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Aging, Speech Production, Speech Planning, Dual Task Demands, Fluency

Abstract:

A digital pursuit rotor was used to monitor speech planning and production costs by time-locking tracking performance to the auditory wave form produced as young and older adults were describing someone they admire. The speech sample and time-locked tracking record were segmented at utterance boundaries and multilevel modeling was used to determine how utterance-level predictors such as utterance duration or sentence grammatical complexity and person-level predictors such as speaker age or working memory capacity predicted tracking performance. Three models evaluated the costs of speech planning, the costs of speech production, and the costs of speech output monitoring. The results suggest that planning and producing propositionally dense utterances is more costly for older adults and that older adults experience increased costs as a result of having produced a long, informative, or rapid utterance.

Text of paper:

Tracking Talking: Dual Task Costs of Planning and Producing Speech for Young versus Older Adults

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Speech production is very flexible, allowing for many variations of fluency, complexity, and content in response to individual, group, and situational factors. Although well-practiced, speech production is affected by many different cognitive abilities including attention (Becic, Dell, Bock, & Garnsey, 2010), verbal ability (Ferreira & Dell, 2000), working memory (Ellis, 1980; Power, 1985 & 1986), processing speed (Goldman-Eisler, 1961; Tsao & Weismer, 1997), and inhibition (Hasher & Zacks, 1988). It is vulnerable to many breakdowns and disruptions such as word-finding problems (Burke, Worthley, & Martin, 1988), hesitations (Bortfield, Leon, Bloom, Schober, & Brenan, 2001; Corely, Stewart, & Jaeger, 2005), and speech errors (Boomer & Laver, 1968) in addition to impairments resulting with neurological trauma and neurogenic conditions (for a review, see Kempler, 2005).

Many aspects of speech production are preserved across the life span while others decline as a result of differing discourse goals, sensory changes, reductions in processing speed, and working memory limitations (for a review, see Burke & Shafto, 2004). As a result, young and older adults adopt different strategies to deal with the costs of speech production. Older adults tend to use a 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). It apparently serves older adults very well as they are able to maintain this speech style by speaking more slowly while engaged in common concurrent activities such as walking or tapping a finger (Kemper, Herman, & Lian, 2003; Kemper, Herman, & Nartowitz, 2005). Young adults use a more complex speech style producing faster, longer, and more complex sentences than older adults. However, young adults' complex speech is vulnerable to dual task demands: during concurrent activities, they not only slow down, but they also use shorter, simpler sentences when attempting to talk while walking or tapping a finger. Indeed, their resultant style of speech in the dual task conditions resembles that of the older adults: it is slow, short, and simple.

To provide a more fine-grained analysis of the effects of dual task demands on young and older adults' speech, Kemper, Schmalzried, Herman, Leedahl, and Mohankumar (2008) (see also (Kemper, Schmalzried, Herman, & Mohankumar, in press; Kemper, Schmalzried, Hoffman, & Herman, in press) combined speech production with tracking a continuously moving digital pursuit rotor. With practice, older adults were able to attain the same level of asymptotic tracking performance as young adults. The costs of concurrent talking for pursuit rotor tracking were similar for young and older adults: tracking performance declined when the participants were talking while tracking as compared to a baseline tracking condition. However, tracking had different costs for language production in the two groups. As in the previous studies, under dual task demands, the dual task speech of young adults came to resemble that of older adults in both the baseline and dual task conditions: both groups used slow, short, simple sentences, as shown in Table 1 (although young adults do use more lexical fillers, such as "like" and "you know" than older adults). Since in the baseline condition young adults spoke more rapidly and used longer, more complex sentences than did older adults, young adults experienced greater dual task costs to speech than did older adults, consistent with prior findings from Kemper et al. (2003, 2005). 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.

In this series of studies (Kemper et al. 2008, in press a & b) aggregate measures of tracking or talking were computed over a trial, typically 4 minutes in length, to compare the costs of speech production for young and older adults. However, a significant advantage of this approach is that the continuous record of pursuit rotor tracking can be time-locked to the speech wave form. The continuous record of tracking performance can be segmented using the time-locked speech wave form as a guide, permitting the analysis of utterance-by-utterance variation in pursuit rotor tracking in order to measure the costs of speech production at the level of individual utterances as well as the pauses that proceed and follow each utterance.

Figure 1 shows the continuous tracking record and time-locked speech wave form for one 4-min trial from Kemper et al. (2008). The speaker used a trackball to control a pointer and track the moving bull's eye target. After 1 min, a question prompt was presented and the speaker started to talk in response to the question after approximately 75 s and continues to speak for an additional 3 min. In addition to the speech wave form (lower panel), two measures of tracking performance are displayed in Figure 1: tracking error (TE; upper panel) and time on target (TOT; middle panel). The pointer's location is sampled every 100 ms and TE, the distance from the pointer to the moving target, and TOT, the percentage of time the pointer was on target, are computed as a running average over 3 successive 100 ms intervals. [1]

[1] Pursuit rotor tracking has long been used as a measure of skill acquisition and perceptual-motor learning and has more recently been used to assess the effects of age differences in working memory and other cognitive resources on skill acquisition (Ghisletta, Kennedy, Rodrigue, Lindenberger, & Raz, 2010). Traditionally, time on target (TOT) is used as the critical measure of performance: participants are required to keep a wand or other device in contact with a rotating target and the percentage of time contact is maintained is determined. The use of a digital pursuit rotor permits a second measure of tracking performance to be determined: tracking error (TE). Participants may abandon tracking, resulting in large TE, or they may lag somewhat behind the target, resulting in smaller TE. Hence, the comparison of

A utility program, the Rotor On-line Speech Segmenter (ROSS), permits these time-locked records to be segmented into utterances and pauses, excluding the initial 1 min tracking interval. The speech samples are replayed while a listener inserts cursors to mark the onset and offset of utterances; play-back speed can be adjusted, the location of the cursors can be manually fine-tuned, and distinctive cursors can be inserted to mark, e.g., sentence versus fragments, lexical fillers, or other types of segments. The ROSS utility then extracts measures of tracking performance corresponding to each segment. These include the duration of each segment, TE and TOT measures of average tracking performance, and variability in TE and TOT during the segment. The resulting segmented performance record can be exported as a spreadsheet, as shown in Table 2. This spreadsheet can then be annotated with additional information about each segment, such as counts of words, propositions, fillers, measures of grammatical complexity, etc., obtained from a transcript of the speech sample.

This technique was used to reanalyze the dual task tracking and speech production records from the Kemper et al. (2008) study. The present analysis examined the utterance-by-utterance costs of language production to address 3 questions: Question 1: Is speech planning costly for both young and older adults? If so, tracking performance should decline during the pauses before difficult utterances. Question 2: Is speech production costly for both young and older adults? If so, tracking performance should decline during the production of difficult

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TOT and TE may reveal the use of different strategies in response to varying task demands. In addition, the digital pursuit rotor also permits measures of TOT and TE variability to be computed and these measures may also be informative as to the sources of group and individual differences in tracking performance.

utterances. Question 3: Is speech output costly for both young and older adults? If so, tracking performance should decline during the pauses after difficult utterances.

To answer these questions, utterance-level predictors of speech planning, production, and output were analyzed to determine how type of utterance-level measures such as utterance-type (sentence versus fragment), utterance length in words or number of propositions, and sentence grammatical complexity affected tracking performance. Person-level predictors such as speaker age group, working memory capacity, and processing speed were also analyzed to determine how the effects on rotor performance of speech planning, production, and output varied with individual characteristics, e.g., if the effects of grammatical complexity on tracking performance were attenuated for young adults. Thus, although young and older adults may use the same style of speech, costs of speech planning, production, or output monitoring may differ for older adults versus young adults or for individuals with working memory or other cognitive limitations.

Method

Participants

Table 3 summarizes information about the 80 participants from the Kemper et al. (2008) study. The young adults were recruited by signs posted on campus and class announcements while the older adults were recruited from a database of prospective and previous research participants. The participants were paid for their participation. The two groups did not differ significantly in the number of years of formal education completed. Older adults scored slightly better on the Shipley (1940) vocabulary test than the young adults. The young adults had higher scores on the Digits Forward test (Wechsler, 1958) than the older adults, as well as higher scores on the Digits Backward test. On the Daneman and Carpenter (1980) Reading Span tests, the two groups did not differ in performance. On the Digit Symbol test of processing speed, the young adults scored higher than the older adults. Young adults attained higher scores on the baseline Stroop test naming the color of blocks of XXXs than the older adults but, relative to their performance on the color word interference test, experienced less interference than the older adults.

Task

For details of the pursuit rotor task and participants' training, see Kemper et al. (2008). In brief, participants tracked a bull's-eye target that rotated around a track using a trackball mouse to control a pointer. The program sampled the location of the pointer and cross-hairs centered on the target, calculated the distance in pixels from the pointer and target center, and determined if the pointer was on the target. Participants were initially trained on the pursuit rotor task to an asymptotic level of performance as the rotor speed was gradually increased until participants were no longer able to maintain tracking accuracy at 80% or better. After the asymptotic tracking speed was established for each participant, participants were given a 4 min tracking task to establish a baseline of performance. As reported in Kemper et al. (2008), the two groups did not differ in their tracking performance during the 4 min baseline and both groups were able to maintain near 80% accuracy. During the dual task condition, participants first tracked the moving target for 1 min; then a prompt appeared, centered in the middle of the track, and participants were asked to respond orally to the prompt. Their response was recorded and the audio wave file was time-locked to the continuous record of tracking performance. All participants responded to the same question, "Please describe someone you admire or someone who has influenced your life." The participants continued to track the moving target while responding for 3 min.

Speech Analysis

Previously coded transcripts of the speech samples collected during the dual task condition were used in this analysis. These speech samples had been transcribed and analyzed following the procedures described by Kemper, Kynette, Rash, Sprott, and O'Brien (1989). The samples were segmented into utterances, and each utterance was coded as a sentence fragment or complete sentence. All lexical fillers, such as "and," "you know," "yeah," "well," etc., were tagged. The content of each utterance was determined by counting the number of words and the number of propositions (Kintsch & Keenan, 1973) in the sentence or fragment. In addition, if the segment was a sentence, the grammatical complexity of the sentence was determined using the Development Level (DLevel) metric developed by Rosenberg and Abbeduto (1987). Using the ROSS utility, two trained coders analyzed 10% of the speech samples to assess reliability; the remaining samples were analyzed by a single coder. After practice, the two coders were able to accurately tag the onset and offset of utterances: the resulting segment durations were highly correlated, $r > .99$, and average disagreement as to the onset or offset of utterances was less than $\pm$ 20 ms. Pauses between the offset of one utterance and the onset of the next were automatically determined by ROSS; agreement was $\pm$ 30 ms for the two coders.

Results

The segmented and coded dual task tracking records were analyzed to determine if there were age and individual differences in the effects of planning, producing, and monitoring speech on pursuit rotor tracking performance. Segments (utterances and pauses) were modeled as nested within participants to examine both utterance-level and person-level predictors of tracking performance. SAS PROC MIXED v. 9.2 was used for these multilevel analyses, employing restricted maximum likelihood estimation and Satterthwaite denominator degrees of freedom. A total of more than 6000 segments were analyzed. For each speech segment, 4 outcome measures were examined: mean tracking error (TE) and its standard deviation (TE SD); mean time on target (TOT) and its standard deviation (TOT SD). To reduce the influence of extreme outliers, TE means were truncated at 60 pixels and TE standard deviations were truncated at 30 pixels. TOT means and standard deviations were bounded from 0 to 100 and were left untransformed. In order to control for the influence of mean tracking performance on the variability of tracking, mean tracking performance, e.g., mean TOT or mean TE, was used a covariate in the analyses of TOT or TE SDs, respectively. The covariance across sequential utterances was first examined in unconditional models, and the best-fit model for the variances included separate variance components for the young and older adults, including a random intercept, residual variance, and autoregressive correlation among the utterance-level residuals.

We then examined main effects for each of the utterance-level predictors (as obtained from the transcripts and segmented tracking records) and person-level predictors, as well for cross-level interactions between the predictors. Because the word counts, propositional counts, and utterance durations were highly correlated, $r > .85$, a composite measure of 'content' was computed from these standardized measures to be used as a predictor. In addition, propositional density, or the number of propositions relative to the number of words in each utterance, was included as a predictor. Because few utterances contained more than 1 lexical filler, the presence or absence of 1 or more lexical fillers was used as a predictor rather than the actual number of fillers. In addition, in the analysis of current speech production (Question 2) and output monitoring (Question 3), the duration of the segment and a words-per-minute speech rate, computed as the natural log of the number of words in the segment relative to the duration of the segment, were included as an utterance-level predictors. The utterance-level predictors were not standardized within age groups so that mean differences due to age would be interpretable.

Person-level predictors included age group, verbal ability (Shipley vocabulary score), processing speed (a composite of scores on the Stroop XXX and digit symbol tests), working memory span (a composite derived from digit forward, digit backward, and reading span tests), and inhibition (the Stroop inhibition score). All person-level predictors (except for age) were within-group standardized for ease of interpretation; all were examined as main effects and as interactions with each of the utterance-level predictors.

Utterance-level and person-level predictors are reported in separate tables for each analysis; significant interactions are presented as figures.

Question 1: Is speech planning costly?

Tracking performance was evaluated during each pause in the participants' speech as a function of the characteristics of the next utterance: whether it was a sentence or fragment, its content in words and propositions, its propositional density, whether it contained 1 or more lexical fillers, and, if the next utterance was a sentence, its grammatical complexity. Table 4 reports significant estimates for the effects of propositional density and utterance content for both TE and TOT. The primary findings were that TE increases and TOT decreases if the next utterance will be propositionally dense or if the next utterance will contain many words or propositions. As shown in Table 4, the main effects of content and propositional density on TOT were negative, indicating a decline in time on target; the same main effects for TE were positive, indicating an increase in tracking error. Thus, speakers who are planning to incorporate a lot of information into their next utterance have greater concurrent difficulty with pursuit rotor tracking.

These models examining rotor outcomes during pauses for planning also included person-level predictors for age group, verbal ability, working memory, processing speed, and inhibition and their interaction with the utterance-level predictors. The results in Table 5 suggest that the costs on rotor tracking of speech planning were very similar for all speakers regardless of age or cognitive ability, as indicated by the nonsignificant main effects of the predictors. However, tracking by older speakers was somewhat less variable during pauses than tracking by younger speakers as indicated by the significant negative main effects for the effect of speaker age on TE SD and TOT SD; this suggests that the older speakers' use of a simplified speech style may have provided some protection from dual task costs.

Further, speakers with better working memory capacity were better at tracking than those with less working memory capacity as indicated by the significant positive estimate for the effect of working memory on TOT; this suggests that planning the next utterance and pursuit rotor tracking both draw on a limited working memory capacity. Further, speakers with larger vocabularies experienced more tracking error than speakers with more limited vocabularies, as indicated by the significant positive estimate for verbal ability on TE. This suggests a link between searching semantic memory and the costs of sentence planning. In addition, there was a significant positive estimate for the effect of inhibition on TE variability, indicating that those with better inhibition were less variable in their tracking performance while planning utterances.

In addition, there were 2 significant interactions between person-level and utterance-level predictors for mean TOT during pauses: working memory by propositional density, est. = 2.55, SE = 0.68, $p < .03$; speaker age by propositional density: est. = -10.59, SE = 3.37, $p < .02$. These interactions are illustrated in Figures 2 and 3; the values plotted were derived from models of TOT that included both person-level and utterance-level predictors. Figure 2 illustrates how TOT was affected by planning utterances that differed in propositional density for hypothetical individuals differing in working memory. This interaction indicates that the costs of planning dense sentences are somewhat attenuated for those with better working memory capacity. Figure 3 illustrates how TOT was affected by planning utterances that differed in propositional density for young versus older adults. The interaction suggests that the costs of planning propositionally dense utterances are attenuated for young adults.

Question 2: Is speech production costly?

Tracking performance was then evaluated during each utterance as a function of whether the utterance was a sentence or fragment, its content in words and propositions, its propositional density, whether it contained 1 or more lexical fillers, and, if the utterance was a sentence, its grammatical complexity. In addition, the duration of the utterance and speech rate were also examined. The results are summarized in Table 6.

Time on target declined with the content and propositional density of all utterances as well as with the grammatical complexity of sentences, as indicated by the significant negative main effects for content, propositional density, and sentence complexity for TOT. Concurrent tracking time on target also became more variable as utterance content, propositional density, utterance duration, and speech rate increased, as indicated by significant positive main effects for TOT SD. Tracking error also increased and became more variable with as the content and propositional density of utterances increased, as indicated by their significant positive main effects, reflecting increased costs of speech production. However, TE also became less variable, indicated by significant negative main effects for TE SD, during longer utterances and as speech rate increased, suggesting that increased fluency can partially offset production costs.

These models examining rotor outcomes during concurrent speech also included person-level predictors for age group, verbal ability, working memory, processing speed, and inhibition and their interaction with the utterance-level predictors. The results are summarized in Table 7.

Older speakers' tracking was no less accurate than young speakers' tracking overall, as indicated by the nonsignificant main effects for speaker age on TOT and TE. However, tracking by older speakers was somewhat less variable while they were talking than tracking by younger speakers, as indicated by the significant negative estimate for TE SD of speaker age, suggesting that the older speakers' use of a simplified speech style may have provided some protection from dual task costs.

Further, speakers with better working memory capacity or who were faster processors were better at maintaining TOT while they were talking, as indicated by the significant positive main effects of processing speed and working memory on TOT in Table 7; this implies that producing speech and pursuit rotor tracking both draw on a common, limited working memory, sharing both capacity and speed.

In addition, there were several significant interactions between person-level and utterance-level predictors: speaker age interacted with 3 utterance-level predictors for mean TOT, including age by content, est. = -5.67, SE = 2.53, $p < .05$; age by propositional density, est. = -16.26, SE = 7.18, $p = 0.02$; and age by sentence complexity, est. = -3.99, SE = 1.83, $p = 0.04$. These interactions are illustrated in Figures 4 – 6. The interactions indicate that the costs for time on target due to increasing utterance content, propositional density, and sentence complexity of the concurrent speech were greater for older speakers than for young adults. There were no significant interactions between other person-level and utterance-level predictors for mean TOT or TE. These null effects indicate that the costs on tracking performance of producing an utterance containing many words or propositions or a complex sentence were similar for all individuals regardless of working memory capacity, verbal ability, processing speed, or inhibition.

Question 3: Is speech output costly?

The final question was evaluated by examining tracking during pauses a function of characteristics of the prior utterance: whether it was a sentence or fragment, its content in words and propositions, its propositional density, whether it contained 1 or more lexical fillers, and, if the prior utterance was a sentence, its grammatical complexity. In addition, the duration of the prior utterance and its speech rate were also included as predictors. Consistently, across all outcomes, whether the prior utterance was a sentence or fragment, propositionally dense or not, contained 1 or more fillers or not, or was a complex or simple sentence, prior utterances did not influence tracking during the subsequent pause; these null effects are not reported. However, as reported in Table 8, tracking TOT declined and became more variable following utterances that contained many words or propositions, ones that were long, and ones produced rapidly, suggesting some ‘spill-over’ from prior utterances. Speakers apparently need to recover after producing a long, informative, or fast sentence. TE was not related to these prior utterance predictors, although greater variability in TE was marginally related to greater content, duration, and speech rate.

These models examining rotor outcomes during prior speech also included person-level predictors for age group, verbal ability, working memory, processing speed, and inhibition and their interaction with the utterance-level predictors. Again, the results were quite consistent: verbal ability, working memory, processing speed, and inhibition did not affect with tracking during pauses following utterances. These null effects are not reported. In contrast, speaker age interacted with the content, duration, and rate of the prior utterance, as summarized in Table 9. Overall, older speakers were no more likely to be off-target, but when their prior utterance was informative, long, or rapid, their tracking was more likely to be off-target and to be more variable relative to young adults, as indicated by the significant age by content, age by duration, and age by speech rate estimates for TOT and TOT SD. This again suggests that older adults experienced differential recovery costs as a result of producing a prior utterance that was informative, long, or rapid.

Discussion

The present analyses were designed to move beyond aggregate comparisons of the speech of young and older adults to examine the utterance-by-utterance variation resulting from the costs of planning and producing speech. Previous studies (Kemper et al., 2008, in press) using the aggregate measures of dual task performance showed that young adults converge on a speech style very similar to that used by older adults, one consisting of slow, short, simple sentences (see Table 1).

The central concern of this re-analysis was to more closely compare speech production costs for young versus older adults utterance by utterance, using a continuous measure of pursuit rotor tracking time-locked to the speech wave form. Utterance-level predictors, such as sentence complexity and utterance duration, as well as person-level predictors, such as speaker age and verbal ability, and their interactions were evaluated as determinates of the costs of planning, production, and monitoring speech. The analysis addressed 3 questions, as elaborated below.

Question 1: Is speech planning costly?

Yes: tracking performance declines during the pauses before utterances that will contain many words or propositions or utterances that will be propositionally dense. Speech planning is somewhat less costly for older adults, resulting in decreased variability on the concurrent tracking task, suggesting that older adult's use of a simplified speech style provides some protection from dual task costs. The costs of planning propositionally dense utterances are somewhat attenuated for those with better working memory capacity and for young adults.

Question 2: Is speech production costly?

Yes: tracking performance declines during the production of utterances containing many words or propositions, those that are propositionally dense, and sentences that are complex. The costs of speech production are greater for those with limited working memory capacity or for those who are slower at processing information. Further, the costs of producing utterances containing many words or propositions, ones that are propositionally dense, or complex sentences are exacerbated for older adults. This pattern suggests that deviating from the simplified speech style greatly increases speech production costs for older adults.

Question 3: Is speech output costly?

Yes: tracking performance declines during the pauses after utterances containing many words or propositions, long utterances, and rapid utterances. This suggests that speakers must recover during the next pause after producing a difficult utterance. Further, these output costs are exacerbated for older adults, suggesting it takes them longer to recover from producing a difficult utterance, one that deviates from the simplified speech style.

Conclusion

Speakers commonly talk while driving, walking, or doing other simple tasks yet there are consequences of doing two things at once for both tasks. Prior research, for example Kemper et al. (in press a and b) has documented the consequences of concurrent activities for the speech of young and older adults. This research shows that as concurrent activities increase in difficulty, the speech of both young and older adults not only slows down but also becomes shorter, less complex grammatically, and less cohesive and propositionally dense. At this aggregate level of analysis, young adults appear to experience greater dual task costs than older adults, since their speech in baseline conditions is faster, longer, and more complex than older adults' speech yet converges on a speech style that is similar to older adults' under demanding dual task conditions.

In contrast, the present work examined utterance-by-utterance variation in dual task performance on a pursuit rotor tracking task time-locked to speech production. These new analyses have revealed that talking has consequences for young and older adults' simultaneous performance on a simple visual/motor task, pursuit rotor tracking. These consequences reflect the concurrent demands of planning, producing, and monitoring speech. Tracking performance declines during the pauses before informative or propositionally dense utterances, reflecting speech planning; tracking performance also declines during the production of informative, dense, or grammatically complex utterances; and tracking performance declines in the pauses after a long, informative, or rapid utterance reflecting speech output recovery.

Although young and older adults use a similar, aggregate speech style when simultaneously engaged in pursuit rotor tracking, their planning and production costs differ at the level of individual sentences. While both young and older adults tend to use slow, short, simple sentence, older adults experience increased costs whenever they deviate from this style of speech to produce utterances that are informative, propositionally dense, or grammatically complex. Older adults' use of a simplified speech style is apparently an accommodation to age-related declines in working memory and processing speed and working memory and processing speed provide some protection from speech planning and production costs.

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Table 1

Similarity of Dual Task Speech of Young and Older Adults from Kemper et al. (2008); Means and Standard Deviations (SD) are Reported along with the Results of a 1-way ANOVA Comparing the Groups.

Dual Task Speech	Young Adults		Older Adults		*F*(1,78) =
	X	*SD*	*X*	*SD*	
Speech Rate	124.71	35.24	121.30	33.63	1.83
% Fragments	49.00	0.15	46.7	0.12	0.61
Fillers/Utterance	0.06	0.02	0.01	0.03	18.19**
MLU	12.03	4.01	11.41	3.45	0.55
DLevel	3.45	1.09	3.12	1.17	1.73
PDensity	5.13	0.97	5.25	0.45	0.55

**$p < .01$.

Note. Speech Rate = words-per-minute; % Fragments = percentage of sentence fragments; Fillers/Utterance = number of lexical fillers per utterance; MLU = Mean Length of Utterance in words; DLevel = Development Level measure of sentence complexity; PDensity = propositional density or number of propositions/number of words. Adapted from "The effects of aging and dual task performance on language production" by S. Kemper, R. Schmalzried, R. Herman, S. Leedahl, and D. Mohankumar, *Aging, Neuropsychology, and Cognition, 16*, 241-259.

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Table 2

Annotated Spreadsheet with the Transcript, Segments, and Tracking Performance Measures along with Word, Proposition, and Filler Counts for Utterances and the DLevel Measure of Grammatical Complexity for Sentences.

Utterance	Segment Label	Tracking Performance							Utterances			Sentences
		Starting Time	Ending Time	Duration (sec)	TE	TE SD	TOT	TOT SD	# Words	# Props	# Fillers	DLevel
I admire ProfessorX because he is a professor of political science who makes his classes very interesting.	sentence 1	82.30	96.90	14.60	18.20	3.50	51.10	42.70	16	8	0	7
	pause 1	96.90	97.40	0.50	40.00	6.00	0.00	0.00				
He is always well prepared before he gives a lecture.	sentence 2	97.40	102.80	5.40	15.30	6.50	78.20	32.30	10	4	0	6
	pause 2	102.80	103.30	0.50	14.40	2.70	100.00	0.00				
He does not need lecture notes to present the material forcefully and accurately.	sentence 3	103.30	111.50	8.20	12.10	6.50	41.70	42.90	13	6	0	7
	pause 3	111.50	112.20	0.70	16.70	3.60	74.00	39.10				
And^	fragment 1	112.20	113.10	0.90	8.70	5.50	70.30	36.40	1	0	0	

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He presents material that is interesting to him, and he conveys a sense of appreciation for the information as well as for the business of teaching students about politics and about government and about the way things work in real life.	pause 4	113.10	113.50	0.40	10.70	3.70	55.50	36.60				
	sentence 4	113.50	140.60	27.10	19.00	8.90	73.20	35.20	41	19	0	7
	pause 5	140.60	141.70	1.10	23.90	3.40	100.00	0.00				
And^	fragment 2	141.70	142.60	0.90	23.30	3.50	100.00	0.00	1	0	0	
	pause 6	142.60	142.70	0.10	26.70	0.00	100.00	0.00				
He is able to convey his sense of excitement about his subject throughout the entire class period, and I always feel that he is just getting fully warmed up when it's time for the class to be finished.	sentence 5	142.70	164.80	22.10	21.10	10.00	77.70	33.50	38	19	0	7
	Pause 7	164.80	165.80	1.00	32.10	5.80	89.20	15.20				
So he leaves his audience with a desire to, to hear more and to hear even the same material explained again from a different point of view.	sentence 6	165.80	178.60	12.80	14.50	7.70	65.60	41.40	26	15	0	7
	pause 8	178.60	179.70	1.10	12.80	5.30	100.00	0.00				
And therefore the attendance in his classes is always very close to 100 percent of the enrollment.	sentence 7	179.70	190.40	10.70	24.00	9.40	85.50	27.20	17	10	0	0
	pause 9	190.40	191.30	0.90	18.70	7.60	100.00	0.00				
And not many professors can claim that kind of loyalty from their students.	sentence 8	191.30	196.60	5.30	18.80	6.60	81.10	30.50	13.00	7.00	0.00	0

Note. TE = tracking error; TE SD = tracking error standard deviation; TOT = time on target; TOT SD = time on target standard deviation; PROPS = number of propositions; FILLERS = lexical fillers such as 'like' or 'you know"; DLevel = Development Level measure of sentence complexity.

Table 3

Participant Characteristics from Kemper et al. (2008); Means and Standard Deviations for each Age Group are Reported.

Characteristic	Young Adults		Older Adults		*p*
	X	SD	*X*	SD	
Age (n = 40)	21.8	3.2	74.3	6.0	<0.001**
Education (years)	16.2	2.6	17.0	3.0	0.173
Digit Forward Span	10.1	2.0	8.9	2.0	0 .009**
Digit Backward Span	8.5	2.4	7.2	2.1	0.009**
Digit Symbol	33.7	5.6	24.5	4.5	<0.001**
Stroop XXX	91.1	11.4	71.7	13.4	<0.001**
Stroop words	66.2	12.0	41.5	8.8	<0.001**
Stroop Inhibition	0.27	0.1	0.41	0.1	<0.001**
Reading Span	3.7	1.0	3.6	3.6	0.881
Shipley Vocabulary	31.4	3.0	34.4	3.3	<0.001**

Note. Adapted from "The effects of aging and dual task performance on language production" by S. Kemper, R. Schmalzried, R. Herman, S. Leedahl, and D. Mohankumar, *Aging, Neuropsychology, and Cognition*, *16*, 241-259.

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Table 4

Summary of Utterance-level Effects on Tracking Performance for Speech Planning by Young and Older Adults. Estimates (Est.) and Standard Errors (SE) are Reported for Tracking Error (TE) and Time on Target (TOT).

	Utterance-Level Predictors																	
Tracking	Intercept			Fragment			Content			Propositional Density			Filler(s)			Complexity (sentences)		
	Est.	SE	*p* <	Est.	SE	*p* <	Est.	SE	*p* <	Est.	SE	*p* <	Est.	SE	*p* <	Est.	SE	*p* <
TE	24.40	0.36	0.01	0.16	0.55	0.74	1.03	0.30	0.01	1.62	0.26	0.02	-0.39	0.59	0.51	0.03	0.11	0.77
TE SD	6.59	0.26	0.01	-0.08	0.27	0.77	-0.29	0.17	0.09	0.30	0.71	0.67	0.39	0.33	0.23	0.02	0.06	0.71
TOT	75.26	1.37	0.01	-1.54	1.75	0.38	-2.21	0.97	0.02	-8.76	4.00	0.03	-0.61	1.88	0.74	-0.35	0.35	0.30
TOT SD	16.23	0.86	0.01	0.89	0.85	0.29	-0.62	0.53	0.26	-0.35	2.28	0.87	1.55	1.06	0.14	0.05	0.19	0.79

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Table 5

Summary of Person-level Effects on Tracking Performance for Speech Planning by Young and Older Adults. Estimates (Est.) and Standard Errors (SE) are Reported for Tracking Error (TE) and Time on Target (TOT).

	Person-Level Predictors														
Tracking	Speaker Age			Verbal Ability			Working Memory			Processing Speed			Inhibition		
	Est.	SE	*p* <	Est.	SE	*p* <	Est.	SE	*p* <	Est.	SE	*p* <	Est.	SE	*p* <
TE	-0.25	0.67	0.71	0.65	0.31	0.04	-0.22	0.45	0.62	-0.18	0.38	0.63	0.26	0.30	0.38
TE SD	-1.27	0.38	0.01	0.00	0.19	0.98	-0.22	0.30	0.47	0.13	0.24	0.57	0.44	0.19	0.02
TOT	-1.74	2.20	0.44	0.34	1.12	0.77	4.79	1.66	0.01	-0.97	1.37	0.48	-1.09	1.10	0.32
TOT SD	-1.66	0.22	0.01	0.77	0.64	0.23	-0.08	0.96	0.94	-0.14	0.77	0.85	0.54	0.62	0.38

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Table 6

Summary of Utterance-level Effects on Tracking Performance for Speech Production by Young and Older Adults. Estimates (Est.) and Standard Errors (SE) are Reported for Tracking Error (TE) and Time on Target (TOT).

	Utterance-Level Predictors																							
Tracking	Intercept			Fragment			Content			Propositional Density			Filler(s)			Complexity (sentences)			Duration			Speech Rate		
	Est.	SE	*p* <	Est.	SE	*p* <	Est.	SE	*p* <	Est.	SE	*p* <	Est.	SE	*p* <	Est.	SE	*p* <	Est.	SE	*p* <	Est.	SE	*p* <
TE	23.16	1.09	0.01	0.37	0.37	0.31	1.75	0.86	0.04	2.70	0.39	0.04	-0.47	0.43	0.28	-0.09	0.08	0.26	3.40	2.71	0.21	1.22	1.55	0.43
TE SD	10.56	0.70	0.01	-0.23	0.23	0.31	4.12	1.18	0.01	2.29	0.90	0.01	-0.09	0.28	0.75	0.02	0.05	0.64	-4.16	1.74	0.02	-4.05	0.99	0.00
TOT	76.29	3.39	0.01	-0.51	1.11	0.64	-11.14	5.62	0.04	-4.92	0.25	0.04	-0.88	1.32	0.50	-4.17	0.24	0.04	-1.41	8.26	0.86	-1.58	4.71	0.73
TOT SD	29.89	2.10	0.01	-0.19	0.69	0.79	13.65	3.52	0.01	5.06	1.70	0.04	-0.31	0.85	0.71	-0.22	0.15	0.15	12.47	5.19	0.02	9.93	2.93	0.00

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Table 7

Summary of Person-level Effects on Tracking Performance for Speech Production by Young and Older Adults. Estimates (Est.) and Standard Errors (SE) are Reported for Tracking Error (TE) and Time on Target (TOT).

	Person-Level Predictors														
	Speaker Age			Verbal Ability			Working Memory			Processing Speed			Inhibition		
Tracking	Est.	SE	*p* <	Est.	SE	*p* <	Est.	SE	*p* <	Est.	SE	*p* <	Est.	SE	*p* <
TE	1.59	2.05	0.43	-0.03	0.96	0.97	0.49	1.28	0.70	-1.60	1.17	0.07	0.35	0.90	0.69
TE SD	-3.47	1.17	0.01	0.20	0.59	0.74	-0.09	0.79	0.91	-1.27	0.71	0.07	0.88	0.54	0.10
TOT	-2.10	6.10	0.73	0.99	2.92	0.74	5.59	3.59	0.01	5.75	1.59	0.02	-2.69	2.75	0.32
TOT SD	-7.53	2.10	0.05	1.33	1.85	0.47	-3.16	2.46	0.20	0.64	2.27	0.78	1.37	1.74	0.43

Table 8.

Summary of Utterance-level Effects on Tracking Performance for Output Monitoring by Young and Older Adults. Estimates (Est.) and Standard Errors (SE) are Reported for Tracking Error (TE) and Time on Target (TOT) .

	Utterance-Level Predictors											
Tracking	Intercept			Content			Duration			Speech Rate		
	Est.	SE	*p* <	Est.	SE	*p* <	Est.	SE	*p* <	Est.	SE	*p* <
TE	24.15	11.05	0.03	-0.17	2.47	0.94	1.17	3.68	0.75	0.36	2.10	0.86
TE SD	4.04	6.04	0.50	2.91	1.41	0.03	3.98	2.09	0.06	2.81	1.20	0.07
TOT	75.99	35.37	0.01	-17.68	7.93	0.02	-23.96	11.81	0.04	-12.12	6.72	0.05
TOT SD	17.95	19.36	0.05	13.80	4.53	0.01	19.04	6.72	0.01	13.78	3.86	0.01

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Table 9.

Summary of Utterance-Level and Person-level Interactions on Tracking Performance for Speech Planning by Young and Older Adults. Estimates and Standard Errors are Reported for Tracking Error (TE) and Time on Target (TOT) .

Tracking	Speaker Age			Interaction of Utterance-Level and Person-Level Predictors								
				Age by Content			Age by Duration			Age by Speech Rate		
	Est.	SE	*p* <	Est.	SE	*p* <	Est.	SE	*p* <	Est.	SE	*p* <
TE	1.38	2.49	0.58	3.03	3.96	0.44	-5.36	5.96	0.37	-2.39	3.56	0.50
TE SD	1.51	1.33	0.26	1.67	2.12	0.43	2.07	3.19	0.51	0.73	1.19	0.73
TOT	-3.56	8.07	0.65	-9.46	12.82	0.04	-11.05	9.31	0.05	-12.65	1.54	0.03
TOT SD	2.18	4.64	0.63	2.47	1.16	0.03	11.45	5.22	0.02	7.18	3.48	0.04

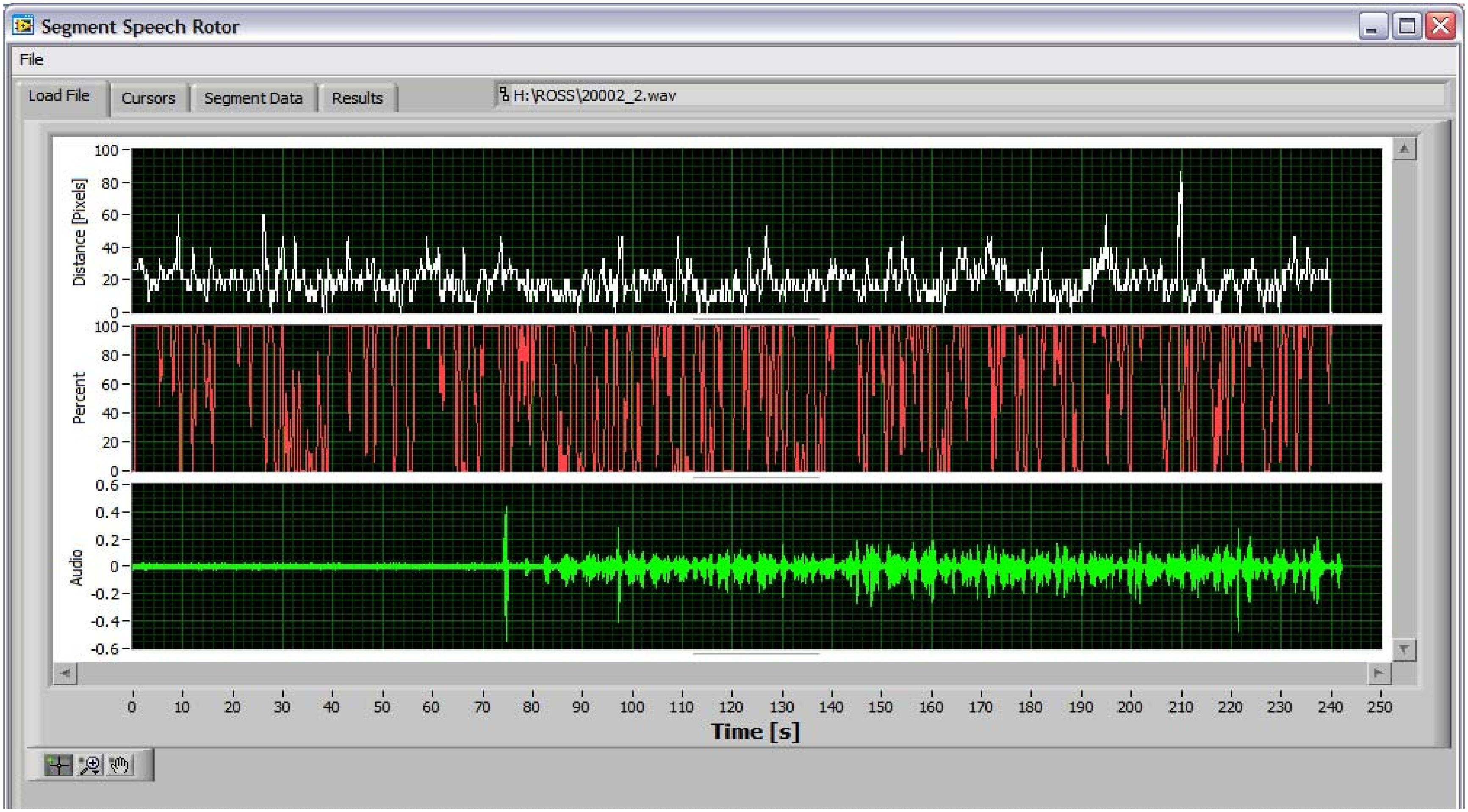

Figure 1. Continuous tracking record with tracking error (TE) or distance from the target (top panel), percent time on target (TOT) (middle panel), and the time-locked speech wave form (lower panel). The onset of speech occurs at approximately 75 s following a 60 s baseline tracking interval.

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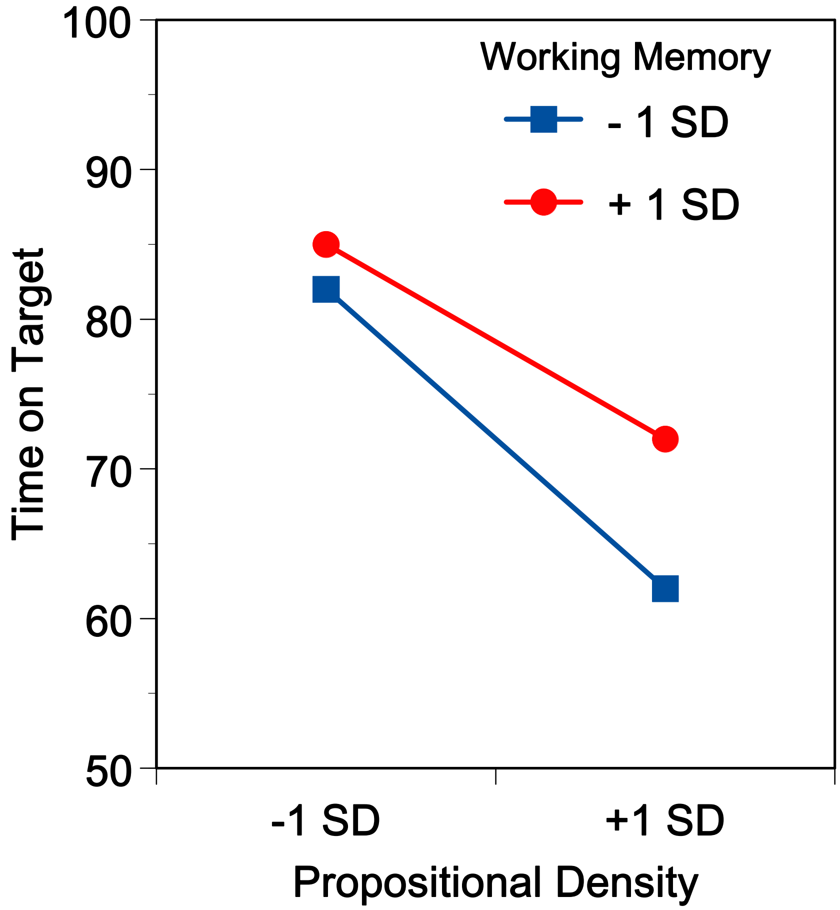

Figure 2. Effect of individual differences in working memory on time on target when planning utterances differing in propositional density (PDensity). Estimates were derived for individuals with working memory composite scores ±1 *SD* relative to the mean working memory score and for utterances ± 1 *SD* relative to the mean PDensity.

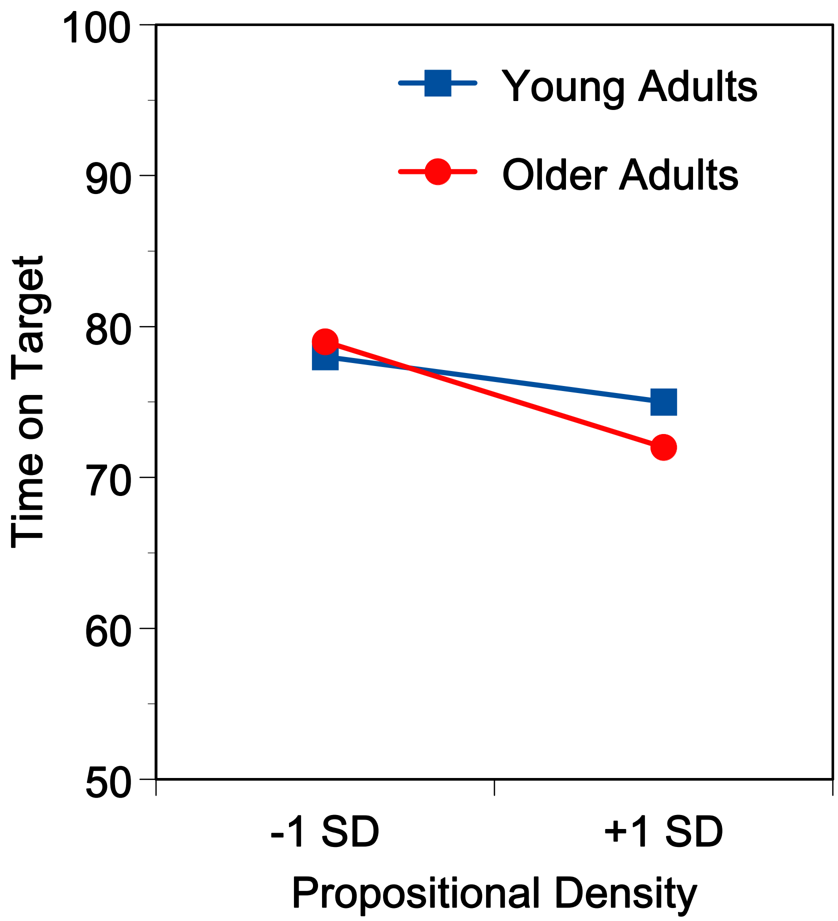

Figure 3. Effect of speaker age group on time on target when planning utterances differing in propositional density (PDensity). Estimates were derived for young versus older adults and for utterances $\pm$ 1 *SD* relative to the mean PDensity.

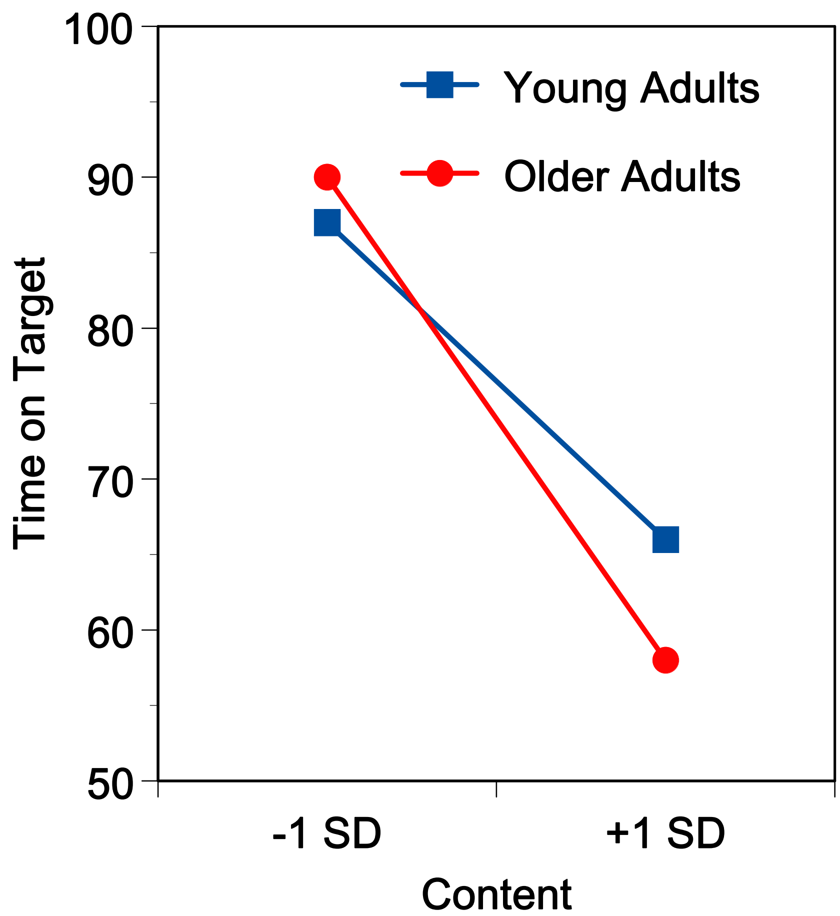

Figure 4. Effect of speaker age group on time on target when producing utterances differing in content (words, propositions, and duration). Estimates were derived for young versus older adults and for utterances ± 1 *SD* relative to the mean content score.

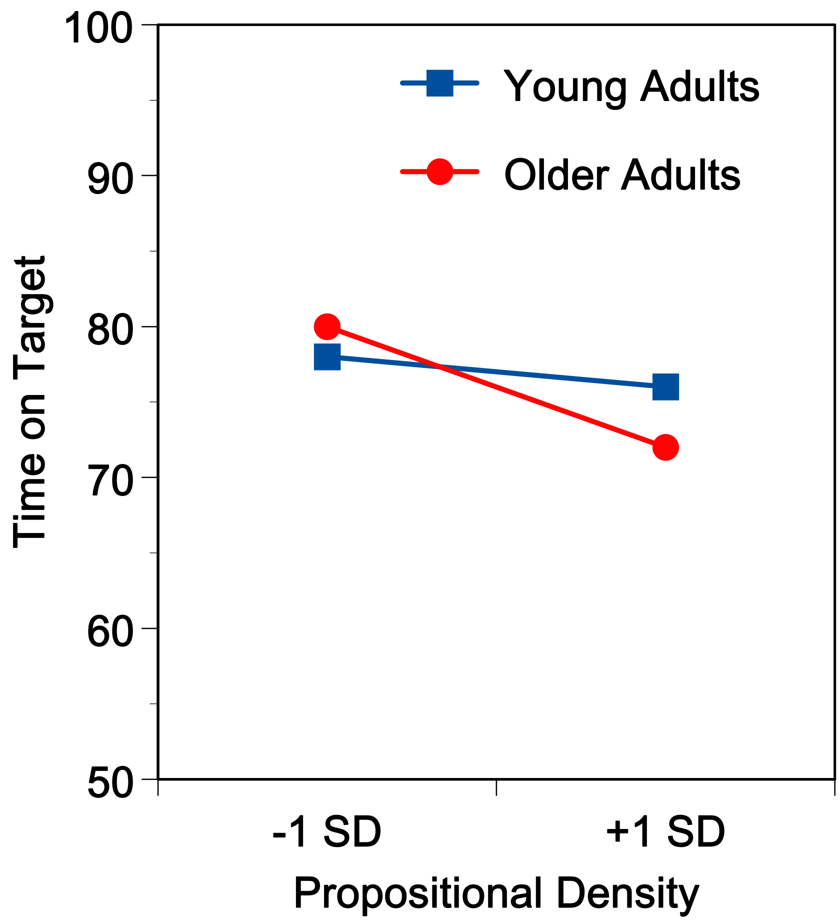

Figure 5. Effect of speaker age group on time on target when producing utterances differing in propositional density (PDensity). Estimates were derived for young versus older adults and for utterances ± 1 *SD* relative to the mean PDensity.

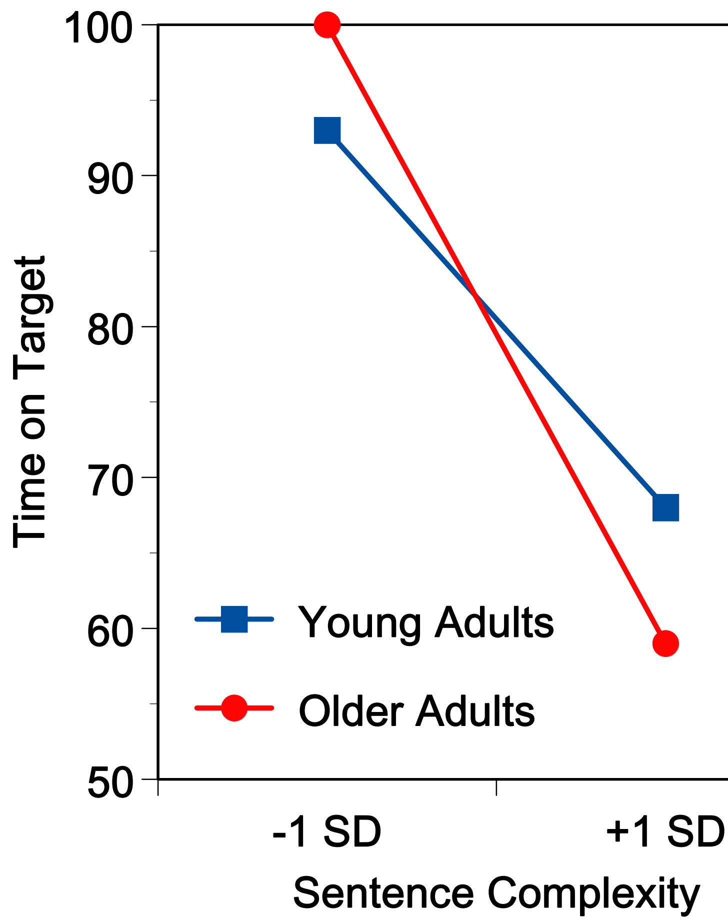

Figure 6. Effect of speaker age group on time on target when producing utterances differing in DLevel measure of sentence complexity. Estimates were derived for young versus older adults and for utterances ± 1 *SD* relative to the mean DLevel.