Paper citation:
Kemper, S., Schmalzried, R., Hoffman, L., & Herman, R. (2010). Aging and the vulnerability of speech to dual task demands. *Psychology and Aging*, 25, 949-96. PMCID: PMC3050491

Keywords: aging, speech, language production, dual task demands, individual differences

Abstract:

A digital pursuit rotor task was used to measure dual task costs of language production by young and older adults. Rotor tracking performance by both groups was affected by dual task demands: time on target declined and tracking error increased as dual task demands increased from the baseline condition to a moderately demanding dual task condition to a more demanding dual task condition. When dual task demands were moderate, older adults' speech rate declined but aspects of their fluency, grammatical complexity, and content were unaffected. When the dual task was more demanding, older adults' speech, like young adults' speech, became highly fragmented, ungrammatical, and incoherent. Individual differences in verbal ability, working memory, processing speed, and executive function affected vulnerability to dual task costs: verbal ability provided some protection for sentence length and grammaticality, working memory conferred some protection for grammatical complexity, and processing speed provided some protection for speech rate, propositional density, coherence, and lexical diversity. Further, verbal ability and working memory capacity provided more protection for older adults than for young adults although the protective effect of processing speed was somewhat reduced for older adults as compared to the young adults.

Text of paper:

Aging and the Vulnerability of Speech to Dual Task Demands

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This research was supported in part by grants from the NIH to the University of Kansas through the Mental Retardation and Developmental Disabilities Research Center, grant number P30 HD-002528, and the Center for Biobehavioral Neurosciences in Communication Disorders (BNCD), grant number P30 DC-005803 as well as by grant RO1 AG-025906 from the National Institute on Aging to Susan Kemper. Its contents are solely the responsibility of the author and do not necessarily represent the official views of the NIH. We thank Shalyn Oberle, Deepthi Mohankumar, and Whitney McKedy for their assistance with data collection and analysis and Doug Kieweg of the BNCD for developing the digital pursuit rotor.

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In everyday life, we commonly perform multiple tasks at once, dividing attention among competing activities and situations. Dual-tasking or multi-tasking is pervasive; we eat while driving, prepare meals while watching television, and listen to the radio while reading the newspaper and eating breakfast. Theoretically, researchers have sought to determine whether dual task costs reflect the operation of a central bottleneck in response selection (Pashler, 1994) or strategic differences in task coordination (Meyer & Kieras, 1997a, 1997b). This debate has focused on questions of practice and automaticity, given that practice should reduce dual task costs by permitting parallel processing in the Meyer and Kieras framework. Recent investigations (see meta-reviews by Riby, Perfect, & Stollery, 2004, and Verhaeghen, Steitz, Sliwinski, & Cerella, 2003) suggest that older adults experience greater dual task costs than young adults, especially with tasks that involve controlled processing or executive functions such as task switching, time-sharing, and updating. Gőthe, Oberauer, and Kliegl (2007) suggest that there are persistent differences in how young and older adults combine even two well-practiced tasks. Gőthe et al. have suggested that older adults adopt a "conservative" approach to managing dual task demands by trading reduced speed for improved accuracy, whereas young adults employ a "risky" approach by emphasizing speed over accuracy.

Talking is one of the most well-practiced tasks for both young and older adults and is often combined with other activities, particularly gross motor activities: we converse while watching television, carry on a conversation while walking, or talk with our passengers while driving a car. Yet even talking is not exempt from dual task disruptions. In a prior study, Kemper, Schmalzried, Herman, Leedahl, and Mohankumar (2008) combined pursuit rotor tracking (McNemar & Biel, 1939) with concurrent talking to assess age differences in dual task costs. The costs of concurrent talking for pursuit tracking were similar for young and older adults: tracking performance, as measured by average time on target and average distance from the target, declined when the participants were talking while tracking as compared to baseline condition. However, tracking had different costs for language production in the two groups. Although both groups spoke more slowly in the dual task condition than in the baseline condition, young adults experienced greater dual task costs to speech than did older adults, consistent with prior research (Kemper et al., 2003, 2005). In particular, concurrent tracking impaired young adults' verbal fluency and grammatical complexity, such that young adults used shorter, simpler sentences under dual task conditions than they did in the baseline condition. Surprisingly, older adults were less vulnerable to dual task demands than young adults, in that concurrent tracking slowed older adults' speech but did not otherwise affect their fluency, grammatical complexity, or linguistic content, as compared to the baseline condition.

Young adults generally use a complex speech style that leaves them vulnerable to dual-task effects on fluency and grammatical complexity whereas older adults tend to use a more restricted speech style composed of short, simple sentences (Kemper, Kynette, Rash, O'Brien, & Sprott, 1989). This restricted speech style appears to be an accommodation to age-related declines in working memory and processing speed (Kemper & Sumner, 2001) and may serve to reduce their vulnerability to dual task demands (Kemper et al., 2008). It apparently serves them very well in dual-task situations as slowing down enables them to maintain this speech style while engaged in a concurrent activity. The present study examines the limits on older adults' ability to maintain their restricted speech style under dual task demands.

Speech that is highly fragmented, ungrammatical, incoherent, disrupted by many word finding problems, and repetitive, and redundant is highly stigmatized and associated with negative stereotypes of older adults (Hummert, Garstka, Ryan, & Bonnesen, 2004). Such speech is dysfunctional in that it results in delays, requests for clarifications, confusions, and other forms of communication breakdown. Hence, older adults may adopt a “conservative” strategy to minimize dual task disruptions to speech by slowing down and sacrificing secondary task performance in order to maintain their speech fluency, complexity, and content. They may be able to continue to do so even during demanding dual task situations.

Alternatively, there may be limits to older adults’ ability to maintain their speech style. Older adults’ speech may break down when dual task demands exceed some threshold, and some may be more vulnerable to dual task demands than others. Kemper et al. (2008) found that working memory capacity predicted vulnerability to dual task demands. Older adults with superior working memory capacity may be better able to resist dual task demands than those with reduced working memory capacity. Kemper et al. also found that slower individuals were less vulnerable to dual task demands in that they were better able to maintain words-per-minute speech rates, suggesting that their slower, “conservative” strategy may reduce older adults’ vulnerability. Hence, individual differences in working memory, processing speed, or other cognitive abilities may determine how successful older adults are at talking while engaged in pursuit rotor tracking and determine their vulnerability to dual task demands.

The present study was designed to examine the limits of older adults’ vulnerability to dual task demands. Performance on baseline tests of pursuit rotor tracking and language production was contrasted with performance in two dual task conditions, (1) a moderately difficult condition that required participants to talk while tracking a pursuit rotor moving at the same speed as in the baseline condition, and (2) a more demanding condition in which the participants talked while rotor speed was accelerated to 150% of the baseline speed. Rotor performance was assessed by the average time-on-target (the percentage of time participant were successful in tracking the moving target) and average tracking error (the average distance from the moving target). Language production was assessed by nine measures of verbal fluency, grammatical complexity, and linguistic content in the speech samples collected in the baseline and two dual task conditions. In addition, an expanded battery of cognitive tests was administered to the young and older adults in order to more thoroughly assess whether individual differences in verbal ability, working memory, processing speed, and executive function would moderate older adults’ vulnerability to dual task demands.

Method

Participants

A total of 100 young adults (18 to 28 years old, *M* = 21.1, *SD* = 2.8) and 97 older adults (65 to 85 years old, *M* = 73.6, *SD* = 7.8) were tested. Young adults were recruited by signs posted on campus and class announcements; older adults were recruited from a database of prospective and previous research participants. Participants were paid $10/hour. Older adults were also compensated for driving to and from the testing site. Data from three additional older adults were lost due to technical problems during testing.

Cognitive Measures

As detailed below, participants were given a battery of cognitive tests to assess individual differences in four constructs assumed to contribute to age-related differences in cognition: verbal ability, working memory, processing speed, and executive function. Table 1 summarizes the means, standard deviations, and age group comparisons for each observed measure; an alpha level of .05 was set for these and all subsequent *t* and *F* tests.

Three indicators of verbal ability were collected. On the Shipley (1940) Vocabulary Test, participants must choose the best synonym from 4 choices and the number correct out of 40 words served as the outcome. On the North American Reading Test (AmNART; Grober & Sliwinski, 1991), participants were asked to read aloud a series of irregularly spelled words and the number of correctly pronounced words out of 50 possible) was the outcome. Finally, educational attainment in years served as a third indicator of verbal ability.

Four indicators of working memory were collected. On the Digits Forward and Digits Backwards tests (Wechsler, 1958), participants repeated strings of numbers, either in the same (forward) or reverse (backward) order as presented. String length increased from 2 digits to a maximum of 9 digits. Two strings at each length were given to the participants, and the number repeated correctly out of 14 strings was the outcome. On the Daneman and Carpenter (1980) Reading Span Test, participants were asked to remember the last word of each sentence in a set; the number of sentences per set, hence the number of words to be remembered, increased. The maximum number of words a participant could recall out of 7 determined their Reading Span. Finally, on the Operation Span task (OSPAN; Turner & Engle, 1989), participants read an arithmetic equation out loud, responded whether the equation was correct, then read a word printed beside the equation. The number of equations, hence the number of words to be remembered, increased. The maximum number of words a participant could recall out of 5 determined their OSpan.

Three indicators of processing speed were collected. In the Digit Symbol Test (Wechsler, 1958), participants were given a key pairing symbols to digits. The number of symbols correctly paired with a digit within 45 seconds served as the outcome. On the baseline condition of the Stroop test (Stroop, 19351935), participants had 45 seconds to name the color of the ink of a series of X's, and number correct served as the outcome. Finally, on the Trails A portion of the Trail Making test (Reitan, 1958), participants connected labeled dots in numerical order, and the total time in seconds required to correctly connect the dots served as the outcome.

Lastly, the Stroop and Trail Making Tests were also used to derive two inhibition measures of executive functioning. First, in addition to the baseline block X's condition of the Stroop test, participants were given a second condition requiring them to name the color of the ink of printed color words (e.g. the word RED printed in green ink). A Stroop interference score was then calculated as shown in Equation (1):

$$\text{Stroop Interference} = (\text{blocks of Xs} - \text{color names}) / \text{blocks of Xs} * 100. \tag{1}$$

Second, in addition to the Trails A test, on the Trails B test, participants connected labeled dots in sequential order, alternating between letters and numbers (1-A-2-B-3-C and so on). A Trail Making interference score was calculated as shown in Equation (2):

$$\text{Trail Making Interference} = (\text{seconds Trail A} - \text{seconds Trail B}) / \text{seconds Trail A} \tag{2}$$

Because only 2 measures of executive function were available, the Stroop and Trail Making interference scores were averaged for each participant to create a summary measure.

Tests of Age Invariance in Factor Structure. Following the procedures recommended by Vandenberg and Lance (2000), 3 latent factors for verbal ability, working memory, and processing speed were estimated and evaluated for measurement equivalence across age groups in a series of 4 increasingly restrictive models: (1) configural invariance of factor structure, (2) metric invariance of factor loadings, (3) scalar invariance of item intercepts, and (4) invariance of residual variances. The baseline 3-factor model in which all parameters were allowed to differ across groups fit well, χ^2 (64) = 89.069, CFI = .952, RMSEA = .063, CI = .026 to .093, indicating that configural invariance was achieved. At the second step, partial metric invariance was obtained: the factor loadings for Trails A, Digits

Backwards, and education differed significantly across groups, likely reflecting a lack of variance in Trails A and education for the young adults and in Digits Backwards for the older adults. Partial scalar invariance was then obtained: the intercepts for the AmNART, Digits Forwards, and Reading Span tests differed significantly across groups. Finally, the residual variances for OSpan, Digits Forward, and Reading Span differed significantly across groups. Consequently, Empirical Bayes estimates for verbal ability, working memory, and processing speed factor scores were derived from this final model separately for each age group for use in subsequent analyses.

Pursuit-Rotor Tracking

Participants were trained on a digital pursuit rotor tracking task developed by the Digital Electronics and Engineering Core of the Biobehavioral Neurosciences and Communication Disorders Center, a component of the Schiefelbusch Institute for Life Span Studies at the University of Kansas. The pursuit rotor featured a bull's-eye target that rotated along an elliptical track. Participants used a trackball mouse to track the target, displayed on a 15" high resolution flat-screen. The pursuit rotor was controlled by a separate laptop computer. At the start of a trial, participants saw a red bull's-eye target and an elliptical track and were instructed to position a pair of cross-hairs over the target using the trackball, which turned the target from red to green. When the target started moving along the track after a 3 sec delay, participants tracked the moving target, attempting to keep the cross-hairs superimposed on the target. The experimenter set the speed at which the target rotated along the track as well as the duration of the trial. The speed could be varied from approximately .2 to 2 revolutions per minute; trial duration could be varied from 30 sec to 4 min or longer. The program sampled the location of the cross-hairs every 100 ms, and determined whether they were centered on the target, and if not, their distance (in pixels) from the center of the target. The probability that the cross-hairs were on-target was averaged over 3 successive 100 ms intervals, and a moving average, time on target, was determined. This moving average could be computed for the duration of the entire trial or for any portion of the trial. In addition, second measure of tracking performance, tracking error, was computed as the distance in pixels from of the center of the target to the cross-hairs, averaged over 3 successive 100 ms intervals; a moving average was determined over successive intervals for the entire trial or for any segment of the trial. A second version allowed the continuous tracking record to be time-locked to a digital recording of the speech sample produced by the participants. The speech wave form was synchronized with the tracking record and was then used to segment the trial to mark the onset and offset of the participants' speech.

Pursuit Rotor Training. Participants were initially trained on the pursuit rotor task to an asymptotic performance level. Initial tracking speed was selected based on pilot testing. Initial tracking speeds for young and older adults were set at 1.2 and 0.45 rev per min, respectively. Participants practiced tracking for 30 sec and received feedback on their performance. A "2 up/1 down stair-case" training procedure was used to gradually increase tracking speed on successive 30 sec trials: if average time on target was 80% or better for a trial, the speed was increased by 10% for the next trial; if less than 80%, the speed was decreased by 5%. The stair-case procedure converged on an asymptotic tracking speed when the speed oscillated around the same value, moving "up" and "down" past this value 3 times.

In general, young adults took more trials to reach an asymptotic tracking speed (M_Y = 22.8 trials, SD_Y = 6.1) than did older adults (M_O = 18.5 trials, SD_O = 5.4), $F(1,195) = 27.34$, $p < .01$. Given their slower starting rate, older adults' tracking speed was changed in smaller increments, and therefore the older adults reached asymptotic levels more quickly than young adults. After training, the young adults' asymptotic tracking speed (M_Y = 2.3 rev/min, SD_Y = 0.9) was faster than the older adults' (M_O = 0.9 rev/min, SD_O = 0.6), $F(1,195) = 306.66$, $p < .01$. However, relative to starting speed, the older adults had improved 204% after training whereas the young adults had improved 180%. After the asymptotic tracking speed was established for each participant, participants were given a 4 min tracking task to establish a baseline of tracking performance. For this 4 min tracking baseline, older adults and young adults were equivalent on time on target (*M* = 79%, *SD* = .04) and tracking error (*M* = 3.7 pixels, *SD* = .03), both $p > .05$.

Dual Task Conditions*.* Following the 4 min tracking baseline, 2 dual task conditions were administered that differed in the speed of the moving target – either using 100% of the baseline speed (moderate condition) or 150% speed (demanding condition). During these dual task conditions, participants first started tracking the rotating target; after either 1 revolution or 1 min had passed, whichever came first, a small window containing a question prompt appeared centered within the track (without obscuring the track, cross-hairs, or target). Participants were instructed to read the prompt aloud and to respond while continuously tracking the moving target for 4 min. The pursuit rotor tracking program recorded tracking performance from the onset of the trial. Using the speech wave form as a guide, the continuous record was segmented to mark the participant's reading of the prompt and the response. Time on target and tracking error were calculated only when the participant was responding to the question.

Language Samples

A baseline language sample was collected from each participant at the beginning of testing. Participants then received training on pursuit rotor tracking and were tested on baseline tracking; two additional language samples were collected while the participants were engaged in the two dual task conditions. Three eliciting questions were used: Who was the greatest president of the U.S. and why? What do you like the most about living [here] and what do you like the least? What was the most significant invention of the 20th century and how did it affect your life? The three questions were counter-balanced across tasks and participants. Each language sample was approximately 4 min in duration and included at least 50 utterances.

Following the procedures described by Kemper, Kynette, Rash, Sprott, and O'Brien (1989), the language samples were transcribed and coded by segmenting them into utterances and then coding each utterance. Utterances were defined by discernable pauses in the participant's speech flow; therefore, utterances did not necessarily correspond to grammatically defined sentences but included nonlexical interjections, fillers (speech serving to fill gaps in the speech flow,) and sentence fragments. Lexical fillers, such as "and," "you know," "yeah," "well," etc. were retained in the transcript. Non-lexical fillers, such as "uh," "umm," "duh," etc., were excluded from the transcript, as were utterances that repeated or echoed the examiner.

The fluency, grammatical complexity, and content of each language sample were then analyzed. Given the large number of language samples, some measures were obtained from two computerized scoring systems, Coh-Metrix (Graesser, McNamara, Louwerse, & Cai, 2004) and CPIDR-3 (Brown, Snodgrass, Kemper, Herman, & Covington, 2008). These computerized measures have been previously validated against conceptually similar measured obtained from trained coders with excellent agreement (see Kemper et al., 2008). Table 2 summarizes the correlations among these measures separately for young and older adults; baseline means and standard deviations are presented in Table 3 along with the dual task results.

Fluency. Fluency is commonly assumed to involve the coordination of word retrieval, sentence formulation, and articulation processes and to be subject to lapses of attention, memory limitations, and motor and articulatory control problems. There is no generally agreed upon measure of fluency, although fluency is commonly assessed by examining utterance length and grammaticality, speech rate, and the occurrence of fillers. Four measures of fluency were computed. First was the average number of fillers per utterance. Young adults used many fillers and many concatenations of fillers, e.g., "…I mean, like, you know, like… ." Although commonly considered to be disfluencies or speech errors, fillers may serve pragmatic and discourse functions (Cuenca, 2008; Sbisa, 2001). Non-lexical fillers, such as "uh," "umm," "duh," etc., were not tallied although they did affect the calculation of speech rates. Second, all grammatical sentences were identified and the percentage of grammatical sentences was computed for the entire language sample. Third, Mean Length of Utterance (MLU) in words was obtained automatically from the Coh-Metrix program (Graesser et al., 2004). Coh-Metrix was designed to assess the coherence of written texts but can be used to obtain many different linguistic measures from transcripts of oral speech. Finally, a measure of word-per-minute (WPM) speech rate was computed from the average of 3 different 45 sec segments.

Grammatical Complexity. Grammatical complexity reflects syntactic operations involving the use of embedded and subordinate clauses. Two measures of grammatical complexity were obtained from each language sample. First, Developmental Level (DLevel) was scored based on a scale originally developed by Rosenberg and Abbeduto (1987). Grammatical complexity ranged from simple one-clause sentences (DLevel = 0) to complex sentences with multiple forms of embedding and subordination (DLevel = 7). Each complete sentence was scored and the average DLevel for each language sample was then calculated. Second, Coh-Metrix provided the Grammatical Index (GIndex) as a sum of 3 counts per 100 words: the number of connectives such as "because", "and," or "if", the number of noun phrases, and the number of higher level constituents, such as noun phrase complements and relative clauses.

Content*.* Content of language samples can be assessed through use of propositions, the overlap or coherence between sentences, or by measuring lexical diversity, redundancy, and repetition. Three measures of linguistic content were obtained from each language sample. First was Propositional Density (PDensity), as calculated by the CPIDR-3 computer program (Brown et al., 2008), in which each utterance was decomposed into its constituent propositions that represent propositional ideas and the relations between them. PDensity was defined as the average number of propositions per 100 words. Second, Coh-Metrix provided a measure of coherence, the Coherence Index (CIndex), as the sum of 2 measures: (1) argument overlap or the proportional of adjacent sentences that share 1 or more nouns, pronouns, or noun phrases, and (2) LSA cohesion. LSA cohesion is based on latent semantic analysis (Landauer, Foltz, & Laham, 1998) which assesses the conceptual similarity of a text relative to that of other texts; in these analyses, the LSA cohesion score measured how conceptually similar each sentence was to all other sentences in the language sample. Similarly is determined by the overlap of specific words, semantically related words, and words that commonly co-occur (e.g., "President" and "White House"). Finally, Coh-Metrix provided a Type-Token Ratio (TTR) to measure lexical diversity; lower TTRs indicate that many words are repeated throughout the language sample and higher TTRs reflect the use of a greater diversity of words.

Baseline Language Age Comparisons. As shown in Table 2, in the absence of dual task demands, young adults use a different speech style than do older adults. Young adults use many more fillers, peppering their speech with "like," "well," and "you know," and as a result they use longer sentences but have less lexically diverse speech. Their speech is also more rapid and cohesive but less propositionally dense, as fillers contribute little propositional information but do not affect coherence. Although young adults are no more likely to produce grammatical sentences than older adults, they do produce more complex sentences.

Correlations among these baseline measures of fluency, grammatical complexity, and content were computed separately for the young adults and the older adults, as shown in Table 3. Young adults who used more lexical fillers also had lower TTRs, reduced PDensity, and higher MLUs; in contrast, older adults rarely used fillers and their use of fillers was not correlated with PDensity, TTR, and MLU. For both young and older adults, the two measures of grammatical complexity, DLevel and GIndex, were strongly correlated with each other and with MLU, given that longer sentences tend to be more complex. Two of the content measures, PDensity and CIndex, were also correlated for both groups indicating that speakers who used informationally dense sentences tended to produce more coherent language samples, reflecting greater overlap of ideas, words, and phrases.

Results

The primary analysis examined how individual differences in verbal ability, processing speed, working memory, and executive function relate to vulnerability to dual task demands in older adults. The multivariate analysis was conducted in SAS PROC MIXED and proceeded in 2 steps. First, the effects of dual task condition, age group, and their interaction were examined for the rotor tracking measures (time on target, tracking error) as well as the language sample measures of verbal fluency, grammatical complexity, and linguistic content. Second, the effects of individual differences in cognition in predicting vulnerability to dual task demands were assessed across age groups. Table 2 provides the means for each outcome by dual task condition and age group, and Table 4 reports the corresponding significance tests.

Pursuit Rotor Tracking Outcomes

Rotor tracking performance (time on target, tracking error) by both age groups was affected by dual task demands: time on target declined and tracking error increased as dual task demands increased from the baseline condition to the moderate dual task condition to the demanding dual task condition. Notably, none of the age group main effects or age by condition interactions for the tracking measures were significant, indicating that concurrent talking had similar costs for tracking performance for young and older adults.

To assess how individual differences in cognition affect pursuit rotor tracking, a series of additional models was then tested. In these models, the factor scores for verbal ability, processing speed, working memory, and composite measure of executive function were entered as separate predictors of tracking performance in the 3 conditions. Although time on target did not vary with any predictor, tracking error was lower in individuals with better processing speed, $F(1, 192) = 4.54$, $p < .05$. The 2-way interactions of processing speed with condition and with age group, as well as the 3-way interaction, were not significant, indicating that the benefits of increased processing speed in reducing tracking error persisted under both dual task conditions and were similar for young and older adults. In addition, tracking error was lower in individuals with better executive function (i.e., who were better able to ignore the distracting words on the Stroop test and alternate between letters and numbers on the Trail Making test), $F(1, 192) = 7.43$, $p < .05$. However, as shown in Figure 1, the advantage for tracking error provided by better executive function was attenuated for older adults, reflecting the significant executive function by age group interaction, $F(1, 192) = 7.40$, $p < .05$. The values plotted in

Figure 1 were derived from a model including a 3-way interaction of executive function, condition, and age group, as evaluated for hypothetical individuals with executive function factor scores ±1 SD relative to their age group.

Language Sample Outcomes

With regard to the language outcomes, as shown in Table 4, the effects of condition were significant for verbal fluency, grammatical complexity, and linguistic content, reflecting increasing dual task costs across conditions, as were the effects of age, generally favoring the younger adults. Also significant, however, were the condition by age group interactions. The speech of young adults became less fluent, less complex, and less informative progressively as dual task demands increased from moderate to demanding, as shown in Table 2. (Curious exceptions are PDensity and TTR, in which propositional density and lexical diversity actually increased in the moderate dual task condition but then decreased in the demanding condition.) Yet a different pattern was evident for older adults: their fluency, grammatical complexity, and linguistic content were resistant to moderate dual task demands, but declined under more demanding dual task conditions. Thus, the two groups converge on similar speech styles in the demanding dual task condition, a speech style characterized by a slow speech rate, many ungrammatical utterances, short, grammatically simple sentences lacking propositional content and coherence but they reached this end-state by dissimilar routes.

The role of individual differences in cognition in predicting vulnerability to dual task demands was then assessed across age groups. Specifically, additional models examined how individual differences in verbal ability, processing speed, working memory, and executive function related to verbal fluency, grammatical complexity, and linguistic content.

Verbal Fluency. Individual differences in verbal ability significantly predicted MLU, $F(1, 192) = 4.72$, $p < .05$, such that those with greater verbal ability (e.g., who knew more synonyms, could pronounce more irregularly spelled words, and had completed more years of formal education) used longer sentences. Further, individuals with greater verbal ability were less vulnerable to dual task demands affecting MLU, resulting in the significant verbal ability by condition interaction, $F(2, 193) = 4.25$, $p < .05$. The effect of verbal ability on MLU was greater for older adults than for young adults, resulting in the verbal ability by age group interaction, $F(1, 192) = 3.92$, $p < .05$. This pattern was constant across conditions, resulting in a non-significant 3-way interaction. These 2 two-way interactions (verbal ability by condition, verbal ability by age) are shown in Figure 2, in which predicted values of MLU are derived from the 3-way interaction model for hypothetical individuals with verbal ability factor scores ±1 SD relative to their age group. Persons with greater verbal ability also produced a significantly greater percentage of grammatical sentences, $F(1, 192) = 6.27$, $p < .05$, but any advantage resulting from superior verbal ability was similar across conditions and for both young and older adults, as shown by the absence of any 2-way and 3-way interactions among verbal ability, condition, and age.

Persons with greater processing speed also spoke significantly faster, $F(1, 192) = 5.52$, $p < .05$, although this speed advantage for speech rate was similar across conditions and age groups, as evidenced by the lack of 2-way and 3-way interactions. Finally, the use of fillers was not related to verbal ability, processing speed, working memory, or executive function. Young adults' heavy use of fillers appears to be a pragmatic choice; fillers may serve to modulate the pragmatic force of their utterances, functioning like hedges (e.g., "sorta") and other devices. Highly verbal young adults, those who speak rapidly, those with excellent working memory, and those with good executive function are just as likely to use fillers as those with more limited vocabularies, slower speaking rates, limited working memory, and poor executive function.

Grammatical Complexity. Working memory significantly predicted DLevel, *F*(1, 192) = 25.51, *p* < .01, such that persons who recalled more digits and words on the span tests tended to use more complex sentences. Persons with better working memory were less vulnerable to dual task demands, as indicated by a significant interaction of working memory by condition, *F*(2, 193) = 10.65, *p* < .01. The effect of working memory on grammatical complexity was greater for older adults than for young adults, resulting in a significant working memory by age group interaction, *F*(1, 192) = 4.82, *p* < .05; however, this pattern was constant across conditions, resulting in a non-significant 3-way interaction. These 2-way interactions (working memory by condition, working memory by age) are shown in Figure 3, in which predicted values of DLevel are plotted for hypothetical individuals with working memory factor scores ±1 SD relative to their age group. The same pattern of findings with regard to working memory were evidenced for the other measure of grammatical complexity, GIndex, including a significant main effect, *F*(1, 192) = 2.84, *p* > .05, a 2-way interaction with condition, *F*(2, 193) = 7.60, *p* < .05, and a 2-way interaction with age group, *F*(1, 192) = 5.96, *p* < .05, as shown in Figure 4 (which was constructed similarly to Figure 3).

Content. In addition to being more rapid, the speech of persons with greater processing speed was more propositionally dense, PDensity *F*(1, 192) = 4.93, *p* < .05, and more cohesive, *F*(1, 192) = 4.26, *p* < .05. This suggests that faster individuals may more rapidly access long-term memory information, search semantic memory, and organize their thoughts than slower individuals. Although the 2-way interactions of processing speed with condition or age were not significant, the 3-way interaction was significant for PDensity, *F*(2, 192) = 4.24, *p* < .05. In the young adults, propositional density actually improved when dual task costs were moderate; this increase may be attributable to the reduction in young adults' use of fillers in the dual task conditions. Fillers contribute little propositional content but add words, thereby reducing propositional density. Although fillers are often considered a marker of disfluency, this pattern suggests that young adults may be using fillers to serve pragmatic functions that are disrupted by dual task demands. However, as Figure 5 indicates (constructed as described previously), young adults are unable to maintain this gain in propositional density when dual task demands increased further and also show a greater effect of processing speed on propositional density than older adults. However, the speech of faster older adults is denser than that of slower older adults. Further, moderate dual task demands do not affect the density of older adults' speech, although the more demanding dual condition resulted in a reduction of older adults' propositional density, especially for the slower ones.

Coherence was also affected by processing speed, as shown in Figure 6, reflecting the significant 3-way interaction of processing speed, age group, and condition, *F*(2, 193) = 3.03, *p* < .05. The effect of processing speed on coherence was attenuated for older adults in the 2 dual task conditions although faster older adults had more cohesive speech than slower older adults in the baseline condition. Young adults exhibited a different pattern: the effect of processing speed was attenuated in the baseline condition but emerged in the dual task conditions, such that faster young adults were better able to maintain the coherence of their speech as tracking speed increased. Nonetheless, the speech of young adults, like that of older adults, became less cohesive as dual task demands increased.

Finally, processing speed also significantly affected lexical diversity, measured by TTR, *F*(1, 192) = 4.09, *p* < .05, such that those who responded faster on the baseline Stroop and Trail Making tests used a greater diversity of words, resulting in higher TTRs, than those who responded more slowly. This pattern was constant across conditions and age groups, as indicated by the nonsignificant 2-way interactions. However, there was a marginally significant 3-way interaction, *F*(2, 193) = 2.99, *p* = .0555, such that young adults' TTRs first increased when dual task costs were moderate, then declined when dual task costs were more demanding and this pattern was somewhat attenuated for slower young adults. In contrast, older adults' TTRs were consistent regardless of dual task demands, although relatively faster older adults did have higher TTRs than slower older adults.

Discussion

This study has examined how aging and individual differences in verbal ability, working memory, processing speed, and executive function relate to vulnerability to dual task demands by measuring the impact of pursuit rotor tracking performance on talking, exploiting the linkage between cognition and the sensory-motor control of behavior (Lindenberger et al., 2000; Li et al., 2001; Welford, 1958). Pursuit rotor tracking, a demanding task by itself, becomes more demanding when it is combined with another task, and even more demanding as the speed of the pursuit rotor is increased. In this study, as tracking demands increased, time on target declined and tracking error increased, demonstrating the effectiveness of the dual task tracking plus talking paradigm. Pursuit rotor tracking was also related to individual differences in processing speed and executive function. Faster individuals had an overall advantage and the protective effects of processing speed on tracking performance were similar for both young and older adults. Individuals with superior executive function were somewhat less vulnerable to the effects concurrent speech on tracking performance and this protective effect was somewhat attenuated for older adults. However, the overall pattern was similar for both young and older adults regardless of individual differences in processing speed and executive function: tracking performance deteriorates with dual task demands.

The primary focus of this research was to investigate how language production is affected by dual task demands and by individual differences in cognition. The results indicate that young and older adults adopted different strategies in order to respond to an elicitation question while engaged in pursuit rotor tracking. Yet, ultimately in the most demanding dual task condition, both young and older adults used a similar speech style, one composed of many ungrammatical fragments and short, simple, incoherent sentences. Individual differences in cognition partially buffered vulnerability to dual task demands, especially for older adults.

In the absence of competing task demands, young adults used a complex speech style that was peppered with many lexical fillers, perhaps serving pragmatically as hedges to weaken the force of their assertions (Cuenca, 2008; Sbisa, 2001). They spoke rapidly and used long sentences with many complex constructions. Their speech was cohesive but not propositionally dense as a result of their excessive use of fillers. But when asked to speak while engaging in pursuit rotor tracking, young adults adopted a different speech style; their speech became slower, shorter, less complex, and less cohesive. They also reduced but did not completely abandon their use of fillers.

In the baseline condition, older adults used a restricted speech style involving few grammatically complex sentences. When pursuit rotor tracking demands were moderate, they were able to maintain their speech style by speaking more slowly. But under the more demanding tracking condition, they tried to maintain their speech style by speaking yet more slowly but they were unsuccessful in doing so: their speech became less grammatical, less complex, and less cohesive than in the baseline and moderate tracking conditions. Indeed, in the demanding dual task condition, the speech of older adults, like that of young adults, was composed of many ungrammatical fragments, short simple sentences, sentences that were lacking in propositional density and coherence.

Individual differences in verbal ability, processing speed, working memory, and executive function were informative in predicting the baseline speech style of both young and older adults: those with better verbal ability used longer sentences and were more likely to produce grammatical utterances, those with better working memory used more complex sentences, and the speech of faster individuals was denser and more cohesive than the speech of slower individuals. Moreover, these individual differences predicted vulnerability to dual task demands: verbal ability moderated the effect of tracking demands on sentence length and grammaticality, working memory provided some protection for the effects of tracking demands on grammatical complexity, and processing speed buffered the effects of tracking demands on speech rate, propositional density, coherence, and lexical diversity.

The extent to which individual differences in cognition moderated vulnerability to dual task costs differed for young and older adults in some regards. Superior verbal ability provided more protection for older adults than for young adults for the effect of dual task demands on sentence length. Greater working memory capacity provided more protection for older adults than for young adults for the effects of dual task demands on grammatical complexity. In contrast, the protective effect of better processing speed on propositional density and coherence was somewhat reduced in the older adults as compared to the young adults. Although these individual and group differences in cognition provided some protection from dual task demands, the overall pattern was similar for both groups and all individuals: both young and older adults spoke more slowly, less fluency, less complexly, and less coherently as dual task demands increased. Individuals with superior verbal ability, working memory, processing speed, or executive function were as vulnerable to dual task demands as individuals with limited verbal ability, reduced working memory, slower processing speed, or poor executive function.

This investigation of aging and vulnerability of speech to dual task demands demonstrates that there are limits to older adults' ability to maintain their simplified speech register. When the going gets tough, or in this case when the rotor speeds up, older adults are no longer able to produce grammatical and coherent speech simply by speaking more slowly. Their speech comes to resemble the speech of older adults with dementia (Kemper, LaBarge, Ferraro, Cheung, Cheung, & Storandt, 1993; Lyons, Kemper, LaBarge, Ferraro, Balota, & Storandt, 1994): it is composed of many sentence fragments, as well as short, grammatically simple sentences, and lacks semantic cohesion, informativeness, and lexical diversity. These results also demonstrate that young adults' speech converges on a similar style under demanding dual task conditions, a speech style that is still marked by young adults' predilection to use lexical fillers but one that is composed of many sentence fragments and short, grammatically simple sentences, and one that is incoherent and uninformative. As a result, both older adults and young adults may experience communication breakdowns, requests for repetition and clarification, and misunderstandings when they attempt to communicate while engaged in concurrent activities. Speech, even that produced by individuals with superior verbal ability, working memory, processing speed, or executive function, is vulnerable to dual task demands.

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Table 1

Age Group Differences on Tests of Verbal Ability, Working Memory, Processing Speed, and Executive Function.

	Young Adults		Older Adults		*F* (1,195)
	Mean	SD	Mean	SD	
Verbal Ability					
Years of Education	16.2	0.7	17.1	2.9	1.89
North American Reading Test	31.0	5.3	36.3	7.4	33.29**
Shipley Vocabulary	31.8	3.2	34.9	3.4	46.78**
Working Memory					
Digits Forward	9.3	2.2	7.7	2.4	4.31*
Digits Backward	7.7	2.4	5.2	0.7	7.68*
Reading Span	3.5	0.8	3.1	0.6	12.43**
Operation Span	4.0	0.9	2.7	1.2	73.45**
Processing Speed					
Digit Symbol	35.1	4.7	24.4	5.2	229.16**
Stroop Xs	89.1	14.2	69.8	13.9	92.76**
Trail Making A	45.7	10.0	78.4	28.5	108.39**
Executive Function					
Stroop words	66.5	12.8	39.3	11.8	43.28**
Stroop Interference %	-25.5	0.10	-42.1	.15	83.89**
Trail Making B	51.8	12.9	104.3	24.8	18.46**
Trail Making Interference %	-10.4	2.7	-38.2	3.8	23.41**

**p* < .05; ** *p* < .01

Table 2

Age Group Differences on Baseline and Dual Task Measures of Tracking Performance, Fluency, Grammatical Complexity, and Linguistic Content.

	Young Adults						Older Adults					
	Baseline		Dual Task Conditions				Baseline		Dual Task Conditions			
			Moderate		Demanding				Moderate		Demanding	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Performance												
Time On Task	79.39^{a}	0.04	68.10	1.12	25.78	1.08	78.76^{a}	1.02	70.69	0.49	24.33	0.72
Error	3.72^{a}	0.02	4.17	0.06	8.34	0.07	3.66^{a}	0.05	3.82	0.02	7.94	0.03
Fluency												
Speech rate	121.39	2.77	100.28	2.39	68.70	2.20	97.48	2.97	84.26	2.91	60.93	2.30
% with Fillers	55.68	3.21	24.51	1.34	21.19	1.24	5.59^{a}	0.61	5.40^{a}	0.39	5.48^{a}	0.49
% Grammatical	51.70^{a}	0.01	43.35	0.01	39.43	0.01	$49.77^{a,b}$	0.01	45.75^{b}	0.01	39.58	0.01
Mean Length Utterance	10.83	0.15	9.26	0.13	7.14	0.16	9.04^{a}	0.25	9.03^{a}	0.27	7.67	0.25
Complexity												
Developmental Level	3.91	0.07	3.25	0.09	1.45	0.10	3.50^{a}	0.10	3.29^{a}	0.10	1.33	0.10
Grammatical Index	4.05	0.06	2.86	0.03	2. 12	0.04	3.99^{a}	0.06	3.55^{a}	0.04	3.11	0.04
Content												
Propositional Density	51.57^{a}	0.03	61.57	0.04	35.91	0.06	$53.82^{a,b}$	0.03	53.61^{b}	0.03	38.68	0.03
Coherence Index	5.25^{a}	0.11	4.92	0.14	2.29	0.16	$3.59^{a,b}$	0.14	3.51^{b}	0.16	1.37	0.13
Type Token Ratio	0.35^{a}	.01	.60	.01	.51	.07	$.64^{a,b}$	.01	$.66^{b}$	.01	$.65^{b}$	.01

NOTE: Within age group, entries sharing the same superscript do not differ at $p < .05$; between age groups, baselines sharing the same superscripts do not differ at $p < .05$.

Table 3

Correlations among the Baseline Language Sample Measures.

	1	2	3	4	5	6	7	8	9
1. Speech Rate	--	-.061	-.117	.170	.079	-.031	.069	-.104	.101
2. Mean Length Utterance	-.105	--	.086	.191	.281**	.299**	.174	.440**	-.115
3. Percent with Fillers	.305**	.408**	--	-.051	-.163	-.031	-.157	.154	-.055
4. Percent Grammatical	.102	.108	-.124	--	.319**	.368**	.123	.136	.048
5. Developmental Level	-.143	.263*	-.035	.158	--	.516**	.155	.013	.140
6. Grammatical Index	-.057	.245*	.054	.128	.545**	--	.061	.103	-.052
7. Propositional Density	.164	.012	.305**	.133	.117	.168	--	.458**	.409**
8. Coherence Index	.137	.333**	.041	.023	-.136	.092	.477**	--	-.192
9. Type Token Ratio	-.233*	-.074	-.405**	.191	.178	.125	.343**	-.133	--

NOTE: Correlations for young adults are reported in the lower-half matrix; those for older adults are reported in the upper-half matrix.

* $p < .05$; ** $p < .01$.

Table 4

Results of the Tests of the Fixed Effects for Rotor Performance, Verbal Fluency, Grammatical Complexity, and Linguistic Content Measures.

	Tests of Fixed Effects		
	Condition (2, 194)	Age Group (1, 195)	Condition x Age Group (2, 194)
Performance			
Time on Task	2736.57**	<1.0	2.28
Error	6006.49**	<1.0	3.08
Fluency			
Speech rate	341.70 **	60.73**	36.66**
% with Fillers	70.77**	282.14**	61.37**
% Grammatical	11.81**	38.82**	54.75**
Mean Length Utterance	390.55**	43.67**	100.54**
Complexity			
Developmental Level	250.52**	21.26**	17.45**
Grammatical Index	2169.48**	28.10**	32.34**
Content			
Propositional Density	7908.61**	339.36**	1313.81**
Coherence Index	399.96**	11.18**	23.08**
Type Token Ratio	5.01*	11.42**	14.60**

* *p* < .05; ** *p* < .01

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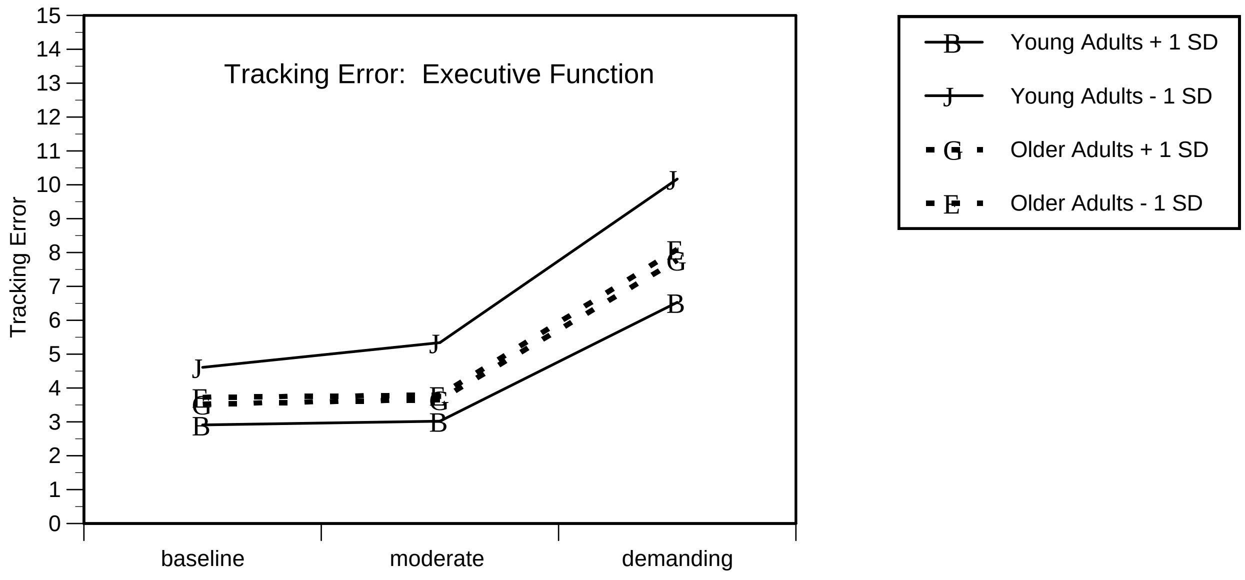

Figure 1: Effect of Individual Differences in Executive Function on Baseline and Dual Task Differences in Tracking Error. Estimates were derived for Young versus Older Adults with Executive Function composite scores ±1 SD relative to their age group.

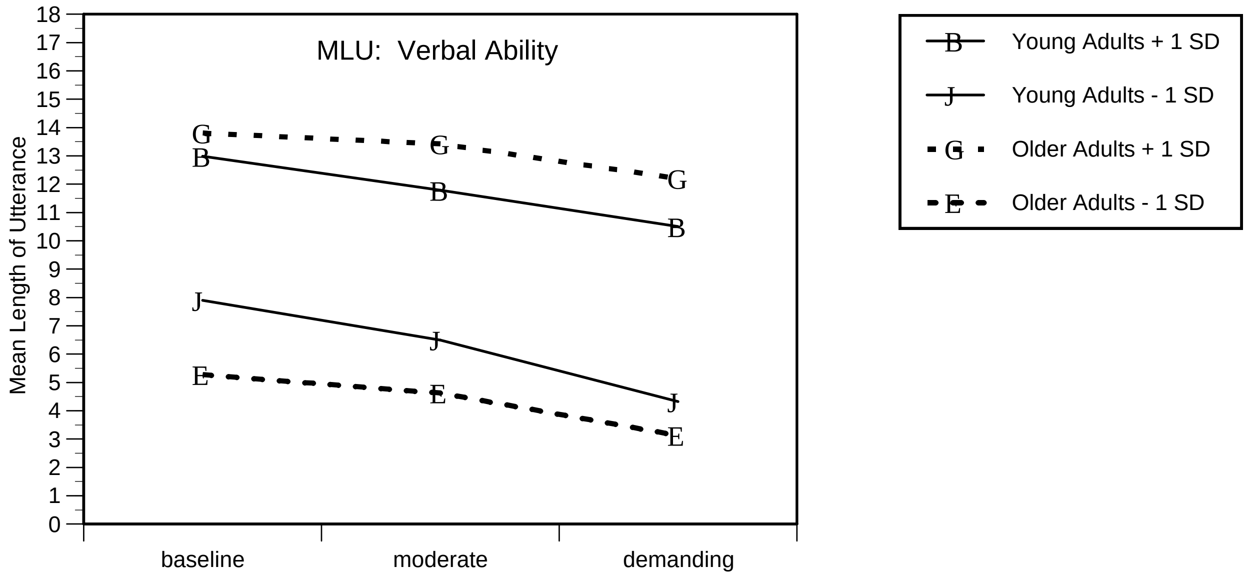

Figure 2: Effect of Individual Differences in Verbal Ability on Baseline and Dual Task Differences on Mean Length of Utterance (MLU). Estimates were derived for Young versus Older Adults with Verbal Ability factor scores +1 SD relative to their age group.

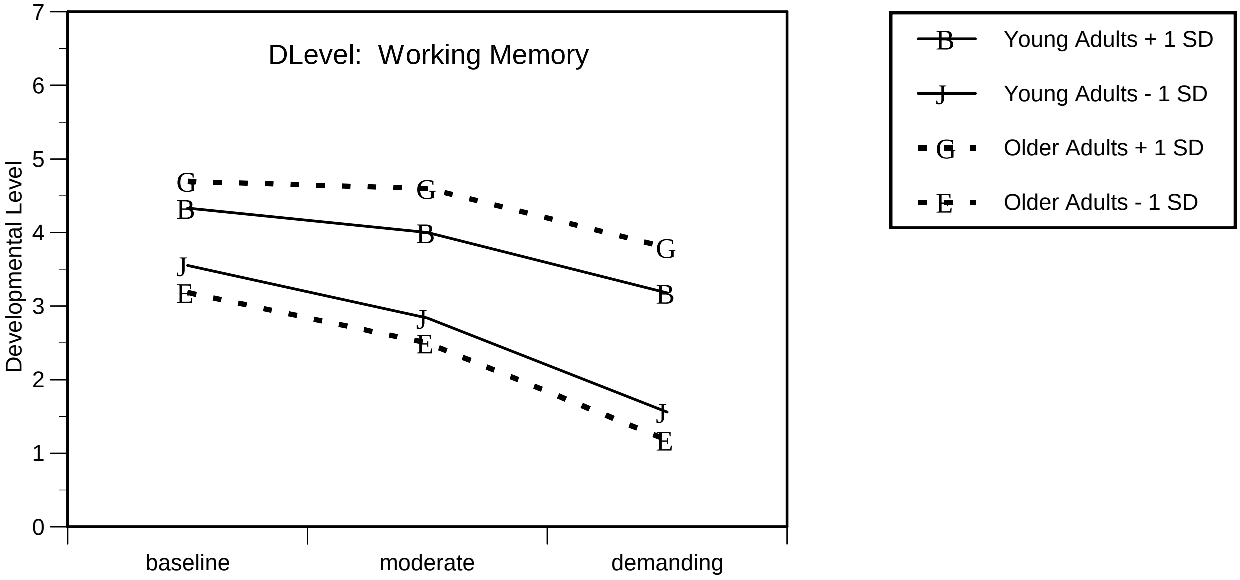

Figure 3: Effect of Individual Differences in Working Memory on Baseline and Dual Task Differences on the DLevel measure of Grammatical Complexity. Estimates were derived for Young versus Older Adults with Working Memory factor scores +1 SD relative to their age group.

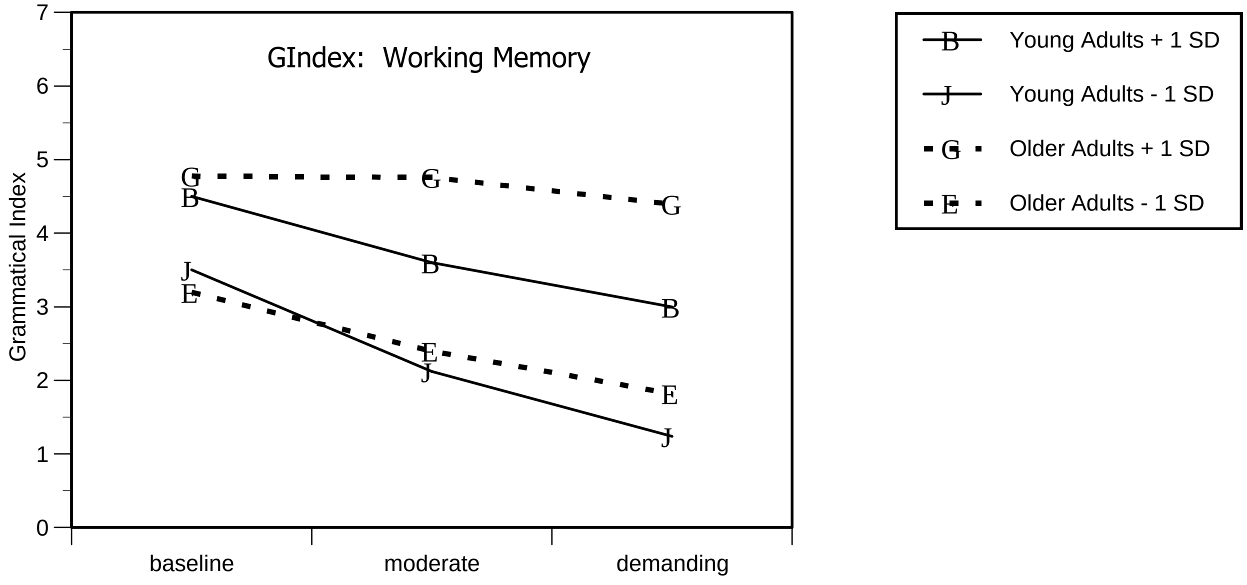

Figure 4: Effect of Individual Differences in Working Memory on Baseline and Dual Task Differences on the Grammatical Index measure of Grammatical Complexity. Estimates were derived for Young versus Older Adults with Working Memory factor scores ±1 SD relative to their age group.

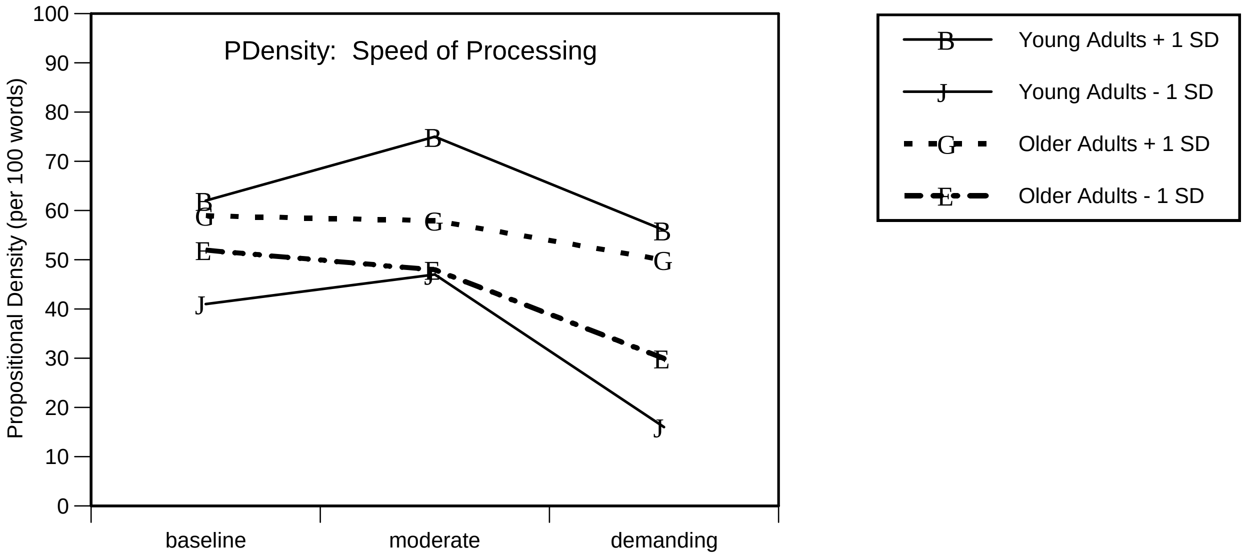

Figure 5: Effect of Individual Differences in Speed of Processing on Baseline and Dual Task Differences on the Propositional Density measure of Linguistic Content. Estimates were derived for Young versus Older Adults with Processing Speed factor scores +1 SD relative to their age group.

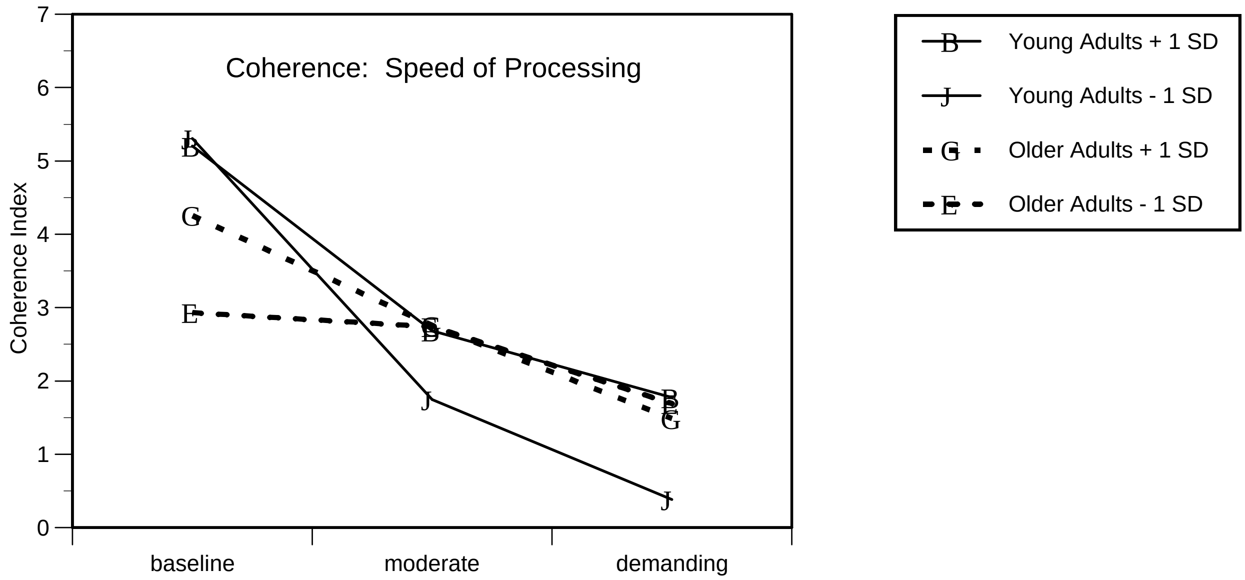

Figure 6: Effect of Individual Differences in Speed of Processing on Baseline and Dual Task Differences on the Coherence Index measure of Linguistic Content. Estimates were derived for Young versus Older Adults with Processing Speed factor scores ±1 SD relative to their age group.