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Natural and constrained language production as a function of age and cognitive abilities

Cristina D. Rabaglia[1] and **Timothy A. Salthouse**[2]

[1]Department of Psychology, New York University, New York, NY, USA

[2]Department of Psychology, University of Virginia, Charlottesville, VA, USA

Abstract

Although it is often claimed that verbal abilities are relatively well maintained across the adult lifespan, certain aspects of language production have been found to exhibit cross-sectional differences and longitudinal declines. In the current project age-related differences in controlled and naturalistic elicited language production tasks were examined within the context of a reference battery of cognitive abilities in a moderately large sample of individuals aged 18–90. The results provide support for age-related increases in lexical sophistication and diversity at the discourse level, and declines in grammatical complexity in controlled and naturalistic contexts. Further, age-related decreases in facility with complex grammatical constructions in controlled sentence production were statistically independent of the cognitive abilities assessed in this project.

Keywords

Grammatical complexity; Ageing; Cognitive abilities

In the past several decades, there has been growing interest in language development across the entire lifespan, and particularly in what happens to language with aging (Thornton & Light, 2006). Within the domain of language production, this research surge has included both what individuals actually produce in naturalistic contexts, and what individuals are capable of producing in controlled psycholinguistic experiments. Evidence for age-related individual differences in language production has come from both types of research.

These studies provide evidence for interesting age-related language differences in both lexical and syntactic domains. Vocabulary knowledge appears to be well maintained across the lifespan, even showing moderate increases at least until age 60 (Wechsler, 1997a). However, this increase in word knowledge is in contrast to apparent changes in the ability to access lexical information, as there is substantial evidence for increases in general word retrieval difficulties (Au et al., 1995; Burke, MacKay, Worthley, & Wade, 1991; Cooper, 1990; Nicholas, Obler, Albert, & Goodglass, 1985) with increasing age. How these age-

Correspondence should be addressed to Cristina D. Rabaglia, Department of Psychology, New York University, 6 Washington Place, New York, NY 10003, USA. rabaglia@nyu.edu.

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related differences play out in terms of lexical selection during everyday discourse production, however, is not yet entirely clear. There is some evidence from diary studies that older adults are more prone to tip-of-the-tongue states during day-to-day language production (Burke et al., 1991), as well as evidence from increased numbers of errors and disfluencies that older adults experience word retrieval difficulties during discourse production (Kemper, 1992). Studies also indicate, on the other hand, that despite these increased retrieval difficulties, some aspects of lexical production are maintained, as evidenced by usage of more diverse vocabulary and uncommon words with increased age (Kemper & Sumner, 2001).

In the domain of syntax, on the other hand, there is substantial support for a decrease across the adult lifespan in the production of complex syntactic constructions such as subordinate and embedded clauses. A series of studies by Kemper and colleagues, for example, indicate a negative association between age and the use of embedding and left-branching sentences in spoken (Kemper, Kynette, Rash, Sprott, & O'Brien, 1989; Kemper & Sumner, 2001; Kemper, Thompson, & Marquis, 2001; Kynette & Kemper, 1986) and written (Kemper, 1987; Kemper et al., 1989) language. Similarly, Bromley (1991) also found a negative relation with age in crude measures of syntactic complexity.

While these age-related grammatical complexity differences in naturalistic production contexts are important, this type of evidence is derived from situations, usually in-lab elicited written or oral language samples or collections of extant writing, over which the investigator has far less control than in typical psycholinguistic experiments. The results from such tasks are thus particularly open to multiple influences, and consequently can be somewhat hard to interpret. Recent research, therefore, has also investigated syntactic production and aging with more controlled tasks. Kemper and colleagues, for example, have presented younger and older adults with words and sentence stems of varying syntactic complexity, and asked participants to form sentences from these constituents. The results from such studies converge with the results from naturalistic language production; although there may be few age-related differences in the production of simple syntax (Altmann & Kemper, 2006; Davidson, Zacks, & Ferreira, 2003), older adults have more difficulty repeating and forming sentences from stems including complex syntactic constructions such as embedding, and are less likely than younger adults to form sentences rich in propositional content when forced to create sentences including these constructions (Kemper, Herman, & Lian, 2003; Kemper, Herman, & Liu, 2004).

Age-related differences in grammatical production in both naturalistic and controlled contexts are thus well documented, but the cause of these differences remains unclear. A number of explanations have been proposed, including decreased exposure to complex syntax due to temporal removal from peak complex syntax exposure during the educational years and the simplified nature of elderly directed speech, and usage of simplified syntax as a strategy for dealing with word-retrieval difficulties (Griffin & Spieler, 2006). The most substantial research history, however, may be that which associates individual differences in language performance with working memory capacity (e.g., Daneman & Carpenter, 1980; Just & Carpenter, 1992); older adults' facility with complex syntactic constructions has been found to be correlated with measures of working memory (Kemper & Sumner, 2001; Kemper et al., 1989, 2001).

However, a limitation of an approach based on zero-order correlations between language measures and working memory measures, or on comparing individuals binned into high and low working memory groups, is that adult age differences have been reported in many different cognitive abilities (e.g., Craik & Salthouse, 2007), and most cognitive variables have been found to be positively correlated with one another (e.g., Jensen, 1998). Salthouse

(2005), for example, reported a latent factor representing episodic memory to be correlated .57 with a perceptual speed factor, .38 with a factor representing word knowledge, and .70 with a spatial visualisation factor in a sample of 328 adults. Indeed, this inter-relatedness of cognitive variables has been called "one of the most replicated findings in psychology" (Deary, Spinath, & Bates, 2006). It is therefore possible that some of the correlation between two sets of measures reflects influences of other factors that cannot be identified when only simple correlations are examined.

A consequence of this cognitive inter-relatedness is that when older adults are said to be impaired on a given cognitive or related task, it is unclear if the age-related declines seen in this task require separate explanation from cognitive abilities already established to show age-related differences (Salthouse, 2005). A potential way of dealing with these issues is with the model displayed in Figure 1, which has been used to examine age-related changes in cognitive variables such as executive functioning and working memory (Salthouse, 2005; Salthouse, Pink, & Tucker-Drob, 2008). This figure depicts a structural equation model, where the circles represent latent constructs formed from the variance shared between several cognitive variables, and numbers adjacent to each arrow represent standardised regression coefficients from which the magnitude of the relationship between these cognitive constructs, age, and a target variable of interest can be determined. Since the cognitive constructs are used as simultaneous predictors, this method is comparable to simultaneous multiple regression performed at the level of latent constructs.

The key to this analytical method is that information from a set of reference variables is obtained from the same age-heterogeneous individuals who perform a cognitive, or, in the current study, language, task of interest. This not only allows the simple, or total, age-related effects on the target variable to be determined, but also the direct, or unique, effects. The unique effects in this model are of particular interest because they are statistically independent of age-related influences shared with other cognitive abilities, and a separate explanation for age-related differences in performance on the language measure may be not be required if no statistically independent age-related effects exist. This analytical method has been termed contextual analysis because age differences in the target variable are examined in the context of already established age-related differences in fluid ability, processing speed, memory, and knowledge (see Salthouse, Siedlecki, & Krueger, 2006; Salthouse et al., 2008).

Another advantage of the contextual analysis approach is that the meaning of target variables can be investigated by examining relations between the variable and established cognitive abilities (represented by the arrows connecting the latent constructs to the target variable in Figure 1). The rationale is that if people who have high levels of ability *A* perform better on the target variable than people with low levels of ability *A*, but there are no differences on the target variable between people who vary in ability *B*, then one can conclude that the variable is more closely related to ability *A* than to ability *B*.

Although this approach has not, to our knowledge, been applied to the types of language-related tasks discussed above, it is important to investigate the nature of relations between language declines and more domain-general cognitive declines since many of the explanations for age-related language production differences hinge on cognitive notions such as crystallised knowledge, memory retrieval, and working memory. This approach therefore could be particularly informative in pitting cognitive-capacity driven explanations, such as decreased working memory resources or increased difficulty retrieving word forms, against more experiential explanations, such as decreased exposure to complex syntax. A failure to find unique language production differences that are statistically independent from age-related differences in other cognitive abilities would be inconsistent with noncognitive types of theories.

The current project was thus designed to take a broader perspective on the relations between language and aging by using the contextual analysis approach in a moderately large sample from a continuous age range. Participants performed both a set of naturalistic language production tasks, in the form of essays written in response to prompts, and a controlled sentence production task. In the controlled sentence production task participants were asked to create sentences from stems that either invited a sentence of a simpler syntactic form or a sentence with the required production of an embedded clause. Each participant also performed 16 cognitive tasks designed to measure the constructs of fluid intelligence, perceptual speed, episodic memory, and vocabulary knowledge. The individual tasks and their relationships with these latent constructs can be seen in Figure 1. In addition, participants in Study 2 performed two working memory tasks, Operation Span, and Symmetry Span.

From the elicited essays, measures of sophistication of word usage and complex syntactic forms and were extracted. As previously discussed, the diversity and sophistication of lexical usage has been shown to increase with age in at least one previous study (Kemper & Sumner, 2001). More sophisticated word usage, in the form of increased use of low-frequency words, is especially interesting because age-related increases in crystallised intelligence might predict increased usage of lower frequency words with age due to increased vocabulary knowledge; however, theories of age-related word production difficulties that stress an age-related weakening of semantic-phonological links predict that low-frequency words should be particularly hard for older adults to produce (Burke & Shafto, 2004).

In the syntactic domain, constructions indicated by previous research as being particularly difficult to understand and produce, such as left-branching and embedded clauses, were investigated. These types of constructions were of particular interest because declines in left-branching sentence production have been called the “primary difference in syntax” with aging and language production (Griffin & Spieler, 2006). Additionally, complex structures such as left-branching and embedding are the same types of constructions implicated in multiple theories explaining age-related syntactic differences; left-branching and embedded clauses are implicated for age-related declines in both “capacity”-based aging theories, as they are hypothesised to load heavily on working memory (Kemper, 1987), and in experience-based theories, as they are also relatively infrequent in the English language and not characteristic of the simplified grammatical nature of elderspeak (Griffin & Spieler, 2006). As such, they are ideal constructions for investigating language and cognition links, and determining the statistical independence of age-related changes from established age-related cognitive declines.

These measures, as well as production performance in the controlled sentence production task, were examined in relation to age, both when it was considered independently, and when it was considered within the structural equation model (Figure 1) described above. If age-related differences in the reference cognitive abilities, not changes in environmental factors or changes in mechanisms specific to language production, are responsible for any age differences in word usage or facility with complex syntax, no unique age relationships were expected within the contextual model. The results from both essay-elicited language production tasks (Studies 1 and 2) will be described first, followed by results from controlled sentence production (Study 3).

STUDIES 1 AND 2: ESSAY-ELICITED LANGUAGE PRODUCTION

Method

Participants—Cognitive and linguistic data were collected in two separate studies involving adults between 18 and 90 years of age who participated in a larger project in response to newspaper advertisements and referrals from other participants. Each participant performed a battery of 16 cognitive tests in addition to two language production tasks. In order to limit the investigation to normal aging, and to ensure enough language data from which to draw the language measures, participants with Mini Mental Status Exam (Folstein, Folstein, & McHugh, 1975) scores below 27 or who produced fewer than 50 words in at least one of the two written passages were not included in the analyses. The resulting sample consisted of 399 adults in Study 1, and 459 in Study 2, with their demographic characteristics summarised in Table 1.

Reference cognitive abilities—Each participant in both studies completed 16 different cognitive tasks (Figure 1) used to represent four distinct cognitive abilities: fluid intelligence; processing speed; episodic memory; and vocabulary. The vocabulary construct has been found to correlate highly with measures of general knowledge (Salthouse, 2001), and thus can be thought of broadly as an indicator of stores of crystallised knowledge, and specifically as an indicator of stores of word knowledge. Information about the tasks, and results of analyses examining construct validity, has been presented in Salthouse (2004, 2005) and Salthouse et al. (2008). In Study 2, participants also completed two storage-and-processing tasks hypothesised to represent working memory, Operation Span, and Symmetry Span. These tasks have been described inConway et al. (2005), Kane, Hambrick, Tuholski, Wilhelm, Payne, and Engle (2004), and Unsworth, Heitz, Schrock, and Engle (2005), and were obtained from http://psychology.gatech.edu/renglelab.

Language samples—In each study, two written language samples were elicited through response to prompts. In Study 1, the prompts were the “cookie theft task” and the “admire task”. In the cookie theft task, participants were shown the cookie theft picture from the Boston Diagnostic Aphasia Examination (Goodglass, Kaplan, & Barresi, 2001), and were asked to “Write everything you see going on in this picture”. In the admire task, participants were asked to respond to the question “What person, living or dead, famous or not, do you admire the most, and why?” (Kemper et al., 2001). In both tasks, participants were allowed 7 minutes to write their responses to the prompts.

In Study 2, the prompts were presented as part of a questionnaire packet completed at home. Participants in Study 2 were encouraged to take no more than 10 minutes in composing their answers. One prompt was the “admire” task, and the second was a “history task”, in which participants were asked to respond to the question “If you could go back in time and witness one historical event, what would it be and why?”

In both studies, the handwritten responses were transcribed into text files, and checked for accuracy by a second rater who corrected the transcriptions if necessary. All of the subsequent analyses were performed on these transcribed files.

Language variables

Lexical variables: The nature of lexical production was assessed by extracting measures of word usage and diversity. The diversity of word usage was measured by the type-token ratio (TTR), the number of unique (type) words divided by the number of times the word was repeated (tokens), and lexical sophistication was assessed by word frequency and word length in letters and syllables. The text files of each language transcription were submitted to two automated text analysis programmes, Linguistic Inquiry and Word Count (LIWC) and Coh-Metrix. LIWC (Pennebaker, Booth, & Francis, 2006) is an automated text analysis programme that finds words or word stems that fall into certain linguistic categories. Coh-Metrix (Graesser, McNamara, Louwerse, & Cai, 2004) is a programme developed to assess the lexical content and different types of cohesion in a written text. From these programmes, the measures of lexical sophistication were extracted. Variables included in the analyses from LIWC were the frequency of words with more than five letters; from Coh-Metrix were the average number of syllables per word, the logarithm of word frequency for content words, and TTR.

Grammatical complexity: The grammatical complexity for each passage was assessed by coding and counting different types of syntactic constructions. In order to provide the most accurate measures possible, and provide the greatest contact with the previous literature, grammatical constructions were coded by hand using a coding manual generously provided by the Kemper Lab. For each passage, the numbers of left-branching clauses and embedded clauses were counted, as well as the amount of overall subordination. All the coding was done by one rater, and reliability was determined by having another rater code 10% of each of the passages. Percent agreement between the two coders was 97%. Coh-Metrix does provide several measures of grammatical complexity, including one measure, the number of words before the first verb in the sentence that could possibly be used as a proxy for left-branching. However, as these were all only weakly correlated with our hand-coded measures, and as we wanted our measures to be as close as possible to those previously published on this topic, we did not include them in our analyses.

Results

Descriptive statistics for the language variable in each study are presented in Table 2, with the final column containing the between-essay correlations for each language variable in the two studies. As can be seen in this column, the magnitude of the correlations ranges from low to moderate, but nearly all are significantly different from zero, suggesting that individuals' tendency to use these different language variables is at least somewhat reliable. However, varying mean levels in usage across discourse topic suggests that, as would be expected, the tendency to use certain constructions is also somewhat dependent on the actual topic or prompt.

In order to reduce the number of variables examined in subsequent analyses and also increase the reliability of the relevant measures, an Exploratory Factor Analysis (EFA) was performed on all variables from the two passages in each study. Single indicators of a construct of interest are generally less reliable than aggregate variables or latent constructs (Rushton, Brainerd, & Pressley, 1983), and this may be even more of a consideration when dealing with language variables extracted from elicited samples of naturalistic language production, which by their nature are so free to vary.

The EFA was conducted with principal axis factoring followed by promax (oblique) rotation. Two factors were extracted based on inspection of the scree plots and theoretical interpretability of the factors. The results of the EFA are displayed in Table 3. The two factors were designated word usage and grammatical complexity; inspection of the linguistic variables loading on these two factors shows the expected delineation between syntax and semantics, with variables related to lexical selection loading on the word usage factor, and the syntactic variables loading on the grammatical complexity factor. These two latent factors were used in subsequent analyses.

As can be seen in the first data column of Table 4, the two latent language constructs display opposite age-related patterns: a positive correlation between age and word usage, and a negative correlation between age and grammatical complexity. These results are consistent across studies (Figure 2), although the magnitude of the correlations is higher for both factors in Study 1.

The grammatical complexity and word usage constructs for each study were then submitted to the contextual analysis based on the model shown in Figure 1. The analysis was performed with a structural equation model using the AMOS statistical package. The cognitive variable construct-to-indicator and construct-to-construct structure used in the model has been shown to be reliable and consistent across studies (Salthouse, 2005; Salthouse et al., 2006, 2008).

The second data column of Table 4 reports the semi-partial correlations between age and the two language constructs that represent the unique influence of age, independent of the influences of the reference cognitive abilities. In contrast to the significant zero-order correlations between the language variables and age, these semi-partial correlations are not significantly different from zero, indicating that neither construct is uniquely related to age within the contextual analysis in either study.

The last four columns of Table 4 report semi-partial correlations representing the unique relationships between each of the cognitive abilities and the language variables within the contextual model. It is apparent from these correlations that the word usage and grammatical complexity constructs had different patterns of relationships in each study. Word usage is only significantly related to vocabulary, in the direction of higher performance on the construct among individuals with greater vocabulary. As can be seen in the separate rows of Table 4, these relationships are consistent across the two studies. Vocabulary is not uniquely related to the grammatical complexity construct in either study, but there is a unique relationship between the episodic memory construct and grammatical complexity in Study 1.

Working memory analyses—Participants in Study 2 also performed two tasks designed to assess working memory, the Operation Span and Symmetry Span tasks. A working memory construct formed from the number of items recalled in the correct order in these two tasks correlated .85 with the Gf construct. Because of collinearity, it was not meaningful to include both the working memory and Gf constructs in same contextual model, and therefore the previously described analysis was repeated with the WM construct replacing Gf in the model. The results of this analysis were very similar to those of the initial analysis, with only slightly stronger (but still not significant) relations ofWM than of Gf to the language constructs (i.e., .19 vs. .13 for the word usage, and .22 vs. .16 for the grammatical complexity constructs).

Discussion

The results of Studies 1 and 2 suggest that latent constructs formed from measures extracted from naturalistic language production tasks are related in interpretable ways to age and to well-established cognitive abilities. The significant zero-order correlations between the word usage construct and age indicates that increasing age is associated with the use of more sophisticated and diverse words. Within the contextual analysis, the word usage construct was uniquely related only to vocabulary and, furthermore, was not related to age after controlling for the influence of vocabulary and other cognitive abilities.

These results suggest that despite increased word retrieval difficulties and tip of the tongue states in older adults, older adults actually use, at the discourse level, more diverse and advanced lexical items. The contextual analyses results further suggest that these increases in lexical sophistication are related primarily to greater stores of lexical knowledge associated with increased age. In interpreting the vocabulary construct, it is worth noting that some research suggests different types of vocabulary tests, though generally used interchangeably as indexes of crystallised word knowledge, may be differentially sensitive to lexical access, word retrieval, and aging (Bowles & Salthouse, 2008; Verhaeghen, 2003); these considerations could make interpretation of relationships between measures of vocabulary and language-related measures challenging. However, the value of a structural equation modelling approach is that the regression analysis is performed at the level of latent constructs; unlike any single vocabulary measure, which reflects both what is common about vocabulary knowledge and what is specific to the particular test format, the latent vocabulary construct used in the current analysis reflects what is shared across multiple test formats. While all of these tasks tap into word knowledge and thus must reflect processes word retrieval in some respect, the specifics of each of the tasks are quite different, requiring different types of retrieval processes. Woodcock–Johnson Picture Vocabulary involves naming of pictures, and thus accessing a phonological representation from meaning, WAIS Vocabulary involves providing definitions, and thus accessing meaning from phonology along with providing in depth descriptions, while Antonym and Synonym vocabulary are multiple choice measures, requiring access of meaning from phonological representations and comparing those meanings, but not generating any phonological representations de novo. While individual tasks thus certainly may differentially tap into aspects of word knowledge and the ability to access and manipulate these stores, that which is shared between these tasks with differing lexical access requirements is most easily interpreted as the underlying word knowledge, and provides the closest approximation to this construct possible.

This interpretation is reinforced by the direction of the age effect, since it would be odd indeed to find a positive association with age if the construct were mainly tapping into word retrieval, given the extensive reports of word retrieval difficulties with increasing age. However, insomuch as any task of word knowledge will reflect retrieval processes, and stores of lexical knowledge are clearly an important component of any language system, this construct is clearly the most intimately tied with the language system. It is not our intention to claim this construct should be entirely separate from language, therefore, but rather that it should mainly measure crystallised stores of word knowledge, likely related to general crystallised knowledge, rather than retrieval processes or other more specific aspects of the language system.

These results may be of particular interest since low-frequency words, according to some theories of age-related word retrieval difficulties, should be especially difficult for older adults to retrieve (Burke & Shafto, 2004). The lack of unique association with age for the word usage variable in the contextual analysis also suggests that all of the age-related influences on this index of word usage are shared with the established cognitive abilities included in the current study, and particularly measures of word knowledge. It is worth noting that although we focus on the results of the EFA in the results section, the overall pattern of results is the same if frequency is examined in isolation, including the direction and, roughly, magnitude of the age effects (note, however, that direct comparison of these coefficients is not really warranted, given the increased reliability of the latent factor). For example, the zero-order age coefficient for word frequency alone in the admire essay in Study 1 is −.43, $p < .05$, (note that this association is negative because lower frequency words are associated with increased age), but within the contextual analysis the age relationship is no longer significant (.02, $p = .857$), and the only significant relationship with the contextual variables is between vocabulary and frequency (−.42, $p < .001$). This is perhaps not surprising, as two of the other indicators for the word usage construct–word length in words and word length in syllables–are in part proxies for frequency, insomuch as longer words are less frequent. The extraction of the latent word usage factor in the EFA from these variables and type to token ratio therefore suggests that the mechanisms involving production of rarer words overlap with the mechanisms that allow people to use more diverse words. Further, the unique association with the vocabulary construct indicates that increased crystallised word knowledge may offset any age-related retrieval problems to such an extent that older adults are actually able to maintain more sophisticated and diverse word usage during everyday discourse.

Because vocabulary size was positively associated with more sophisticated and diverse word usage, these results may be inconsistent with vocabulary diffusion theories (i.e., Griffin & Spieler, 2006), which posit that increased vocabulary size and resulting diffused semantic-to-phonological links are responsible for word retrieval difficulty with old age. That is, if vocabulary diffusion were in play in the current results, one would expect greater vocabulary size to be associated with greater difficulty with word retrieval, perhaps evidenced by more restricted lexical selection or the usage of less sophisticated words. The current results therefore suggest that either vocabulary diffusion may not be a mechanism that needs to be considered at discourse-level word usage, or that increases in lexical knowledge can offset any word-retrieval difficulties related to increased vocabulary size to such an extent that preserves diverse and sophisticated lexical production at the discourse level.

In contrast, cross-sectional age-related differences in the usage of complex syntactic constructions were found in both studies. These results are consistent with previous findings indicating a decreasing facility with, and usage of, complex syntax across the lifespan. This significant negative relationship between age and syntactic complexity, however, was not present in the contextual analysis, indicating that relationships with the reference cognitive abilities overlap with the declines seen in syntax. Like the results for the word usage construct, this indicates that there is considerable overlap in age-related variance between the reference cognitive abilities and this grammatical complexity construct, suggesting that no additional explanations may be required above and beyond those needed to explain the reference abilities' declines. However, what specific cognitive ability or abilities may account for these declines is less clear than for the word usage construct. There was a significant unique relation between grammatical complexity and the episodic memory construct, but only in Study 1. This difference across studies may be attributable to the fact that essays in Study 1 were written in the laboratory, but essays in Study 2 were written at home. It is therefore possible that additional time gave participants the opportunity for revision, thus diminishing the constraints on production that particular processing deficits would create. This interpretation is reinforced by the overall lower magnitude of the age-related differences seen in Study 2.

Additionally, there were no unique influences of the working memory construct when it replaced Gf in the model. These results are therefore not consistent with a working memory-based explanation for age-related differences in the production of complex syntactic constructions, at least not domain-general working memory as is assessed by storage-and-processing tasks. Working memory tasks based on remembering words while carrying out arithmetic operations (Operation Span) and spatial positions while making symmetry judgments (Symmetry Span), may be less related to language than working memory tasks with more explicit language requirements, such as Reading Span, in which participants remember words while evaluating sentences (i.e., Daneman & Carpenter, 1980). Although this is a possible consideration in these results, it should be noted that previous individual differences work has found measures from reading span tasks to be moderately correlated with other measures of working memory (Swets, Desmet, Hambrick, & Ferreira, 2007; Salthouse et al., 2008).

STUDY 3: CONTROLLED SENTENCE PRODUCTION

An additional task performed by participants in Study 1, the controlled sentence production task, imposes more constraints on production by requiring the completion of sentences beginning with different types of stems. Previous research with these types of tasks has demonstrated that increased age is associated with greater errors in production and the formation of shorter, less complex sentences (Kemper et al., 2003, 2004). Performance on these more controlled tasks could be more informative about participants' abilities, since production of the constructions is explicitly required, rather than spontaneously produced. This ensures that every participant will be required to at least attempt production of these constructions. Production data may therefore be less influenced by topic or pragmatic considerations such as the imagined audience (Kemper et al., 2003, 2004; Thornton & Light, 2006), and/or less subject to floor effects if participants who have less experience with complex syntactic constructions or who have difficulty producing them due to cognitive load, in whatever form, are less likely to attempt producing these constructions in naturalistic contexts.

Method

The participants and reference cognitive abilities were the same as those described in Study 1.

Procedure—The controlled sentence production task, which was administered on a computer, was adapted fromKemper et al. (2004). The initial display on each trial was a three-word sentence stem, which was followed by a display of two common nouns. The task for the participant was to study the stem as long as desired, then inspect the two additional words, and generate a sentence beginning with the stem that incorporated the two additional words. The participant pressed the space bar on the computer when he or she was finished studying the three-word stem, and then pressed it again when the sentence was created, at which time the sentence was spoken aloud and transcribed by the examiner.

Twenty sentence stems, 10 right-branching stems and 10 left-branching stems, were presented in a randomly intermixed order. Right-branching stems allowed for a main clause to be constructed first, and consisted of a subject and verb plus "that", "what", or "who", such as "Billy found that". Left-branching stems required the production of an embedded clause, and consisted of "that", "what", or "whom" plus a subject and verb, such as "What Tony wanted". The transcribed responses were coded in terms of whether a complete and coherent sentence was produced that included the stem and both additional words. Coefficient alpha reliabilities for the measure of the proportion of valid sentences across the 10 items with each stem type were .72 for right-branching stems, and .79 for left-branching stems.

Results

The bottom section of Table 2 displays the descriptive statistics for this task. As expected, a significantly higher proportion of valid sentences was produced from right-branching stems than from left-branching stems. The second column of Table 5 indicates that successful sentence generation was related to age, with significant zero-order correlations between age and production of valid sentences for both left and right branching stems (Figure 3).

The contextual analysis model was then applied to the measures of the proportions of valid sentences in each condition, with the results presented in Table 5. In order to ensure that results were not simply due to a general lack of understanding of the task, two additional analyses were conducted. One controlled for the proportion of valid right-branching constructions when examining the proportion of left-branching constructions, and the other was based only on data from the participants who were successful at generating valid sentences for at least 80% of the right-branching stems.

It can be seen that there were no unique age-related declines in valid sentence production for right-branching stems, but there were significant negative age relations on the left-branching stems, and this was also true in both supplementary analyses controlling for accuracy of right-branching stems by partialling out right from left stem performance, and restricting the data analysis to participants with high levels of valid right-branching sentence generations. There was a unique influence of episodic memory on performance with the right-branching stems, and of vocabulary ability on both right-branching and left-branching stems.

A number of additional analyses were carried out to examine the robustness of the results in Table 5. Two separate models were created by restricting the analyses to the first 10 production trials in one model, and the second 10 trials in another model. A model was also run where the Gf construct was represented only by reasoning variables instead of both reasoning and spatial variables. In each case the results of the contextual analysis procedure were very similar to the results reported in Table 5, with strong unique effects of age and vocabulary ability on the proportion of left-branching sentences, but no influence of other cognitive abilities.

Because the participants in this study also completed the essays in Study 1, it was possible to examine correlations of the factor scores extracted from the essays with the proportion of left-branching sentences after controlling for the proportion of right-branching sentences. The correlation with the word usage factor was not significant (r = .05), but the correlation with the grammatical complexity factor was significant (r = .16), indicating that participants who used more complex syntax in their essays were also somewhat more successful in producing sentences beginning with difficult grammatical constructions (i.e., left-branching stems).

Discussion

The results of this study both replicate and extend previous results using similar tasks (Kemper et al., 2003, 2004). Successful sentence generation was significantly lower with increased age for both left and right branching stems. This is consistent with previous research that found less successful sentence generation in older adults with complex sentence formation tasks, but somewhat inconsistent with studies which have suggested preserved syntactic processing with sentence generation tasks involving simple syntax (Davidson et al., 2003). Further, while there are clearly substantial differences in how easily sentences can be produced from left-branching stems compared to right-branching stems, the lack of significant unique relationships between left-branching performance and fluid intelligence, episodic memory, or perceptual speed in the contextual model indicate that these differences are not uniquely associated with greater demands on any of these abilities.

Instead, two unique relationships between sentence production and the cognitive abilities were found in the contextual analysis model. Better sentence production performance in both left and right branching conditions was associated with higher scores on the vocabulary construct. The significant, unique relations of the vocabulary construct in both conditions of this task indicate that the ability to produce sentences satisfying specific constraints at least partially reflects the breadth of an individual's word knowledge. These relations could reflect a natural correlation between greater exposure to different types of words and more frequent or more recent exposure to different types of grammatical constructions, which may be related to better performance with complex constructions (Bock, 1986; Bock & Griffin, 2000).

Perhaps the most noteworthy finding of these analyses is the discovery of unique age-related influences on constructing sentences beginning with left-branching stems. The contextual analysis results revealed that at least some of the age-related differences in producing left-branching sentences are independent of age differences in processing speed, episodic memory, Gf, and vocabulary. Additionally, the results of the supplementary analyses suggest that these statistically independent age effects are not simply due to participants misunderstanding the task, since the same pattern was evident after restricting the analysis to those participants with good performance on the right branching constructions; if anything, the age relationships and unique age relations are even stronger within this restricted sample. Overall, this pattern of results suggests that something independent of the reference cognitive abilities assessed in this study appears to be driving performance decrements on the left-branching clauses specifically within the controlled sentence production task. Because unique age relations in the contextual analysis procedure are statistically independent of age-related influences on the reference abilities, the effects of aging on controlled sentence production observed in this study will require an explanation distinct from that contributing to the age differences in the other cognitive abilities in the analysis. Moreover, since these unique relationships were only present for the left-branching stems, and the left-branching condition requires the ability to construct an embedded clause in order to successfully form a sentence, the results imply that an explanation is required for something specific to the formation of these complex constructions, not a general sentence formation deficit.

What could be the cause of the unique age relations in the controlled task? Several possibilities are consistent with these results. One is that other cognitive abilities not specifically assessed in the current project are associated with age-related differences in syntactic ability. Some theories propose that age-related problems with syntactic production stem from word-retrieval difficulties, which cause older adults to adopt a more simplified syntactic structure as a means of dealing with these retrieval difficulties (i.e., Griffin & Spieler, 2006), and this would be consistent with the unique role of vocabulary found in both conditions, if a greater vocabulary base to draw from could alleviate word-retrieval difficulties. If this is the case, the unique age effect observed here *could* be consistent with word production theories that postulate weakening of the links between semantic and phonological representations, such as the Transmission Deficit Hypothesis (i.e., Burke et al., 1991), but it is an open question whether this weakening process would be statistically independent of the differences in the cognitive abilities examined in this project. However, it is not obvious why these processes would only come into play with the left-branching constructions, as they might be postulated to operate with all types of constructions.

Another possibility could be a language-specific working memory resource suggested in dedicated-resources accounts (i.e., Waters & Caplan, 2004), which posit a specific, separate working memory resource that uniquely supports on-line language production and comprehension. This explanation would be consistent with the unique effect only being seen for the left-branching condition, since the formation of these constructions is hypothesised to draw more heavily on working memory.

Alternatively, these results could reflect age-related declines that are entirely mechanistically separate from the rest of cognition, such as changes in the experiences and social situations of older adults. Theories that stress such processes could be consistent with these unique age effects, since these noncognitve factors-input from elderspeak, less complex input from peers, more elapsed time since peak exposure to complex syntax during the educational years (see Griffin & Spieler, 2006)–would reasonably be expected to be statistically independent of the cognitive abilities represented here. This is also consistent with the unique age effect only existing in the left-branching condition, as these types of theories posit very specific difficulty for these types of complex constructions due to their rarity in the English language in general, and especially after the educational years (Miller & Weinart, 1998) and in elderspeak (Giles, Fox, & Smith, 1993).

The current study cannot differentiate between these potential explanations for the unique age-related variance, but does suggest that there is independent variance that requires separate explanation. Further research measuring performance on a wide variety of language tasks in the same individuals could be particularly informative in differentiating between these possibilities.

GENERAL DISCUSSION

The current work is unique in that it examines language production associated with two separate types of tasks within a continuous age range of individuals for which a broad array of cognitive assessment data are also available. The results from the three studies presented here are consistent on several points. First, there is clear support for greater usage of more diverse and sophisticated words with increased age, and this was found across two separate samples of naturalistic production at the discourse level. Second, the contextual analysis results suggest that these age-related word usage differences are largely due to increases in stores of word knowledge, as the word usage construct was uniquely related to the vocabulary construct, and all of the age-related variance in the word usage construct was accounted for by the reference cognitive abilities.

In contrast, both controlled and naturalistic production tasks were consistent in revealing significant negative associations between the production of complex syntax and age, which was evident in decreased usage of complex grammatical constructions in the elicited language tasks, and greater difficulty producing left-branching sentences in the controlled sentence production task. However, the two tasks differed with respect to the statistical independence of these age-related effects from the reference cognitive abilities. Successful sentence generation with the left-branching stems in the controlled sentence production was uniquely associated with age, but there were no unique age relations in the production of left-branching clauses or other complex syntactic forms in the essays, even though these two language variables were significantly, albeit weakly, correlated with one another. This pattern of results suggests that the mechanisms involved in age-related declines in the naturalistic production tasks overlap with mechanisms involved in the reference cognitive abilities, but that because the age-related differences in the controlled sentence production are statistically independent of the reference cognitive abilities, these differences apparently involve separate and distinct mechanisms.

Given these results, it is natural to ask why statistically independent age effects were seen in the controlled task, but not the naturalistic task. One possible explanation for this difference is the overall low frequency of production of complex sentences in the elicited essays. That is, the complex constructions in the essays could have been subject to floor effects, which may have made it difficult to detect relations with other variables.

Another potentially important difference between the controlled and elicited tasks was that while the elicited language samples were written, the controlled task required spoken production. How separate the systems underlying written and spoken production are is, of course, still open to debate. In terms of individual differences research, some studies suggest that, within individuals, the two domains are similar in terms of readability and grammatical errors (Hartley, Sotto, & Pennebaker, 2003), while others suggest the two domains may not be comparable in important ways (Mitzner & Kemper, 2003). Even if one or more aspects of the systems subserving written and spoken production are separable, however, it is still an empirical question as to whether those aspects differ as a function of age. There is some evidence that written language is generally more complex, as it allows for greater planning and revision (Hartley et al., 2003; Mitzner & Kemper, 2003). It is therefore possible that writing affords extra planning that can alleviate age-related declines seen in spoken production, but that the ability to utilise this extra planning is not statistically independent (i.e., results from shared mechanisms) with general cognitive declines already observed in the cognitive literature. The results of this study would be in line with this type of account. While the current work cannot differentiate between these possibilities, the analytical approach presented here could be an important tool in future works investigating the distinctness of language declines from cognitive declines, and inform the debate about the similarity of the processes underlying written and spoken language production.

Additionally, the results from all three studies are consistent in the lack of significant unique relationships between either fluid abilities or working memory and the production of difficult syntactic constructions. This might be unexpected, because working memory deficits are often offered as a cause of age-related differences in syntactic ability, and working memory and Gf are reported as moderately to highly correlated in the literature (Ackerman, Beier, & Boyle, 2005; Salthouse et al., 2008). Nevertheless, the grammatical complexity factor in Study 2, when working memory was directly assessed, was not uniquely related to either the Gf or the working memory construct, nor was Gf uniquely related to the grammatical complexity factor in Study 1 or to the sentence generation measures in either condition of the controlled sentence production task in Study 3. Previous research with large samples and a broad age range indicates that the reference cognitive abilities included in the model discussed here overlap almost completely with these measures of working memory, suggesting that shared mechanisms may be involved in the age-related declines in both of these types of tasks (Salthouse et al., 2008), and this result was reinforced in the current analyses by the need to run separate Gf/Working memory models in Study 2 to eliminate problems of multi-collinearity. This suggests that, even though working memory was not directly assessed in Studies 1 and 3, we would have expected a unique relationship with the Gf construct in these studies if age-related working memory decrements were responsible for age-related language production differences.

While these results do not preclude a zero-order relationship between these abilities and facility with complex syntax that would be consistent with prior research (indeed, there were significant zero-order correlations, not reported, with language performance and nearly all the cognitive measures), they do suggest that there are no unique relations between Gf or working memory, at least as it assessed by storage-and processing tasks, and syntactic ability. Since the current analytic approach involves partialling out the reference abilities' shared variance, there could still be relations between the production of these constructions and whatever is shared among the reference cognitive abilities.

It is interesting to note, in addition, that episodic memory was inconsistently related to performance in some tasks. Sentence generation only in the right-branching condition of the controlled sentence production task was uniquely related to episodic memory, as was the grammatical construct in Study 1. This inconsistency makes these relationships hard to interpret, but it could indicate a role of some memory-related processes, such as retrieval processes implicated by some current theories of sentence processing and production (e.g., Lewis, Vasishth, & Van Dyke, 2006; Gordon, Hendrick, Johnson, & Lee, 2006), that were perhaps only weakly assessed with the memory tasks included in the current study. Further research with time-limited language tasks and direct assessment of working memory, or with additional types of episodic and working memory tasks, however, could more fully pinpoint specific contributions of working or episodic memory performance.

This study's novel finding of unique age-related declines in the ability to construct left-branching sentences in the controlled sentence production task is particularly noteworthy, as prior applications of the contextual analysis procedure have revealed very few unique age-related effects (cf. Salthouse, 2005). The ability to generate grammatically complex sentences in these types of tasks may therefore deserve special attention because, unlike many other measures of cognitive functioning, it appears to decrease with age independently of vocabulary, fluid intelligence, episodic memory, and perceptual speed. While uncommon, the robustness of this finding across multiple approaches to the analyses presented here suggests that the finding is not spurious or simply due to task demands, and thus deserves further investigation.

The cognitive abilities assessed in the current study are certainly not an exhaustive list of possibly related cognitive constructs, but rather a logical starting point as these abilities have been shown to exhibit discriminant validity in the context of aging, and to overlap with many of the age-related declines seen other areas (Salthouse, 2005). While the current study is unable to pinpoint the cause of these unique age relations, it does present an analytic method that, while not currently commonly used to investigate individual differences in language, could be useful in investigating questions related to the relationship between language and cognition in aging. One potential direction for future research is to investigate these and other language production tasks at the latent variable level with a different set of reference cognitive abilities, to specifically target possible hypotheses about causes of the age-related differences.

Acknowledgments

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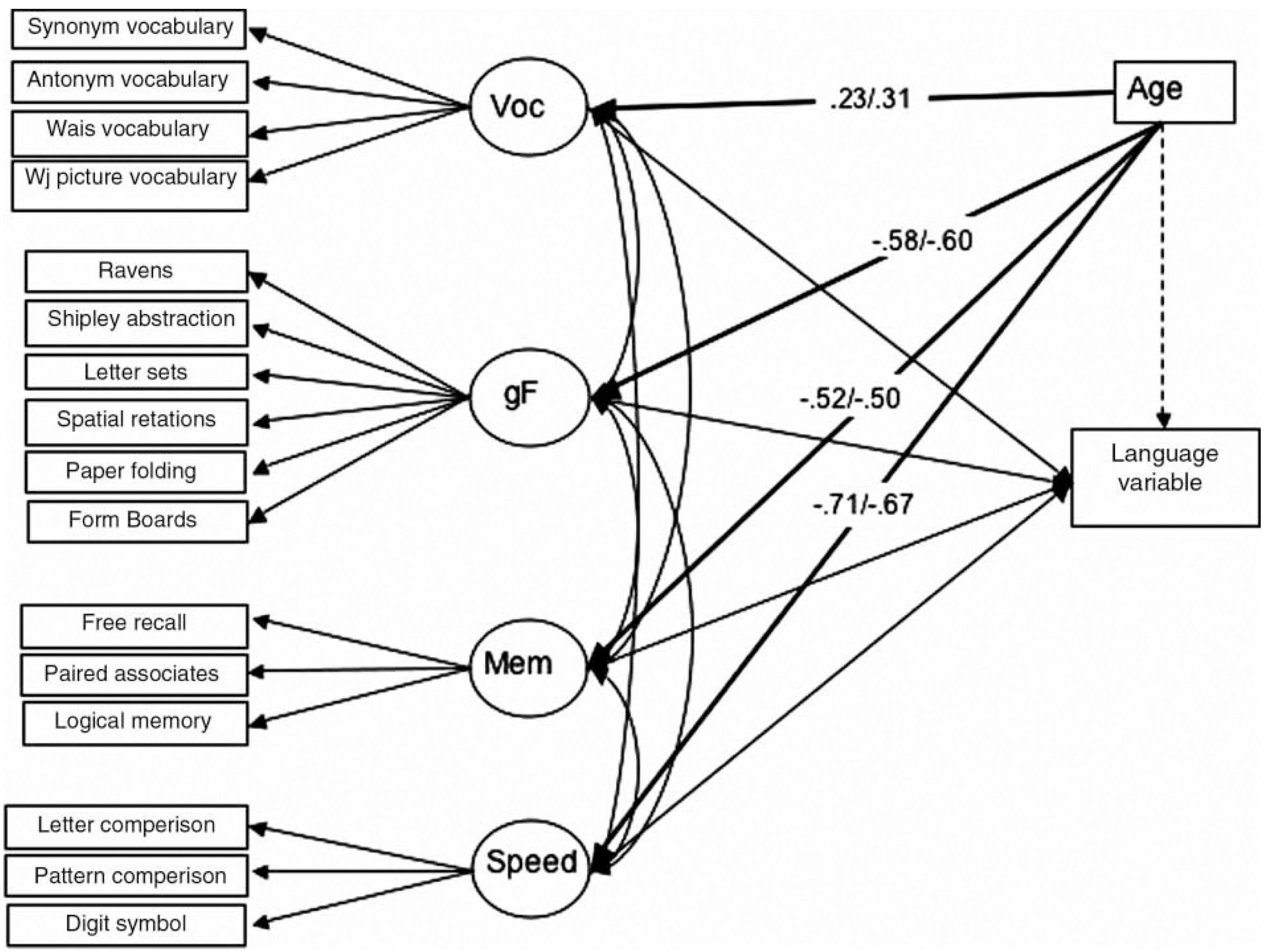

Figure 1.
Structural equation model for the contextual analysis in all studies. The values in the arrows represent the standardised regression coefficients age regressed on the latent constructs in Studies 1 and 2, respectively.

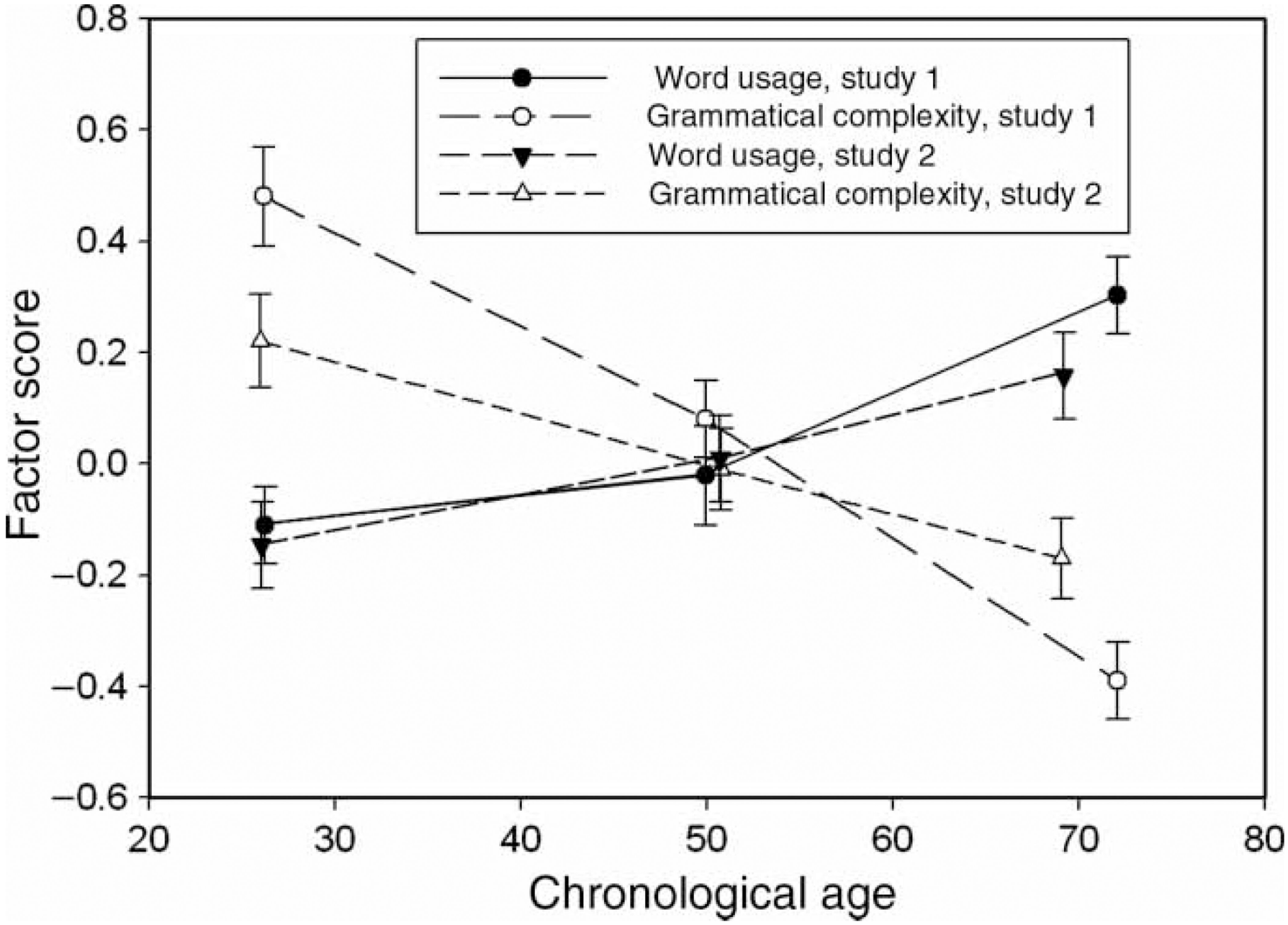

Figure 2.
Grammatical complexity and word usage factor scores by age in Studies 1 and 2.

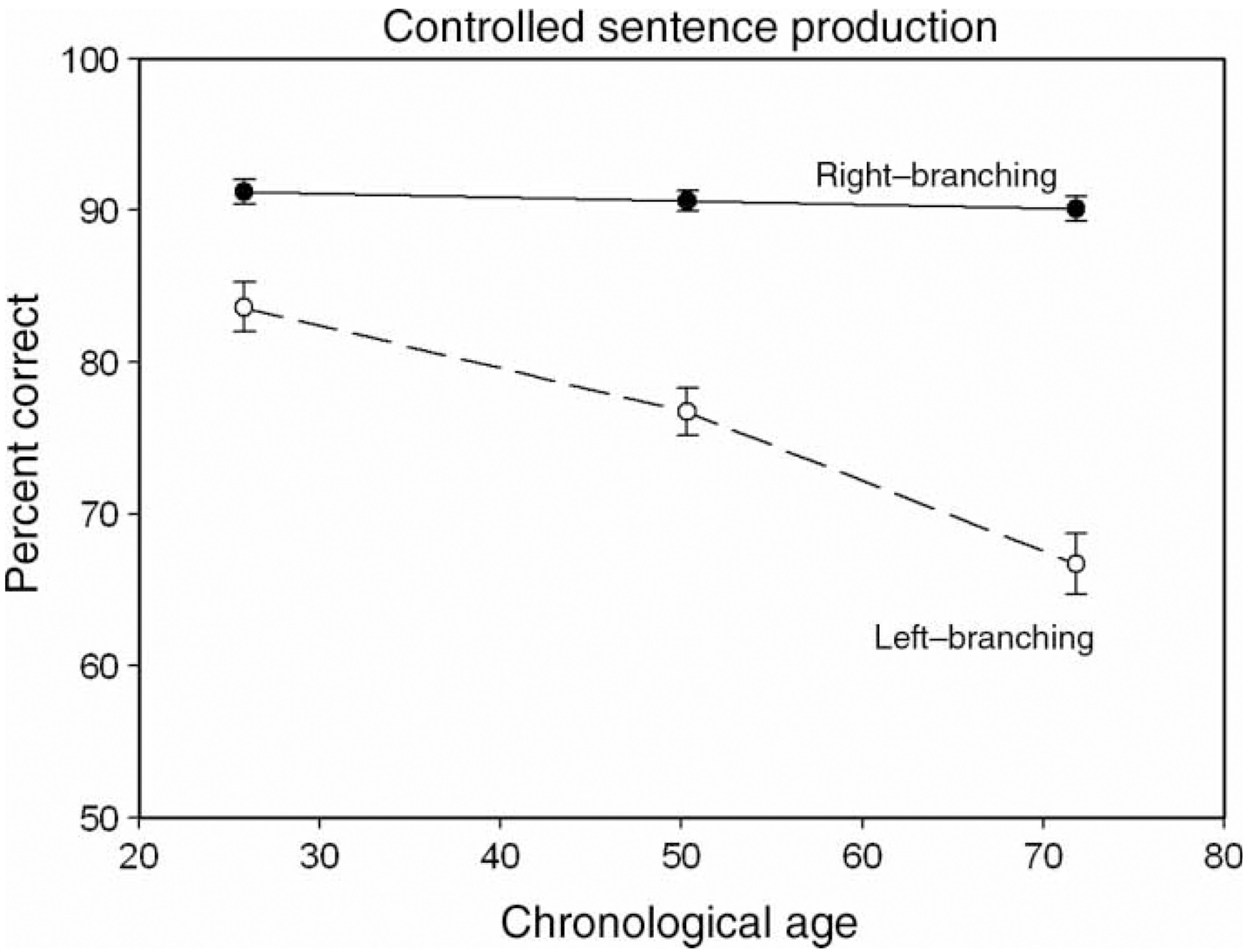

Figure 3.
Percent of valid sentences generated in the left and right branching conditions of controlled sentence production by age.

TABLE 1

Descriptive statistics for participants in Studies 1 and 2

	18–39	40–59	60–90	Age corr.
Study 1				
N	85	169	145	NA
Age	26.1 (6.3)	50.0 (5.3)	72.1 (7.5)	NA
Percent females	61	72	54	−.08
Self-rated health	1.9 (0.8)	2.0 (0.9)	2.1 (0.8)	.16*
Years of education	15.2 (2.1)	16.0 (2.9)	16.3 (3.0)	.17*
Scaled scores				
Vocabulary	13.6 (2.9)	12.7 (2.9)	14.1 (2.5)	.12
Digit symbol	11.7 (2.6)	11.5 (3.1)	12.0 (2.7)	.08
Logical memory	12.2 (2.5)	11.7 (3.0)	13.0 (2.2)	.14*
Word recall	12.4 (3.2)	12.7 (3.9)	13.3 (3.9)	.09
Study 2				
N	129	169	161	
Age	26.0 (6.3)	50.8 (5.6)	69.1 (6.7)	NA
Percent females	67	79	65	−.01
Self-rated health	1.5 (0.8)	1.5 (0.9)	1.7 (0.9)	.11*
Years of education	15.3 (2.2)	15.9 (2.1)	16.8 (2.8)	.28*
Scaled scores				
Vocabulary	14.0 (2.5)	13.2 (2.4)	14.1 (2.2)	.02
Digit symbol	11.7 (2.5)	12.0 (2.6)	12.4 (2.6)	.14*
Logical memory	12.5 (2.4)	12.5 (2.6)	12.8 (2.2)	.07
Word recall	12.4 (3.0)	13.1 (3.1)	13.0 (3.2)	.05

Note: Health was rated on a scale ranging from 1 for Excellent to 5 for Poor. Scaled scores are age-adjusted scores from the Wechsler adult intelligence scale III (Wechsler, 1997a) and the Wechsler memory scale III (Wechsler, 1997b) which in the normative sample have means of 10 and standard deviations of 3.

* $p < .01$.

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TABLE 2

Linguistic variable descriptive statistics. Values in parentheses are standard deviations

	Elicited language production					
	Study 1			Study 2		
	Cookie	**Admire**	**Corr.[a]**	**Admire**	**History**	**Corr.[a]**
Variable						
Words >5 letters	13.74 (3.35)	16.78 (5.80)	.15*	18.90 (5.91)	19.25 (5.22)	.41*
Syllables/word	1.34 (0.07)	1.46 (0.13)	.17*	1.49 (0.13)	1.47 (0.12)	.39*
TTR	0.71 (0.10)	0.84 (0.06)	.29*	0.87 (0.06)	0.88 (0.06)	.18*
Word frequency	2.36 (0.20)	2.40 (0.21)	.30*	2.41 (0.23)	2.41 (0.19)	.39*
Embedded clauses	3.77 (2.91)	6.98 (3.88)	.23*	6.66 (3.81)	7.13 (4.19)	.34*
Subordination	6.80 (4.38)	9.52 (4.81)	.35*	8.58 (4.67)	9.11 (5.15)	.38*
Left branching	0.62 (1.00)	1.42 (1.60)	.16*	1.50 (1.60)	2.04 (2.34)	.17*
Controlled sentence production						
Right stems			.91 (.20)			
Left stems			.66 (.24)			

[a]Entries in the "Corr" columns are correlations between the values in the two passages.

*p <.01.

TABLE 3

Factor loadings for Studies 1 and 2

	Word usage	Gram. compl.
Study 1		
Cookie words >5 letters	.43	.14
Cookie syllables/word	.40	.01
Cookie type-token ratio	.40	.02
Cookie word frequency	−.36	−.01
Admire words >5 letters	.70	−.17
Admire syllables/word	.71	−.20
Admire type-token ratio	.47	−.19
Admire word frequency	−.71	.14
Cookie embedded clauses	.06	.68
Cookie subordination	.08	.76
Cookie left branching	.09	.29
Admire embedded clauses	−.38	.58
Admire subordination	−.47	.68
Admire left branching	−.14	.46
Proportion of variance	24.8	18.8
Study 2		
Admire words >5 letters	.82	−.03
Admire syllables/word	.79	−.05
Admire type-token ratio	.29	−.35
Admire word frequency	−.73	.06
History words >5 letters	.67	−.06
History syllables/word	.66	−.06
History type-token ratio	.15	−.41
History word frequency	−.62	.10
Admire embedded clauses	−.14	.64
Admire subordination	−.14	.70
Admire left branching	−.01	.43
History embedded clauses	.02	.80
History subordination	.03	.84
History left branching	.05	.55
Proportion of variance	24.4	20.1

Gram. compl.= Grammar complexity.

TABLE 4

Correlations (first data column) and standardised regression coefficients (remaining columns) based on the structural equation model portrayed in Figure 1 for the measures derived from elicited language production in Studies 1 and 2

	Age			Cognitive ability		
Latent constructs	**Total**	**Unique**	**Gf**	**Memory**	**Speed**	**Vocabulary**
Word usage						
Study 1	.26*	.00	.18	−.17	−.20	.48*
Study 2	.16*	−.05	.11	−.09	−.08	.50*
Grammatical complexity						
Study 1	−.31*	−.09	.04	.25*	.08	−.08
Study 2	−.12*	.01	.16	.02	.02	−.05

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TABLE 5

Correlations (first data column) and standardised regression coefficients (remaining columns) based on the structural equation model portrayed in Figure 1 for the measures derived from controlled sentence production

	Age			Cognitive ability		
	Total	Unique	Gf	Memory	Speed	Vocabulary
Proportion valid sentences (All participants, *N* = 399)						
Right stems	−.16*	−.16	.09	.31*	−.18	.25*
Left stems	−.33*	−.36*	.04	.09	.06	.46*
Left/right	−.27*	−.31*	−.01	−.09	.18	.37*
(Only participants with proportion >.79 for right-branching stems, *N* = 314)						
Right stems	−.08	−.10	.03	.15	−.10	.11
Left stems	−.33*	−.45*	−.01	.04	.06	.49*
Left/right	−.31*	−.43*	−.02	−.01	.08	.47*

Note: Left/right refers to the residual of the variable with the left-branching stems after partialling the influence of the same variable with the right-branching stems.

* $p < .01$.