59)
Grammatical complexity	4.24 (0.62)	2.99 (0.63)	2.01 (0.60)	1.61 (0.55)	1.42 (0.48)
Propositional content	4.46 (0.77)	3.44 (0.81)	2.92 (0.93)	2.38 (0.83)	1.84 (0.74)
Digit span	8.70 (1.15)	6.17 (1.12)	4.20 (1.29)	3.68 (1.29)	3.25 (1.06)
Vocabulary	30.43 (4.52)	24.90 (5.09)	20.84 (5.76)	16.74 (5.24)	15.75 (5.89)
MMSE	18.43 (2.13)	16.50 (2.29)	12.44 (2.52)	9.74 (2.79)	7.67 (1.97)

Note. MMSE = Mini-Mental State Examination.

that linguistic abilities of healthy adults decline in late adulthood. Both the grammatical complexity and propositional content of older adults' spontaneous speech decline between ages 74 and 78. In both cases, the pattern of decline is a cubic function of age, such that a period of relative stability is followed by a period of accelerated decline and by a third period of more gradual decline. Language samples were limited to adults 65.25 to 75.25 years ($M = 71.76$) at the time of the first assessment and 79.42 to 83.33 ($M = 81.04$) at the time of the final assessment; hence, these models cannot be projected to younger or older adults. There are very few observations from adults older than 80 years of age; hence, the statistical models may not reliably estimate the degree of late-life decline in grammatical complexity or propositional

content. The period of rapid decline followed by a period of gradual decline exhibited by both measures in the mid 70s may correspond to a period of rapidly declining health that is followed by a period of further, more gradual decline that foreshadows the withdrawal or exclusion of most participants from this study for reasons of health (Berg, 1996; Kleemeier, 1962; Small & Backman, 1999).

The mixed modeling also indicated that there is considerable individual variation in older adults' initial level of grammatical complexity and propositional content as well as individual variation in their rate of decline. The initial level of grammatical complexity was predicted in part by the participant's composite score on the Digits Forward and Digits Backward tests; further, the

Table 5
Grammatical Complexity Models for Older Adults With Dementia, REML Estimates

Predictor	Model 1: Time effect				Model 2: Vocabulary as a covariate				Model 3: Digit span as a covariate			
	Estimate	SE	F	df	Estimate	SE	F	df	Estimate	SE	F	df
Fixed effects												
For base level												
Intercept	-1.500	1.631			-1.529	1.568			-2.982	1.831		
Mean age	0.057	0.023	6.16*	1, 28	-0.051	0.022	5.27*	1, 27	0.061	0.022	7.42*	1, 27
Covariate					-0.042	0.022	3.84	1, 27	0.138	0.084	2.68	1, 27
For linear effect												
Time	-1.917	0.182	110.87*	1, 83	-1.921	0.182	111.00*	1, 83	-1.917	0.182	110.64*	1, 83
For quadratic effect												
Time ²	0.677	0.138	24.23*	1, 83	0.702	0.138	25.98*	1, 83	0.673	0.138	23.90*	1, 83
For cubic effect												
Time ³	0.422	0.185	5.21*	1, 83	0.425	0.184	5.32*	1, 83	0.423	0.185	5.21*	1, 83
Variance components												
Intercept	0.216*	0.081			0.195*	0.074			0.198*	0.079		
Linear slope	0.196	0.132			0.198*	0.132			0.196	0.132		
Residual	0.269*	0.053			0.266*	0.052			0.270*	0.053		

Note. REML = restricted maximum-likelihood.

* $p < .05$.

Table 6
Propositional Content Models for Older Adults With Dementia, REML Estimates

Predictor	Model 1: Time effect				Model 2: Vocabulary as a covariate				Model 3: Digit span as a covariate			
	Estimate	SE	F	df	Estimate	SE	F	df	Estimate	SE	F	df
Fixed effects												
For base level												
Intercept	3.220	0.111			4.056	0.226			3.317	0.253		
Covariate					0.080	0.020	16.18*	1, 28	0.042	0.099	0.18	1, 28
For linear effect												
Time	-1.535	0.099	239.57*	1, 85	-1.530	0.100	235.89*	1, 85	-1.530	0.099	239.55*	1, 85
Variance components												
Intercept	0.313*	0.096			0.186*	0.065			0.314*	0.096		
Linear slope	0.128*	0.069			0.130*	0.069			0.127*	0.070		
Residual	0.186	0.033			0.186*	0.033			0.188	0.033		

Note. REML = restricted maximum-likelihood.

* $p < .05$.

grammatical complexity of those with higher initial scores also declined somewhat more rapidly with advancing age. In contrast, the initial level of propositional content was predicted in part by the participant's score on the Vocabulary test, and those with higher initial scores declined somewhat more rapidly with advancing age.

Attrition could have led to overestimating the degree of decline in grammatical complexity or propositional content for those participants with high scores if participants with lower initial scores were more likely to drop out of the study. This does not appear to be the case. Both grammatical complexity and propositional content may be subject to "floor" effects or a lower limit that arises from the use of language sample methodology. Both measures are computed from a language sample; the grammatical complexity measure, D-Level, is computed for complete sentences, whereas the content measure, P-Density, is computed for complete sentences as well as sentence fragments. As indicated in Figure 1 and Table 1, D-Level declined from an average of 6.06 to 2.98 over 15 years, whereas P-Density declined from an average of 7.25 to 5.84. Neither score appears to be approaching the actual floor of 0.0 for grammatical complexity (a language sample composed of single clause sentences) or 0.0 propositions per 10 words (a language sample containing only fragments and nonlexical or lexical fillers that do not contribute any information). It may be, however, that fluent, grammatical, informative speech imposes a functional floor such that a language sample is likely to contain many utterances with infinitive clauses, compound sentences, and other forms that contribute 1 or 2 points to the calculation of D-Level and utterances that express many basic predicate-argument relations that contribute to P-Density. Hence, those participants with higher initial levels of grammatical complexity and propositional content will exhibit a more rapid decline as they approach this functional floor than those participants who begin with lower levels of grammatical complexity and propositional content.

Dementia appears to accelerate the decline in linguistic abilities, although time rather than age was the more useful predictor of language decline for the individuals with Alzheimer's disease. The centering procedure used in the mixed modeling of the data from

adults with dementia allowed us to distinguish the effects of time from those of age. By subtracting each person's mean age from age at each observation, we obtained measures of elapsed time between observations. Also, by including mean age as a parameter of the model, we were able to consider the effects of time controlling for age. Both time and age effects were significant for D-Level, whereas only time was significant for P-Density.

The pattern of decline in grammatical complexity for those individuals with dementia was similar to that for the healthy older adults, captured by a cubic model, whereas the patterns of decline in propositional content for the two groups were different. Whereas the decline in propositional content was a cubic function of age for the healthy older adults, the decline in propositional content for the adults with dementia was a linear function of time. Grammatical complexity declined from an average of 4.24 to 1.42, indicating that even the adults with advanced dementia were still capable of producing grammatical sentences; propositional content declined from 4.46 propositions per 10 words to 1.84, suggesting that the participants were still able to convey much basic information despite their word finding and memory problems.

Those participants with dementia who had lower initial P-Density scores were more likely to drop out of the study than those with higher P-Density scores. The results indicate that those with a higher initial level will undergo the most rapid decline, and those with a lower initial level will undergo a more gradual decline. Therefore, selective attrition could have led to a small degree of overestimation regarding the decline in P-Density. Yet it is likely that a functional floor imposes a lower limit on P-Density.

Language sample analyses of written samples collected as part of the Nun Study have shown that linguistic ability in young adulthood is predictive of linguistic ability in late life and that linguistic ability gradually declines over the life span (Kemper et al., 2001; Snowdon et al., 1996). The present analyses demonstrate that linguistic ability further declines in late adulthood. This decline in linguistic ability appears to have multiple determinates; the differential patterns of decline for grammatical complexity and propositional content argue against a "common cause" for the decline such as processing speed (Salthouse, 1996) or nervous

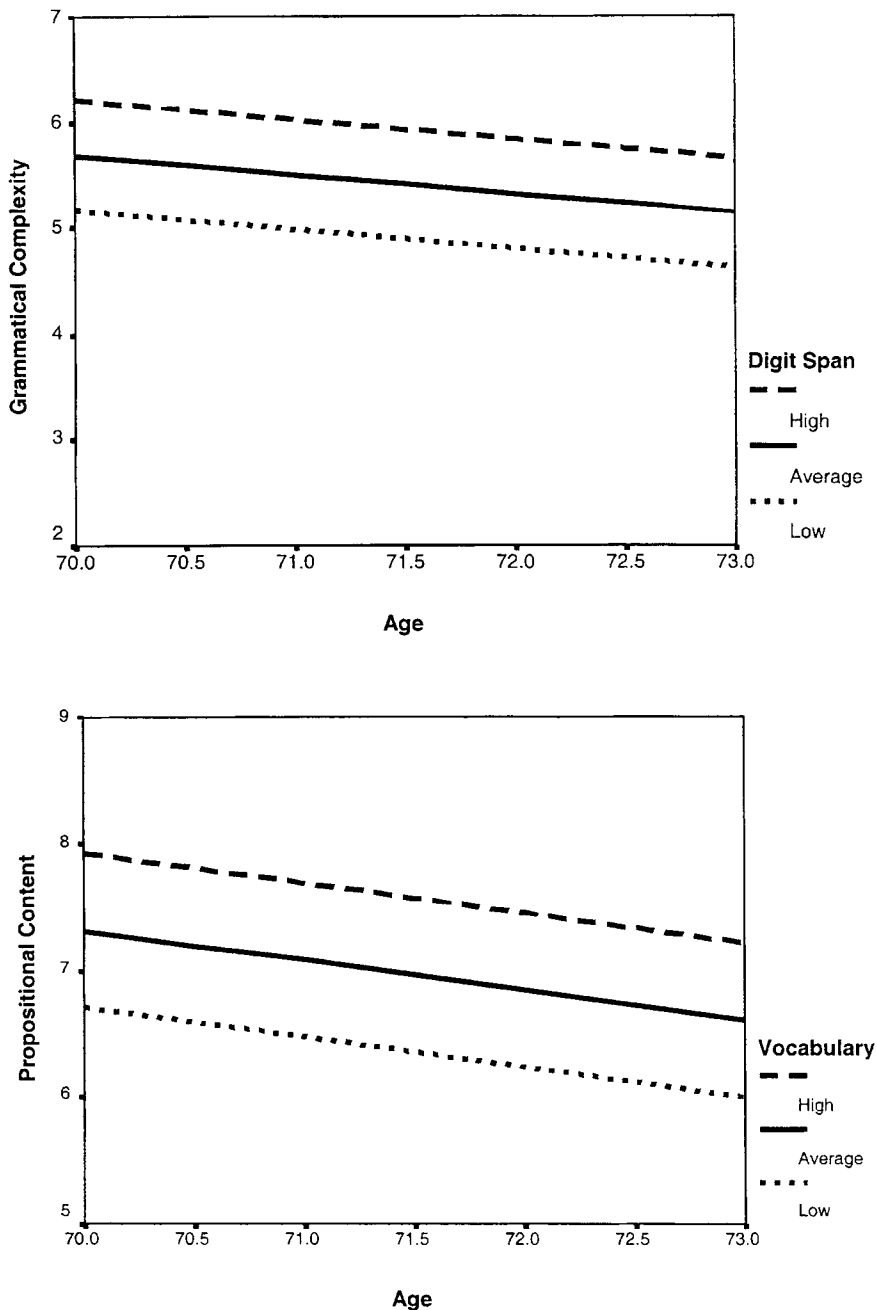


Figure 4. Illustration of digit span as a covariate in the grammatical complexity model for older adults with dementia (Table 5, Model 2; top panel) and vocabulary as a covariate in the propositional content model for older adults with dementia (Table 6, Model 3; bottom panel).

system integrity (Lindenberger & Baltes, 1994). Although only a limited set of covariates was available, it appears that individual differences in two aspects of cognition contributed to the age-related declines. Individual differences in digit span, assumed to measure working memory capacity, accounted for a significant part of the initial variance in grammatical complexity; further, those participants with higher initial digit span scores showed a greater decline in grammatical complexity with age. In contrast,

individual differences in vocabulary accounted for a significant part of the initial variance in propositional content, and those with higher initial vocabulary scores exhibited a greater decline in propositional content with age. Although a very small, highly select sample of older adults provided the language samples used in this analysis, the results suggest that the linguistic abilities of healthy older adults decline between the ages of 65 and 80 years as a result of working memory limitations affecting grammatical

complexity and digit span and verbal processing limitations affecting propositional content and vocabulary knowledge. Prior observations (Kemper et al., 1993; Lyons et al., 1994) had suggested that grammatical abilities are somewhat buffered from the effects of Alzheimer's disease, whereas P-Density declines very rapidly with the progression of the disease. The present study suggests both aspects of language are affected by Alzheimer's disease as well as by age-related changes to working memory and verbal processing.

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