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Abstract:

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 spans were collected annually from healthy older adults and semi-annually from older adults with dementia. The language samples were scored for grammatical complexity and semantic content. For the normal group, an age-related decline in grammatical complexity was observed. The decline was most rapid during the mid-70s. Modeling indicated initial digit span was associated with change in grammatical complexity over advancing age but did not fully explain the between-subject variation in initial grammatical complexity. A similar pattern of decline in semantic content was observed; however the decline during the mid-70s was less rapid than that for grammatical complexity. Modeling indicated initial vocabulary was related to initial semantic content, and those with higher initial vocabulary declined more rapidly in semantic content with advancing age. For the dementing group, grammatical complexity and semantic content also declined over time, regardless of age. The best-fitting models indicated that grammatical complexity was related to digit span whereas semantic content was related to vocabulary. Rates of decline were similar for the two measures and uniform across individuals when the respective covariates were included in the models. These analyses reveal how grammatical complexity as well as semantic 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.

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Longitudinal change in language production: Effects of aging and dementia on grammatical complexity and semantic content

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Longitudinal change in language production: Effects of aging and dementia on grammatical complexity and semantic content

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; Zelinksi & 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 langauge samples to examine the effects of aging on linguistic ability (Kee & Cherry, 1990; 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 WAIS-R subtest (Wechsler, 1981). 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 (embedded clauses are double-underlined). 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, Conseco-Gonzalez, & Hickok, 1996a; Gibson, Schutze, & Salomon, 1996b).

Although the primary target for Alzheimer's disease is the memory system, it also affects linguistic ability. Kemper, LaBarge, Ferraro, Cheung, & Storandt (1993) and Lyons, Kemper, LaBarge, Ferraro, Balota, & Storandt, (1993) 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 healthy elders. 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 semantic 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; and eventually adults with Alzheimer's disease become mute and nonresponsive (Hamilton, 1994).

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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. Longitudinal analyses directly investigate intra-individual change due to age or disease as well as inter-individual change due to individual differences in cognitive abilities. Language samples had been collected annually from the older adults who initially participated in the Kemper et al. (1989) study and returned to participate in the study of story-telling by Kemper, Rash, Kynette, and Norman (1990). Many of these individuals participated in a series of laboratory experiments over the next 15 years, including studies reported in Norman, Kemper, Kynette, Cheung, and Anagnopoulos (1991), Norman, Kemper, and Kynette (1992), Jackson and Kemper (1993), Kemper, Jackson, Cheung, and Anagnopoulos (1994b), Kemper, Othick, Warren, Gubarchuk, and Gerhing (1996) and Kemper, Ferrell, Harden, Finter-Urczyk, and Billington (1998). After five years, a preliminary 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, 1994a) or in a study of meta-linguistic judgments (Kemper, 1997); semi-annual language samples were collected from many of these same individuals for two to five 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 semantic content. D-Level is correlated with measures of working memory, including digit span and reading span (Sumner & Kemper, unpublished). 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 based on 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 zero points whereas sentences with multiple forms of embedding and subordination earn seven points. Sentences containing infinitives, gerunds, relative clauses, and other forms of embedding earn immediate points and left-branching forms are assigned more points than right-branching forms.

The second measure was Propositional Density (P-Density) (Kintsch & Keenan, 1973), a measure of semantic content assessing how much information is packed into a sentence, relative to the number of words. P-Density appears to reflect processing efficiency in terms of how efficiently semantic information can be expressed. Processing efficiency, typically measured by speeded tasks, declines with advancing age and with poor health status (Earles & Salthouse, 1995; Earles, Connor, Smith, & Park, 1997; Hultsch et al., 1998; Light, 1978; Salthouse, 1996). P-Density is correlated with verbal fluency tasks and with reading rate (Sumner & Kemper, unpublished). Verbal fluency tasks, sometimes termed "generative naming," typically require the person to generate as many words as possible meeting a 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).

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, Kemper, Mortimer, Greiner, Wekstein, and Markesbery (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, at 18 - 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) and/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. P-Density appears to be a general measure of cognitive and neurological development; 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 and dementing older adults, cognitive aging is 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 & Buschke (1999) clarified and demonstrated statistical analyses representing two types of age effects, both of which aim to quantify cognitive aging: age differences (a cross-sectional, between-person effect) and age-related changes (a longitudinal, within-person effect). Additionally, they described differential change effects as longitudinal, between-person age effects that reflect individual differences in cognitive aging. The latter two types of effects – age-related changes and differential change effects – are of interest in the present study.

A statistical model useful for assessing longitudinal change in grammatical complexity and semantic content must support estimation of within- and between-subject information. Such a model allows for both fixed and random age effects. Fixed effects describe the nature of age- or time- related changes in the linguistic measures. The fixed effects in our models include the intercept, the mean linear slope for age, and potentially coefficients for higher order age terms (e.g., age^2 and age^3). Random effects are required in the model to the extent that age-related changes vary among individuals. Specifically, the initial measure (intercept) and the relationships (e.g., slopes) that describe the age- or time-related changes in the linguistic outcomes may vary across individuals. The data are additionally complex due to correlated observations within any individual, varying numbers of observations between participants, and varying intervals between observations within and between participants. These complexities make traditional statistical methods based on the general linear model inappropriate. The general linear mixed model provides tremendous flexibility and utility for modeling longitudinal data and is employed in this study. Mixed models have also been 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 utilized in studies of aging to assess change in various types of cognitive function (Sliwinski & Buschke, 1999; Jacqmin-Gadda, Fabrigoule, Commenges, & Dartigues, 1997; Teri, Hughes, & Larson, 1990; Rasmusson, Carson, Brookmeyer, Kawas, & Brandt, 1996).

In this study, we used mixed modeling to examine the pattern of change over time, or growth curves, in grammatical complexity and semantic content. Repeated observations of these outcome measures were obtained from spontaneously produced language samples 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 might be an appropriate covariate for inclusion in growth models for semantic content as a measure of overall verbal ability, and composite digit span might be relevant in models for grammatical complexity as a measure of working memory. Therefore, we examined the effects of individual differences in initial vocabulary and composite digit span on the growth curves for the two outcomes.

Methods

Participants

The participants in this study were 60 older adults; 30 had been clinically diagnosed with probable Alzheimer's disease within six months of entering the study. Participants were 65 to 75 years of age at the first assessment. All were native speakers of English who were recruited via newspaper solicitations, personal referrals, or referrals from the University of Kansas Medical Center Alzheimer's Disease Center. 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 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), because the individual entered an congregate living facility (n = 2), moved from the locale (n = 7), or when their performance on the annual MMSE was 27 or lower (n = 1).

The older adults with dementia met 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 six-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 major medical conditions such as cancer or kidney or liver disease developed (n = 1), they entered an assisted living center (n = 5), died (n = 3), or because 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, in any, of this medication.

An attrition analysis 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. Specifically, independent-samples t tests were conducted within the normal and dementing groups to detect any appreciable relationship between initial performance and attrition; 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 for 10 years, 10 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 (n=10) were compared to those who remained in the study for fewer than 11 years (n=20). Initial mean differences between those who continued and those who did not continue were not statistically significant for D-Level, t (16.46) = 1.47, p = .161, and for P-Density, t (15.12) = 1.57, p = .136. Those who remained in the study for 11 or more years averaged 68.3 years of age at the initial observation whereas those who completed fewer than 11 years were 73.5 years of age initially, t (14.19) = -7.17, $p < .001$.

Attrition occurred more quickly in the group of older adults with dementia: all 30 participants were present for the first two biannual assessments, 25 for 3 assessments, 19 for 4 assessments, and 12 for all 5 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 dementing participants who remained for 4 or 5 assessments (n=19) to those who remained in the study for fewer than 4 assessments (n=11). Initial cognitive function, as measured by MMSE scores, was comparable among dementing participants who continued through 4 or 5 assessments and those who contributed 2 or 3 assessments, t (21.07) = -0.041, p = .968. Additionally, these groups did not differ significantly on the initial D-Level outcome, t (25.56) = 0.049, p = .961, however, participants who remained in the study longer had somewhat higher initial measures on the P-Density outcome, t (27.76) = 5.31, $p < .001$. Those who remained in the study for 2 or more years averaged 68.6 years of age at the initial observation whereas those who participated less than 2 years had an initial mean age of 74.0 years, t (27.31) = -4.54, $p < .001$.

Assessments of Linguistic and Cognitive Ability

At each assessment, all participants were given the MMSE as well as the Digits Forward and Digits Backward tests from the Wechsler Adult Intelligence Scales -Revised (WAIS-R) (Wechsler, 1981) 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 and then coding each utterance. Utterances were defined by discernable pauses in the participant's flow of speech; therefore, segments did not necessarily correspond to grammatically defined sentences but included interjections, fillers, and sentence fragments. "Fillers," defined as speech serving to fill gaps in the speech flow, included both lexical and non-lexical fillers. Non-lexical fillers, such as "uh," "umm," "duh," etc., were excluded from the transcript. Lexical fillers, such as "and," "you know," "yeah," "well," etc. 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 Developmental Level (D-Level), an index of grammatical complexity based 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. The second measure was Propositional Density (P-Density), which can be thought of a measure of the semantic content of a passage. P-Density was calculated according to the procedures described by Turner and Green (1977). Each utterance was decomposed into its constituent propositions, which represent semantic concepts and relations between them. The P-Density for each language sample was defined as the average number of propositions per 10 words. 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

Rationale for a mixed model approach. Longitudinal data offer efficiency in research designs by having multiple observations of the same measure for each individual. However, correlations among the multiple observations for any individual are typically observed in such data, complicating statistical analyses. Therefore, observations within persons cannot be treated independently. Traditional repeated-measures techniques based on the general linear model are appropriate for assuming within-person dependence among observations, but these methods assume observations are measured at the same time intervals and are complete for all individuals. Additionally, the restrictive sphericity assumption applies if univariate repeated-measures analyses are employed. In practice, these assumptions are nearly always untenable. Researchers frequently have unequal numbers of observations per subject due to attrition or to the absence of one or more observations. Missing data forces listwise deletion of subjects or imputation of missing values when traditional repeated-measures analyses are conducted. Further, longitudinal data is often complicated by unequal spacing of observations among individuals, particularly in research requiring individually-administered assessments. Such complexities in the data necessitate alternatives to traditional repeated-measures approaches.

Mixed models have been widely used to analyze nested data, where dependence exists among observations at a level. Dependence may exist in clustered data, as among students nested in classrooms, or in longitudinal data, where multiple observations are nested in individuals. The general linear mixed model provides flexibility and utility for modeling longitudinal data with a variety of covariance structures. Mixed models facilitate the use of all data, including repeated observations taken at unequal intervals and data for subjects with missing observations. Additionally, the within- and between-subject information contained in longitudinal data can be fully distinguished in mixed models.

Our research questions can be readily addressed by specifying and estimating mixed models. The general linear mixed model is "mixed" because both fixed effects and random effects can be specified. In the context of the present study, the fixed effects estimates are coefficients representing average initial levels and age- or time- related changes in grammatical complexity and semantic content (average longitudinal, within-person effects). These fixed effects are mean estimates and, therefore, are constant across persons. However, the initial level on a dependent variable as well as the age- or time-related changes in the dependent variable may vary across individuals. Random effects can be included in a mixed model to indicate variability in the coefficients for fixed effects. Unlike traditional repeated-measures models which pool all unexplained variability in the dependent variable into a single error term, mixed models support specification of a specific covariance structure for the variability in growth parameters (longitudinal, between-person effects). Hence, random effects quantify individual differences in initial level and age- or time-related change in changes in grammatical complexity and semantic content. The mixed model also supports evaluation of whether pertinent covariates, such as digit span and vocabulary in this study, might account for any observed individual differences in age- or time-related linguistic decline.

In summary, the general linear mixed model was used in this study to model changes in linguistic ability in healthy older adults and older adults with dementia and to examine how digit span and vocabulary were related to variability in the participants' initial level of linguistic ability or age- or time-related change in linguistic ability. The SAS PROC MIXED program was used to estimate the models of interest. The use of likelihood-based estimation allows for missing data, eliminating the need for imputation of missing data or omissions of individuals missing data at one or more occasions. The mixed model accommodates data from participants remaining in the study for varying lengths of time and assessed individually at slightly different intervals. Multiple options exist for modeling the within-subject dependency across multiple measurements, allowing for more appropriate statistical inferences due to accurate estimation of standard errors for model parameters. Finally, use of the general linear mixed model promotes modeling that is conceptually consistent with the nested structure of the data.

The mixed models. Several assumptions should be considered in employing a longitudinal mixed model. First, it is assumed that there will be longitudinal correlation of repeated measures on a participant. Second, a linear relationship between the outcome and the predictors is assumed. Third, the residuals should be approximately normally distributed. [Marilyn to add more comments here re assumptions vis a vis our data]

The mixed models employed in this study consist of two levels: an individual growth model at the observation level (level 1), which specified the within-person parameters, and a model that specified between-person parameters at the person level (level 2) to explain variation in the growth model parameters. These can be combined to yield a mixed model in the form of an unconditional linear growth model:

$$Y_{ij} = \beta_{00} + \beta_{10} T_{ij} + u_{0j} + u_{1j} T_{ij} + r_{ij}, \qquad (1)$$

where Y_{ij} is the outcome for person i at observation j and T_{ij} indicates time or age of the person at this observation. The first two terms of the equation contain fixed-effects parameters that reflect average population characteristics across all individuals. These fixed effects are the intercept, ⍰$_{00}$, and the slope for time or age, ⍰$_{10}$. The remaining three terms specify random effects that reflect variability within and between individuals. The model residuals are the random within-person residuals at the observation level, r_{ij}, where r_{ij} ~ N (0, ⍰^{2}). Recall that random effects are required at the person level (level 2) in the model to the extent that age-related changes vary among individuals. Equation 1 includes two terms that allow between-person parameter variability to be estimated. Residual intercepts are represented as u_{0i} and residual slopes as $u_{1i.}$ The random effects parameters at the person level in this model are actually the variance of the residual intercepts (☺$_{00}$), the variance of the residual slopes (☺$_{11}$), and covariance between the residual intercepts and slopes (☺$_{01 \text{ or }}$☺$_{10}$), where:

$$\begin{pmatrix} u_{0j} \\ u_{1j} \end{pmatrix} \sim N\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \tau_{00} & \tau_{01} \\ \tau_{10} & \tau_{11} \end{pmatrix}\right] \qquad (2)$$

It is quite possible that the relationship between the outcome, Y_{ij}, and the time or age, Tij, would be best described by a polynomial model. In this case, terms representing quadratic and perhaps cubic components can be added to the model. For example, a cubic growth curve model can be represented as follows:

$$Y_{ij} = \beta_{00} + \beta_{10} T_{ij} + \beta_{20} T_{ij} + \beta_{30} T_{ij} + u_{0j} + u_{ij} T_{ij} + r_{ij} \qquad (3)$$

The fixed effects in Equation 3 include the intercept (⍰$_{00}$), the mean linear slope for age (⍰$_{10}$), and coefficients for higher order age terms (⍰$_{20}$ and ⍰$_{30}$). As in Equation 1, the model in Equation 3 only specifies person-level random effects for the intercept and slope.

In growth curve models displaying appreciable variability in intercepts and slopes, it may be of interest to explore whether a person-level covariate can account for some of this variation. Commonly, a useful covariate consists of an initial measure of something related to the initial level on the outcome. Addition of a person-level covariate to Equation 1 yields:

$$Y_{ij} = \beta_{00} + \beta_{10} T_{ij} + \beta_{01} X_{i} + \beta_{11} X_{i} T_{ij} + u_{0j} + u_{1j} T_{ij} + r_{ij} \qquad (4)$$

where X_i is the person-level covariate. Two new fixed effects result: the relationship between the covariate and the initial level, ⍰$_{01}$, and the interaction between the covariate and time or age, ⍰$_{11}$.

Variables must be centered appropriately to facilitate interpretations of parameter estimates. Specifically, the intercept is the mean value on the dependent variable when all explanatory variables are equal to zero. Therefore, variables should be centered by deviating scores about a conceptually relevant value for the variable, such as the mean age or the maximum score observed on a covariate. Additionally centering procedures can be useful in separating potentially confounded effects, such as age and time. In this study, the choice of centering method varied according to the particular variables and research questions for each model, so centering procedures are presented along with the results.

Approach to model comparison. There is no one widely-accepted modeling approach for obtaining a statistical model including fixed and random effects. We find it useful to examine growth trajectories both by graphic models and by statistical models. We used spaghetti plots to display individual growth curves of the subjects in order to refine the initial research hypotheses. Further, the plots were useful in suggesting a strategy for modeling the data in terms of the shape of growth curve as well as the combination of fixed and random effects. For example, individuals within a group displayed the same general pattern of change in linguistic ability over time, while initial levels on the outcome and rate of declines appeared to vary from person to person, suggesting the need for random intercepts and slopes.

Our statistical modeling approach was a forward selection approach (Snijders, 1996). Starting with a linear time or age model, we used restricted maximum likelihood estimation (REML) and the associated deviance statistic (-2 log likelihood) to evaluate the need for a random intercept and slope. We then progressively evaluated higher order fixed effects using both REML F-tests and ML deviances (consistent in all cases). The random components were then re-evaluated using REML deviances. Differences in deviance statistics are approximately chi-square distributed and are evaluated as chi-square difference tests, with degrees of freedom equal to the difference in parameters between nested models. A similar modeling strategy involving descriptive analyses followed by alternate evaluations of fixed- and random-effects components was recommended by Wallace and Green (in press). For additional detail on the specifying and evaluating models using SAS PROC MIXED, see Singer (1998) and Littell et al. (1996).

More specifically, in the context of this study, we used this modeling procedure to develop growth models involving either time or age predicting the outcome. The random effects in these growth models provided information regarding the stability or variability in initial levels or growth curves among individuals. We then added hypothesized covariates (e.g., digit span or vocabulary) to the growth models in an attempt to explain between-subject variance or covariance for the random intercept and slope.

Results

The healthy older adults and the older adults with dementia exhibited dramatically different patterns of linguistic decline. The data for these groups were separately analyzed, and the results are presented in a manner representative of the modeling process. Descriptive statistics are presented first, followed by the models of linguistic decline in the healthy and dementia samples.

Descriptive Statistics

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, while Figure 2 illustrates the relationship between age and P-Density. 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.

Older adults with dementia participated at six-month intervals for 6 to 30 months. Table 2 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 Figures 3 and 4, respectively. Strongly contrasting with the healthy older adults, these graphs both indicate a striking lack of an age effect. 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 although all participants were taking donepezil hydrochloride by the time of their final assessment There is some evidence of individual variability in initial levels, but little variability in the apparent rate of decline. Figures 3 and 4 indicated that decline in the two outcomes should be modeled as a function of time rather age for those persons diagnosed with dementia.

Statistical Models of Linguistic Changes in Healthy Older Adults

As observed in Figures 1 and 2, 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 Methods. 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 and/or slopes was present, so 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 3 and 4, respectively.

Grammatical Complexity. An age-related decline in D-Level was hypothesized a priori, and the plot of age vs. D-Level (Figure 1) 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 3, 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 3, Model 1) 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). The fixed effect estimates 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 3, 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 3, Model 3). Initial digit span reduced but did not fully account for the between-subject variation in 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 τ_{00} for

Models 1 and 3 on Table 3). Figure 5 illustrates this, in addition to aiding in the interpretation of the age*digit span interaction term. D-Level growth curves were generated for hypothetical subjects having high, average, and low initial digit span scores using the fixed effects coefficients reported in Table 3, Model 3. Figure 5 illustrates that differences in predicted D-Level scores for subjects having high, average, and low digit span scores become smaller with advancing age. The sign of the estimate for the age*vocabulary effect is negative, reflecting 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.

Semantic content. As observed in Figure 2, 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, however the rate was more gradual and the inflections were less pronounced. Again, a cubic model best represented the relationship between advancing age and P-Density (Table 4, Model 1). The intercept estimate, 7.485, reflects the predicted P-Density score for a person at the 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 2 displays this variability in growth curves among individuals.

The between-subject variability in the initial level and linear component of the decline in P-Density was reduced and their covariance was functionally eliminated by inclusion of initial vocabulary as a covariate (Table 4, Model 2). Figure 6 is helpful in understanding the estimates for the vocabulary covariate and the age*vocabulary interaction term. P-Density growth curves were generated for hypothetical subjects having high, average, and low initial vocabulary scores using the fixed effects coefficients reported in Table 4, 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 ⍰$_{00}$ for Models 1 and 2 on Table 4). Figure 6 also shows that differences in predicted P-Density scores for subjects having high, average, and low initial vocabulary scores become smaller with advancing age. The sign of the estimate for the age*vocabulary effect 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 subjects (compare ⍰$_{11}$ for Models 1 and 2 on Table 4) 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 also evaluated as a potential covariate for the P-Density model (Table 4, Model 3). The fixed effect 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 model fit statistics were not improved by inclusion of the digit span covariate.

Statistical Models of Linguistic Changes in Older Adults with Dementia

D-Level and P-Density declined over time for the dementing group, regardless of age, as displayed on Figures 3 and 4. For the older adults with dementia models, time rather than age was a more useful predictor of language decline. To separate the effects of time and age in the older adults with dementia analyses, a different centering procedure was applied. Age at each observation was centered around the person mean to yield the time effect. The person mean was then added back in at the subject level to yield the mean age effect.

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 Methods. Random between-subject variation in intercepts and/or slopes 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 progressing time and D-Level was best described by a cubic model. Estimates for the time effect model are specified in Table 5, Model 1. Due to 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 of the person means (71.286). The expression (-1.500 + 0.057*71.286) yields 2.563, the estimated mean D-Level score of all persons at their mean age. 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 effects for the intercept and slope were 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 how long a patient has been dementing prior to entering the study.

The initial digit span measure was found to be a relevant covariate in analyses for the healthy older adults, so it was explored as a potential covariate in the older adults with dementia as well. Digit span was centered at the 11, the largest score observed in the older adults with dementia. Inclusion of digit span dramatically improved overall model fit and accounted for the random variability in the intercept and slope (Table 5, Model 2). Further, the linear, quadratic, and cubic components of time were no longer statistically significant with digit span as a covariate in the model. The higher order time effects were sequentially backed out to arrive at the final model for D-Level with digit span as a covariate. Model 3 in Table 5 includes statistically significant effects for time, mean age, and digit span, with no appreciable unexplained intercept and slope variability. Figure 7 illustrates this relationship between D-Level and digit span for the older adults with dementia.

Semantic 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 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 means for age, P-Density decreases by 1.535. The fixed effect for time was statistically significant, $p < .0001$, however the mean age effect was not significant. The random effects for the intercept and slope were statistically significant, reflecting unexplained intercept and slope variability.

As in the normal group models for P-Density, vocabulary was again a useful covariate. Vocabulary was centered at 41, the largest score observed in the older adults with 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 effect was statistically significant along with the time effect. The model containing the time effect along with vocabulary fits only slightly better than the model containing only vocabulary as a predictor (Table 6, Model 3). Figure 8 illustrates this relationship between P-Density and vocabulary for the older adults with dementia.

In the D-Level models, adding digit span as a covariate eliminated the time effects but maintained mean age [Table 5, Model 2]. As a follow-up, a cubic time model including mean age was fitted to predict digit span as an outcome. All of the time effects were statistically significant, but the relationship between mean age and digit span was not. This supports the idea that the decline in digit span is related to time but not to mean age. The effectiveness of vocabulary as a covariate in the P-Density models may arise because time has a similar relationship with both vocabulary and P-Density in the older adults with dementia. Models using time to predict either P-Density or vocabulary as an outcome were compared. While a linear model of time best predicted P-Density (Table 6, Model 1), a cubic model of time was required to predict vocabulary. Vocabulary has a somewhat different relationship to time than does P-Density.

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Discussion and Conclusions

Like vocabulary-based assessments of linguistic abilities, the present assessments, based on language sample analysis, indicate that linguistic abilities of healthy adults decline in late adulthood. Both the grammatical complexity and semantic content of older adults' spontaneous speech exhibit a similar pattern of decline between ages 74 and 78 although the decline in semantic content is more graduate than that for grammatical complexity. 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 xx to xx at the time of the first assessment and xx to xx at the time of the final assessment; hence, these models cannot be projected to younger or older adults. It may be that the period of rapid decline exhibited by both measures corresponds to a period of rapidly declining health in these participants that foreshadows their withdraw or exclusion from this study for reasons of health within a few years.

The mixed modeling also indicated that there is considerable individual variation in older adults' initial level of grammatical complexity and semantic 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 Backwards test; further, the grammatical complexity of those with higher initial scores also declined somewhat more rapidly with advancing age. In contrast, the initial level of semantic 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 lead to over-estimating the degree of decline in grammatical complexity or semantic 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 semantic 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 semantic content measure, P-Density is computed for complete sentences as well as sentence fragments. As indicated in Figures xxx and and Table 1, D-Level declined from an average of 6.06 to 2.98 over 15 whereas P-Density declined from an average 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 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 will higher initial levels of grammatical complexity and semantic 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 semantic 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 semantic content for the two groups were different. Whereas the decline in semantic content was cubit function of age for the healthy older adults, the decline in smeantoc 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; semantic content decline from 4.46 propostions 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 small degree of overestimation regarding the decline in P-Density. Yet it is likely that a functional "floor" again imposes a lower-limit on P-Density.

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

	Time of measure and sample size			
Variable	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)	9.96 (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)

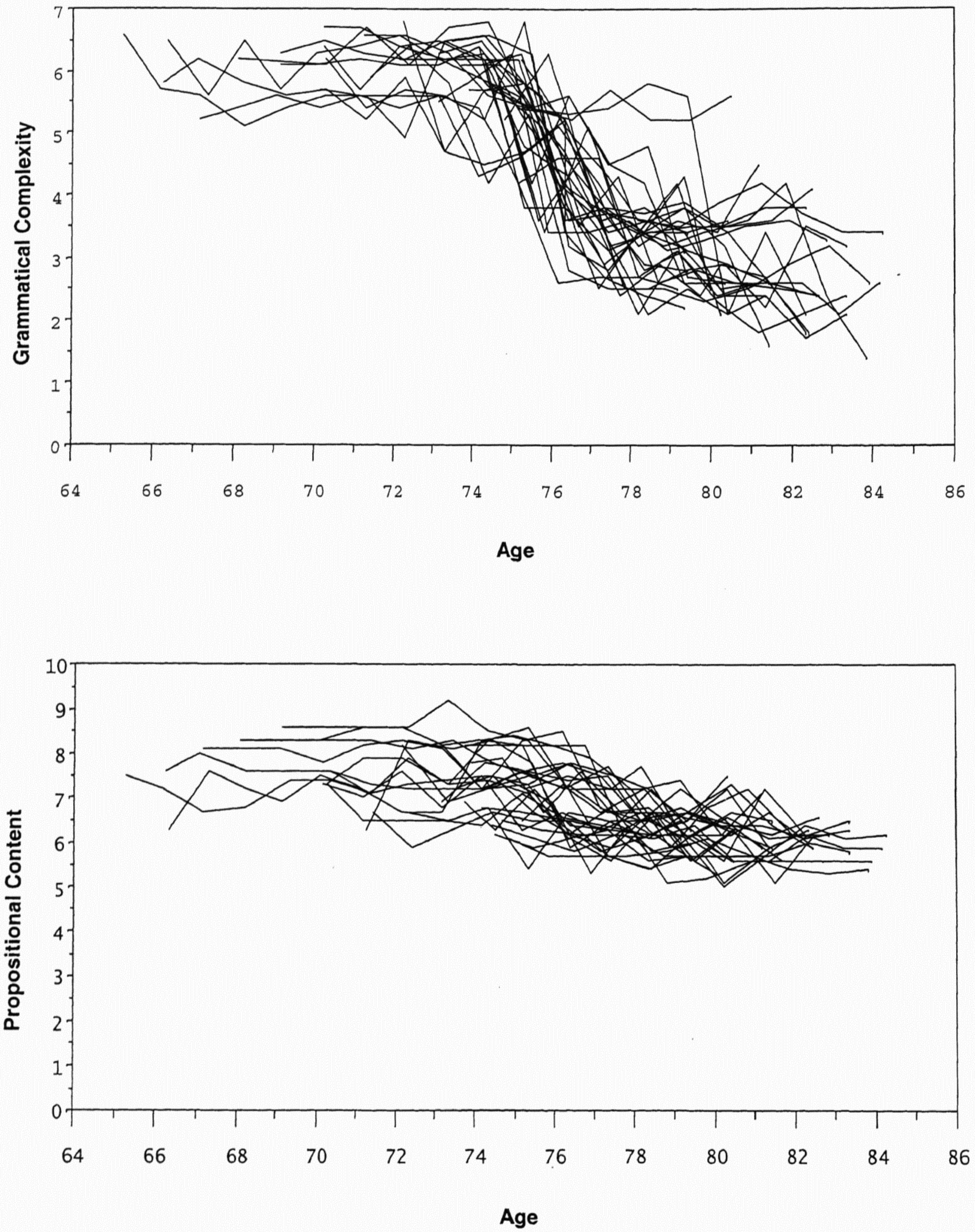

Figure 1. Longitudinal change in grammatical complexity (D-Level; top panel) and in propositional content (P-Density; bottom panel) for healthy older adults.

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Table 2

Grammatical Complexity Models for Healthy Older Adults, REML Estimates

	Model 1: Age effect				Model 2: Vocabulary as a covariate				Model 3: Digit span as a covariate			
Predictor	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.

Kemper, S. & Sumner, A. (2001). The structure of verbal abilities in young and older adults. Psychology and Aging, 16, 312-322. Publisher's official version: http://psycnet.apa.org/doi/10.1037/0882-7974.16.2.312. Open Access version: http://kuscholarworks.ku.edu/dspace/.

Table 3

Propositional Content Models for Healthy Older Adults, REML Estimates

	Model 1: Age effect				Model 2: Vocabulary as a covariate				Model 3: Digit span as a covariate			
Predictor	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.

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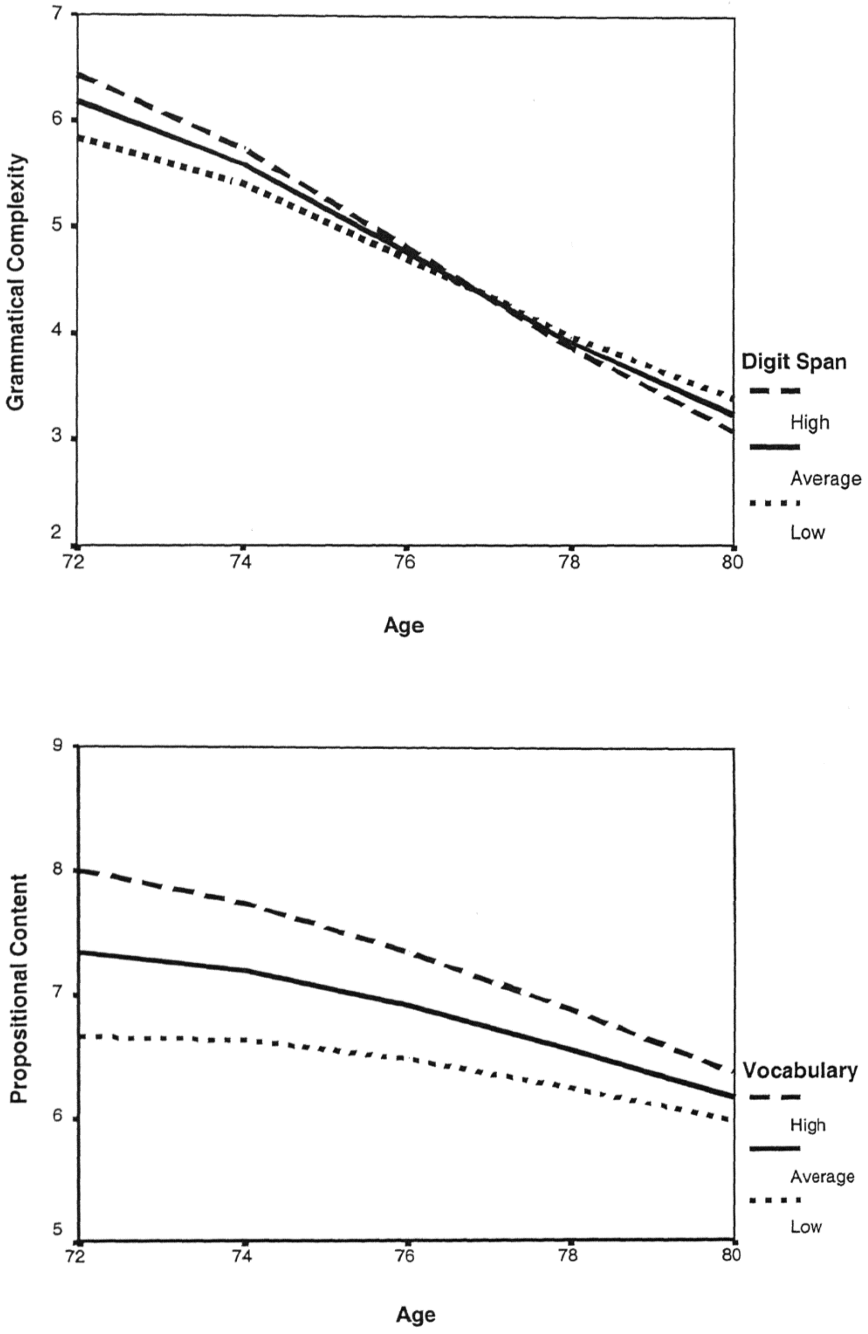

Figure 2. Illustration of digit span as a covariate in the Age × Grammatical Complexity model for the healthy older adults (Table 3, Model 3; top panel) and vocabulary as a covariate in the Age × Propositional Content model for the healthy older adults (Table 4, Model 2; bottom panel).

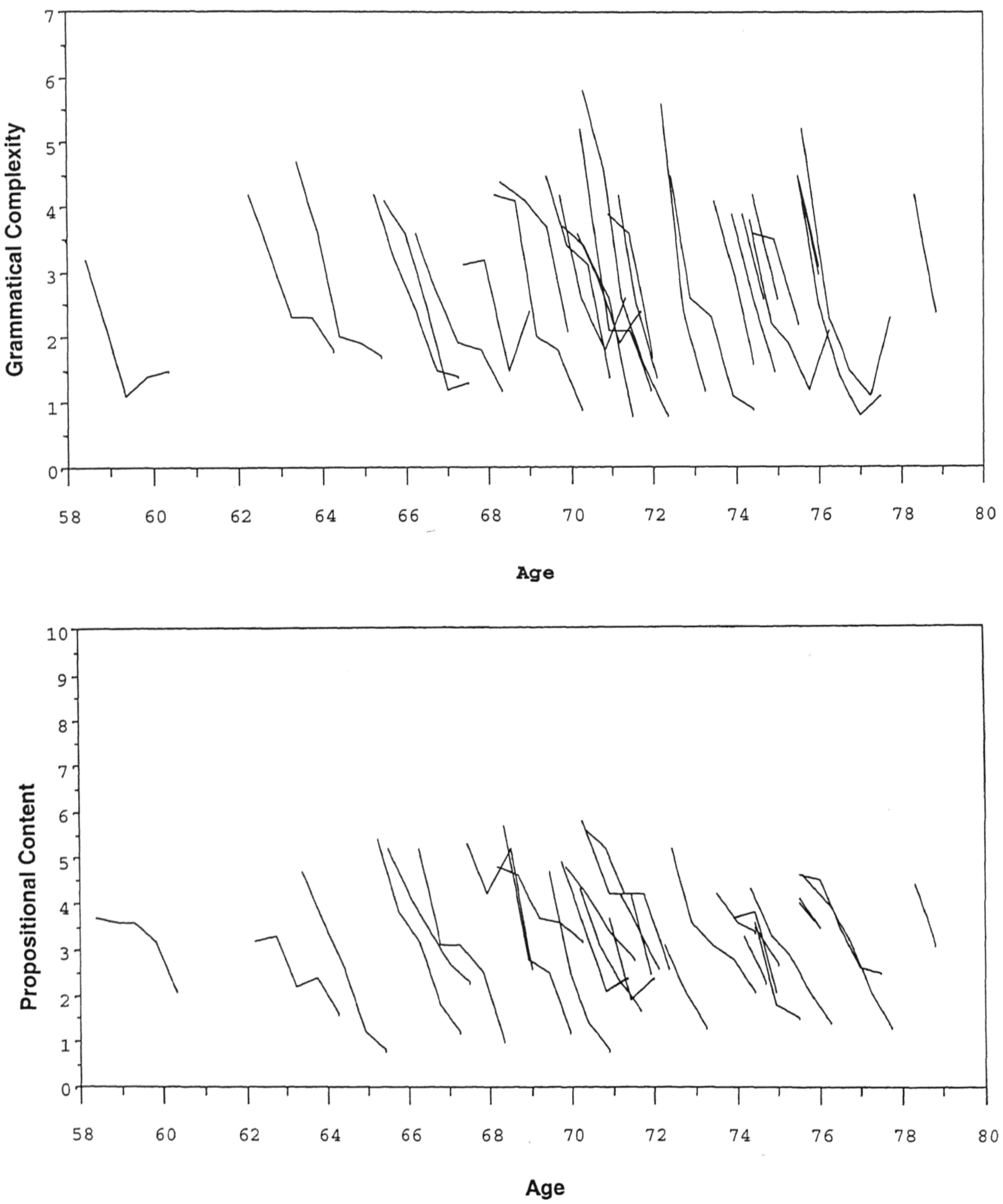

Figure 3. Longitudinal change in grammatical complexity (D-Level; top panel) and in propositional content (P-Density; bottom panel) for older adults with dementia.

Table 4

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

	Time of measure and sample size				
Variable	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

Table 5

Grammatical Complexity Models for Older Adults With Dementia, REML Estimates

	Model 1: Time effect				Model 2: Vocabulary as a covariate				Model 3: Digit span as a covariate			
Predictor	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	0.296*	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

	Model 1: Time effect				Model 2: Vocabulary as a covariate				Model 3: Digit span as a covariate			
Predictor	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

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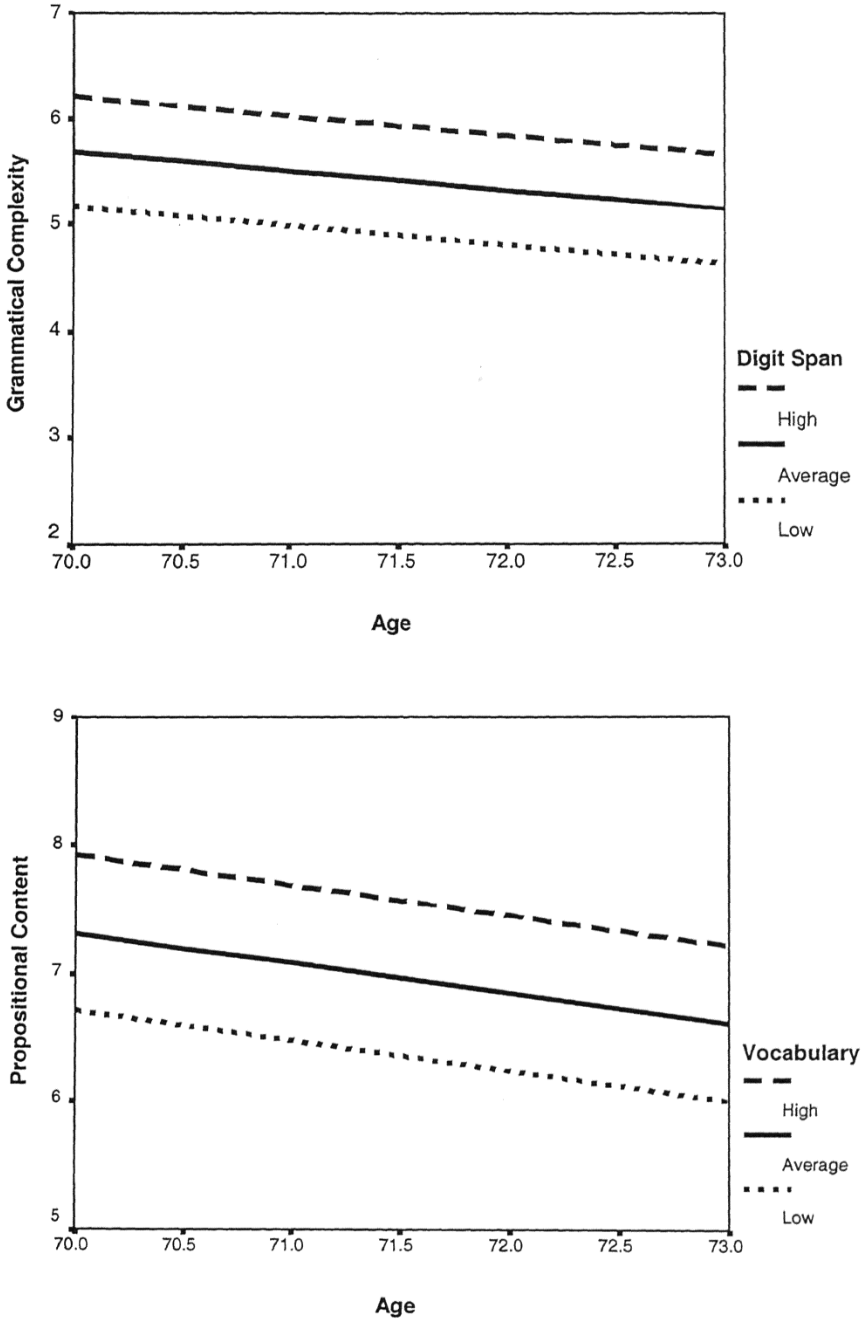

Figure 4. Illustration of digit span as a covariate in the grammatical complexity model for older adults with dementia (Table 5, Model 2; top panel) and vocabulary as a covariate in the propositional content model for older adults with dementia (Table 6, Model 3; bottom panel).