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Keywords: Language production, dual task demands

Abstract:

A digital pursuit rotor task was used to measure dual task costs of language production by young and older adults. After training on the pursuit rotor, participants were asked to track the moving target while providing a language sample. When simultaneously engaged, young adults experienced greater dual task costs to tracking, fluency, and grammatical complexity than older adults. Older adults were able to preserve their tracking performance by speaking more slowly. Individual differences in working memory, processing speed, and Stroop interference affected vulnerability to dual task costs. These results demonstrate the utility of using a digital pursuit rotor to study the effects of aging and dual task demands on language production and confirm prior findings that young and older adults use different strategies to accommodate to dual task demands.

Text of paper:

The Effects of Aging and Dual Task Demands on Language Production

The use of concurrent tasks to study the allocation of attention and/or working memory has a rich history in psychology and neuropsychology (Baddeley, 1986; 1996; Baddeley, Lewis, Eldridge, & Thompson, 1984; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Rosen & Engle, 1997). The study of dual task costs has become a central concern in cognitive aging research for both practical and theoretical reasons. Dual task costs may disrupt and impair the performance of older adults are watching television while responding to conversational inquiries (Tun, O'Kane, & Wingfield, 2002), driving a car while talking on the telephone (Strayer & Johnson, 2001), or ambulating round their environment in the company of others (Li, Lindenberger, Freund, & Baltes, 2001). Dual task costs have been linked theoretically to impairments of executive function (Baddeley, 1996), arising from deficits in time-sharing between the two tasks, costs of switching between tasks, failures to update task-specific cognitive representation, or a breakdown in the inhibition of automatic responses (Salthouse, Atkinson, Berish, 2003).

Previous studies have examined the "penetration" of cognitive and attentional tasks by the simultaneous performance of motor tasks such as walking or other tasks such as word memorization (Lajoie, Teasdale, Bard & Fleury, 1996; Lindenberger, Marsiske, & Baltes; 2000; Li, et al., 2001; Maylor & Wing, 1996; Maylor, Allison, & Wing, 2001; Melzer, Menjuya, & Kaplanski, 2001; Teasdale, Bard, LeRue, & Fleury, 1993; Verghese, Buschke, Viola, et al., 2002). These studies of dual task costs confirm a link between cognition and sensory-motor control of behavior (Lindenberger et al., 2000; Welford, 1958) and suggest that motor tasks such as walking become increasingly dependent upon cognitive reserve capacity in order to compensate for sensory losses, attentional lapses, slowing of response times, and other age-related deficits. The idea of cognitive reserve capacity (Kinsborne & Hiscock, 1983; Satz, 1993) is intended to capture the notion that trade-offs between cognition and task performance may be revealed only when the two tasks are performed under sufficiently challenging conditions.

Kemper and her colleagues (Kemper, Herman, & Lian 2003; Kemper, Herman, & Nartowicz, 2004) extended this approach to assess the effects of dual task demands on language production. Young and older adults were asked to provide language samples in response to probe questions while concurrently carrying out a variety of concurrent tasks including walking. In general, both young and older adults were able to meet the demands of doing two things at once. However, in contrast to the studies by Lindenberger et al. (2000) and Li et al. (2001), young adults exhibited greater dual-task costs than the older adults (see also the meta-analysis by Verhaeghen, Steitz, Sliwinski, & Cerella, 2003). Young adults exhibited a decline in grammatical complexity, sentence length, and propositional content in response to the dual task demands. In contrast, older adults spoke more slowly in all dual-task conditions compared to their single-task baseline but experienced no other dual-task disruptions of language production, suggesting that older adults' language production is buffered from dual task demands. However, a number of observations raise questions about this conclusion. Riby, Perfect, and Stollery (2004) note in their meta-analysis of dual task studies that motor tasks result in greater age-related dual task impairments than language processing tasks. However, gross motor tasks such as walking may affect breathing and speech respiration, especially for older adults, and thus, differentially affect speech rate versus other aspects of language production. Thus, the concurrent tasks used by Kemper et al. (2003, 2004) may have differentially affected young and older adults, leading different costs to language production.

In order to further investigate age-differences in the effects of dual task demands on language production, a digital version of the classic pursuit rotor tracking task (Travis, 1937; McNemar & Biel, 1939) was developed. Pursuit-rotor tracking offers two advantages over walking and other gross motor tasks; it does not interfere with breathing and speech respiration, performance on the rotor can be time-locked to a digitally-recorded language sample, both tracking and language production can be assessed using a portable device, and participants can be trained to an asymptotic level of tracking performance in a few minutes. This technique also provides a continuous record of performance so that it is possible to synchronize moment-by-moment variation in language production with moment-by-moment fluctuations in secondary task performance. In this experiment, young and older participants were trained on a digital pursuit rotor administered by a laptop computer and then their performance was compared when pursuit rotor tracking was performed concurrently with a language production task. In additional, individual differences in processing speed, working memory, and Stroop interference were assessed in order to investigate how these factors affected performance in the baseline and dual task conditions. Although processing speed was expected to be associated with baseline tracking speed, working memory was expected to be associated with baseline measures of language complexity (Kemper & Sumner, 2001). Of interest was determining how processing speed, working memory, and Stroop interference are associated with dual task costs to tracking or language production.

Method

Participants

Forty young adults (18 to 34 years old, $M = 21.8$, $SD = 3.17$) and 40 older adults (65 to 85 years old, $M = 74.3$, $SD = 6.07$) were tested. 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 $10/hour for their participation with the opportunity to earn bonuses based on performance. The older adults were also given compensation for driving to and from the testing site. Two additional young adults and three additional older adults were tested, but data from these participants was lost due to technical problems during testing.

The two groups did not differ significantly in the number of years of formal education completed ($M_{\text{Y}} = 16.2$, $SD_{\text{Y}} = 2.6$; $M_{\text{O}} = 17.1$, $SD_{\text{O}} = 3.0$), $p = .173$. Participants were given a battery of cognitive tests designed to assess individual differences in verbal ability, working memory, inhibition, and processing speed. The Shipley (1940) Vocabulary Test was used to test verbal ability. It is comprised of 40 target words, and the participants choose the best synonym from 4 choices. Older adults scored slightly better on this test ($M_{\text{O}} = 34.4$, $SD_{\text{O}} = 3.3$) than the young adults ($M_{\text{Y}} = 31.4$, $SD_{\text{Y}} = 3.0$), $p < .001$, $p_{rep} = .989$. The Digits Forward and Digits Backwards tests (Wechsler, 1958) of working memory capacity were also administered. 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 a point was given for each string the participant repeated correctly. The young adults had higher forward spans ($M_{\text{Y}} = 10.2$, $SD_{\text{Y}} = 2.0$) than the older adults ($M_{\text{O}} = 9.0$, $SD_{\text{O}} = 2.1$), $p = .009$, $p_{rep} = .935$, as well as higher backward spans ($M_{\text{Y}} = 8.6$, $SD_{\text{Y}} = 2.4$) than the older adults ($M_{\text{O}} = 7.2$, $SD_{\text{O}} = 2.1$), $p = .009$ $p_{rep} = .932$, . The Daneman and Carpenter (1980) Reading Span Test was also used to assess working memory. Participants were asked to remember the last word of each sentence in a series; the number of sentences, hence the number of words to be remembered, gradually increased. On this complex span test, the two groups did not differ in performance ($M_{\text{Y}} = 3.7$, $SD_{\text{Y}} = 1.0$; $M_{\text{O}} = 3.6$, $SD_{\text{O}} = 3.6$), $p = .881$, $p_{rep} = .571$. Scores on the three span tests were correlated, r = .65 to .75, for both young and older adults; a working memory composite score was based on a confirmatory factor analysis with a single latent working memory factor (Loehlin, 1998). Young adults had a higher composite working memory score than did older adults, $F(1, 78) = 15.548$, $p < .001$, $p_{rep} = .974$. To test processing speed, participants were given the Digit Symbol Test (Wechsler, 1958). Participants were given symbols to pair with each digit, and had 45 seconds to fill as many symbols corresponding to a series of digits. The young adults scored higher on the Digit Symbol Test ($M_{\text{Y}} = 33.7$, $SD_{\text{Y}} = 5.6$) than the older adults ($M_{\text{O}} = 24.5$, $SD_{\text{O}} = 4.5$), $p < .001$, $p_{rep} = .999$. A Stroop test was also administered to assess inhibition. Participants had 45 seconds to name the color of the ink of a series of X's and later to name the color of ink of a series of printed color words (e.g. the word RED printed in green ink). Older adults named fewer blocks of X's ($M_{\text{O}} = 71.7$, $SD_{\text{O}} = 13.4$) than the young adults ($M_{\text{Y}} = 91.1$; $SD_{\text{Y}} = 11.4$), $p < .001$, $p_{rep} = .999$. Older adults also named fewer blocks of color words than young adults ($M_{\text{O}} = 41.5$, $SD_{\text{O}} = 8.8$; $M_{\text{Y}} = 66.2$, $SD_{\text{Y}} = 12.0$), $p < .001$, $p_{rep} = .999$. An interference score was calculated using formula (1):

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

Older adults experienced more interference ($M_{\text{O}} = 41.0$, $SD = 12.75$) than young adults ($M_{\text{Y}} = 27.5$, $SD = 7.6$), $p < .001$, $p_{rep} = .999$. An alpha level of .05 was set for these and all subsequent t and F tests.

Pursuit-Rotor Tracking Program

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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 an elliptical track with a bull's-eye target that rotated along the track. Participants used either a 4" x 6" touchpad or a trackball mouse to control the cursor and track the target, displayed on a 15" high resolution flat-screen. The pursuit rotor was controlled by a separate laptop computer. All young adults used the touchpad, and many older adults used the trackball mouse, as the touchpad was not always sensitive to the touch of the older participants. Participants were given a choice of tracking devices and allowed to practice with each before training began; once a tracking device was selected, the participant continued to use the same device in baseline and all dual task conditions. A comparison of the use of these two tracking devices by the older adults indicated there were no systematic differences in tracking performance due to use of the touch pad versus track ball. A further comparison of 10 individuals who used both tracking devices also failed to reveal any systematic advantage of one device over the other with regards to tracking performance or dual-task interference with language production. However, since the choice of tracking device may have contributed to older adults' somewhat greater baseline tracking error, proportional differences scores (see formula 2) are used to examine the effects of dual task demands on tracking performance.

At the start of a trial, the participant saw a red bull's-eye target and an elliptical track. The participant positioned a pair of cross-hairs over the target using the touchpad or trackball. Positioning the cross-hairs on the target turned the target from red to green. After a 3 s delay, the target started moving along the track. As the target moved along the track, the participant 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 20 revolutions per minute; trial duration could be varied from 30 s to 4 min or longer.

The program sampled the location of the cross-hairs every 100 ms, and determined whether they were on or off the target, and if off target, how far off they were. The probability that the cross-hairs were on-target was averaged over 3 successive 100-ms intervals, and moving average of the percentage time on target score was determined. In addition, an average time on target score was computed for the duration of the trial or any segment of the trial. Tracking error, computed as the distance, in pixels, from of the target to the cross-hairs, was also averaged over 3 successive 10 ms intervals; a moving average error score was determined over successive intervals and an average error score was calculated for the duration of the trial or segment. A second version allowed the continuous tracking record to be time-locked to a digital recording of a speech sample produced by the participant. The speech wave form was synchronized with the tracking record and could be used to segment the time on target and error records.

Pursuit Rotor Training

Participants were initially trained on the pursuit rotor task to an asymptotic level of performance. Initial tracking speed was selected based on pilot testing. Initial tracking speeds for young and older adults were approximately 2 and .75 revolutions per min, respectively. Participants practiced tracking for 30 s and received feedback on their tracking performance. A " 2 up/1 down stair-case" training procedure was used to gradually increase tracking speed on successive 30-s trials: if average time on target was 80% or better for a trial, the speed was increased by 10% for the next trial; if average time on target was 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 = 23.8 trials, SD_Y = 7.0) than did older adults (M_O = 16.1 trials, SD_O = 4.3), $p < .001$, p_{rep}= .999. 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 = 3.4 rev/min, SD_Y = 0.1) was faster than the older adults' (M_O =1.5 rev/min, SD_O = 0.1), $p < .001$, p_{rep}= .999. However, relative to starting speed, after training, older adults had improved 200% whereas the young adults had improved by 170% of their starting speed.

After the asymptotic tracking speed was established for each participant, participants were given a 4 min tracking task to establish a baseline of performance. The two groups did not differ in their time on target during the 4 min baseline and both groups were able to maintain near 80% time on target (M_Y = 81%, SD_Y = 3.5; M_O = 78%, SD_O = 7.1), $p = .295$, p_{rep}= .049 . However, tracking error for young adults (M_Y = 1.6 pixels, SD_Y = 0.7) was significantly lower than that of the older adults (M_O = 3.6 pixels, SD_O = 0.6), $p < .001$, p_{rep}= .999. Therefore, when the participants were off target, older adults were off by a greater distance than young adults.

To explore how individual differences in cognitive ability affect performance on the pursuit rotor tracking, baseline time on target and tracking error scores were correlated with the cognitive measures. Shipley vocabulary scores, working memory scores, and Stroop interference scores were not correlated significantly with either tracking measure. Processing speed, measured by the Digit Symbol test, was correlated with baseline rotor tracking performance: faster individuals attained faster asymptotic tracking speeds ($r(40)$ = +.68 and +.54, for young and older adults, respectively) and were more likely to be on-target (r(40) = +.35 and +.41) , and closer to the target ($r(40)$ = -.39 and -.40, respectively) than slower individuals, all $p < .05$, $p_{rep} \geq .989$.

Dual Task Condition

During the dual-task condition, participants first started tracking the rotating target; after either 1 revolution or 1 min had passed, whichever came first, a small window appeared centered within the track and a question prompt was displayed within the window. The window did not obscure the track, cross-hairs, or target and participants were able to continue tracking while reading and responding to the prompt. Participants were instructed to read the prompt aloud and to respond to while continuously tracking the moving target. 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 participant's response. Time on target and error were calculated for only the final segment, while the participant was responding to the question.

Language Samples

A baseline language sample was collected from each participant at the beginning of the testing session. Participants then received training on pursuit rotor tracking and were tested on baseline tracking; a second language sample was collected while the participants were engaged in pursuit rotor tracking. Two questions were used to elicit language samples: "where were you and what were you doing on 9/11" and "describe someone you admire and why you admire them." Each language sample was approximately 4 min in duration and included at least 50 utterances.

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

The fluency, grammatical complexity, and content of each language sample was analyzed by trained coders. Two trained coders independently scored 10% of the language samples to establish reliability. Agreement exceeded r (40) > .90 for all measures and interclass correlations for all coders exceeded .8 for all language sample counts and measures. To verify these analyzes, 10% of the language samples were submitted to two computerized scoring systems. Measures of sentence length (MLUs) and lexical diversity using type-token ratios (TTRs) were compared to those generated by the Coh-Metrix analysis computer program (Graesser, McNamara, Louwerse, & Cai, 2004). These machine-scored measures were highly correlated with those from the trained coders, all r(24) > .97. Propositional densities were compared to those produced by another computer program, CPIDR -3 (Brown, Snodgrass, Kemper, Herman, Covington, in press), with good agreement, r(40) = .98.

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. Five measures of fluency were computed: (i & ii) The percentage of utterances with 1 or more lexical fillers was determined and the average number of fillers per utterance was also computed. Both measures of fillers are reported since the young adults, particularly in response to the baseline question, 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 (Fox Tree, 1995; Ozuru & Hirst, 2006). Although non-lexical fillers, such as "uh," "umm," "duh," etc., were excluded from the transcript as they could not be reliably segmented and transcribed (Brennan & Schober, 2001; Ferber, 1991), they did affect the calculation of speech rates. (iii) All grammatical sentences were identified and the percentage of grammatical sentences was computed for the entire language sample. (iv) Mean Length of Utterance (MLU) was obtained automatically using the Systematic Analysis of Language Transcripts (SALT) software (Chapman & Miller, 1984).; (v) A word-per-minute (WPM) speech rate was also computed by timing the duration of 3 different 45 sec segments and computing an average. With the exception of the two measures of fillers, these measures of fluency are not highly correlated, suggesting that they are differentially modifiable aspects of fluency. The two filler measures were highly correlated for young adults, r(40) = .84, but somewhat weakly correlated for older adults, r(40) = .28.

Grammatical complexity reflects syntactic operations involving the use of embedded and subordinate clauses. Two measures of grammatical complexity were obtained from each language sample: (i) Mean Clauses per Utterance (MCU) was obtained by identifying each main and embedded or subordinate clause in each utterance; (ii) Developmental Level (DLevel), an index of grammatical complexity, was scored based on a scale originally developed by Rosenberg and Abbeduto (1987). Grammatical complexity ranged from simple one-clause sentences to complex sentences with multiple forms of embedding and subordination. Each complete sentence was scored and the average DLevel for each language sample was then calculated.

Finally, the content of the language samples was assessed. Content can be measured by identifying and tallying individual propositions or by assessing lexical diversity, redundancy, and repetition. Two measures of linguistic content were obtained from each language sample: (i) Propositional Density (PDensity) was calculated according to the procedures described by Turner and Greene (1977). Each utterance was decomposed into its constituent propositions, which represent propositional ideas and the relations between them. The PDensity for each speaker was defined as the average number of propositions per 100 words. (ii) A Type-Token Ratio (TTR) was also computed for each language sample based on the ratio of the number of different words in the sample to the total number of words in the sample. TTR was automatically computed by the SALT program.

Results

The results are organized around 4 issues: the effects of concurrent language production on tracking performance, baseline comparisons of language production, the effects of concurrent pursuit rotor tracking on language production, and individual differences in language production and dual task demands. Dual task costs (DTCs) were computed for the measures of tracking performance and language production. to control for baseline differences in performance. Dual Task Costs (DTCs) were computed using formula (2). Reduced time on target in the dual task conditions compared to the baseline condition result in positive DTCs and increased tracking error in the dual task conditions compared to the baseline condition also results in positive DTCs.

$$\text{DTC} = (\text{Baseline} - \text{Dual Task})/\text{Baseline} * 100. \tag{2}$$

Tracking Performance

Concurrent language production did affect tracking performance. DTCs were computed using formula (2). Young adults experienced a decrease in time on target (DTC = +9.1, *SD* = 1.4) and an increase in tracking error (DTC = +9.6, *SD* = 6.2) while talking; older adults experienced a similar decrease in time on target (DTC = +9.3, *SD* = 1.9) and increase in tracking error (DTC = +8.5, *SD* = 6.5) while talking. Two ANOVAs with age group as a between-subjects factor indicated that DTCs for time on target and tracking error were similar for young and older adults, both $p > .50$. Thus, relative to their tracking baselines, concurrent language production was equally costly to young and older adults' tracking performance. When talking while tracking, participants were less likely to be on target and, if off-target, were off by a greater distance, than during the tracking baseline.

The measures of processing speed, working memory, and vocabulary from the cognitive battery were not correlated with dual task costs for either tracking measure all $p > .50$. Stroop interference was significantly correlated with DTCs for the time on target measure for both tasks (young adults: $r(40) = +.38$; older adults: $r(40) = +.36$), both $p < .05$, $p_{rep} \geq .980$. Stroop interference was also significantly correlated with DTCs for tracking error (young adults: $r(40) = +.58$; older adults: $r(40) = +.65$, both $p < .05$, $p_{rep} \geq .986$.

Individuals who experienced more interference on the Stroop task were less able to maintain tracking performance while simultaneously talking.

Baseline Language Sample Comparisons

Table 1 summarizes baseline language sample measures for young and older adults and the results of a series of 1-way ANOVAs comparing the two groups. Young adults used longer sentences, and spoke more rapidly than older adults and they used more complex sentences. Young adults also used more fillers than older adults, resulting in lower TTRs and lower propositional density. These results are similar to ones previously reported by Kemper et al. (2003, 2004).

Insert Table 1 here

Language Production while Tracking

Table 2 summarizes the effects of dual task demands on language production by young and older adults. Correlations between the baseline and dual task language samples are reported for each measure; in general, these measures were correlated across samples, suggesting individuals use a consistent speech style characterized by their sentence length in words, speech rate, grammatical complexity, and propositional density. Young adults' speech style also is marked by their use of fillers.

Dual Task Costs (DTCs) for each measure of fluency, grammatical complexity, and lexical and propositional content were calculated using formula (2). Table 2 indicates DTCs significantly greater than zero for both young and older adults, based on a series of *t* tests. Concurrent pursuit rotor tracking had different effects on young and older adults' language production. Both young and older adults spoke more slowly in the dual task condition than in the baseline language sample, resulting in positive DTCs for the words-per-minute speech rate measure. However, this was the only dual task effect on older adults' language whereas in the dual task condition, young adults used fewer fillers, resulting in positive DTCs, and less complex sentences, also resulting positive DTCs for DLevel and MCU. The decline in fillers also resulted in a slight gain in propositional density, resulting in a negative DTC. A series of 1-way ANOVAs were used to compare DTCs for young and older adults (see Table 4). Young adults experienced greater DTCs than older adults for both measures of fillers as well as both measures of grammatical complexity, DLevel and MCU. Young adults' DTCs for propositional density were smaller than older adults' since young adults' proposition density increased during the dual task condition, reflecting the loss of fillers. In contrast, older adults had larger DTCs for speech rate than young adults.

Insert Table 2 here

Individual Differences

Table 3 summarizes correlations between the cognitive measures of processing speed, Stroop interference, and working memory and the baseline language sample measures of fluency, grammatical complexity, and content. Correlations with the percentage of grammatical sentences, TTRs , and PDensity are not reported as these correlations were uniformly nonsignificant. With 2 exceptions, Shipley vocabulary scores were not correlated with any of the baseline language measures and are not reported; the exceptions were that young adults with higher scores on the vocabulary test used fewer utterances with fillers, $r(40) = -.39$, $p < .05$, $p_{rep} = .995$, and fewer fillers per utterance, $r(40) = -.43$, $p < .01$, $p_{rep} = .998$, in the baseline language sample. Stroop interference was not correlated with any of the baseline language production measures. The processing speed measure obtained from the Digit Symbol task was correlated with 2 baseline measures of fluency: faster individuals used longer sentences and spoke more rapidly than slower individuals. In addition, the working memory composite measure was correlated with both baseline measures of grammatical complexity: individuals with better working memories used more complex sentences containing embedded and subordinate clauses.

Insert Table 3 here

Table 3 also summaries correlations between the cognitive measures and the DTCs for the language samples collected during the dual task condition. Processing speed on the Digit Symbol task was correlated positively with DTCs for speech rate in the dual task condition, indicating that faster individuals experienced a greater disruption in speech rate when simultaneously engaged in the tracking task. As Table 3 indicates, working memory was correlated negatively with DTCs for both measures of grammatical complexity for young adults in the dual task condition. This suggests that working memory capacity partially buffered the effects of the dual task demands on grammatical complexity. Finally, for young adults, Stroop interference was correlated positively with DTCs for both measures of fillers. This pattern suggests that young adults who experienced more interference on the Stroop task also experienced a greater reduction in their use of fillers during the dual task condition.

Discussion

Combining a language production task with a visual-spatial tracking task reveals age-group similarities and differences in dual task performance. Concurrent language production affects tracking performance with similar costs for young and older adults. Time on target declined approximately 9% and tracking error increased approximately 9% for both groups when they were talking while engaged in pursuit rotor tracking. Susceptibility to Stroop interference was correlated with dual task costs to tracking for both young and older adults. Individuals who experience more task interference from the color words on the Stroop task also experienced more task interference from concurrent language production during pursuit rotor tracking.

Although the costs of concurrent language production were similar for young and older adults with regards to tracking performance, tracking had different costs to their language. Consistent with prior research (Kemper et al., 2003, 2005), younger adults experienced greater dual task costs to language than did older adults. Both groups spoke more slowly in the dual task conditions but this was the only cost to older adults' language. Tracking imposed additional costs on young adults use of fillers, long sentences, and complex sentences. Under dual task conditions, young adults shifted to a restricted speech register similar to that used by older adults in the baseline condition, using short, simple sentences with few fillers.[1]

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[1] Baseline rates for the use of fillers were markedly higher in this study compared to prior studies by Kemper et al. (1989 & 2005) that used the same "admire" elicitation question (young adults: 66% of their utterances in this study contained fillers versus 26% in the 2005 sample and 12% from the 1989 sample; older adults: 26% of their utterances in this study contained fillers versus 8% from the 2005 sample and 5% from the 1989 sample). The use of fillers reflects not only word retrieval and sentence planning but also pragmatic functions (Fox Tree & Schrock, 1999; 2002): Fillers such as "like" and "you know" serve to hedge assertions,

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Older adults' use of a restricted speech register in the baseline conditions appears to be an accommodation to age-related changes in working memory and processing speed. Working memory limitations affect the ability of older adults to plan and produce complex, multi-clause utterances and limitations on processing speed affect ideation, word retrieval, and other aspects of sentence planning and production. Kemper, Thompson, and Marquis (2001) suggested that a "functional floor" imposes minimum limits on the fluency, grammatical complexity, and propositional content of older adults' speech such that conversational speech is likely to contain more sentences than fragments and at least a few long, complex, and propositionally dense sentences. As a result of age-related changes to working memory and processing speed, older adults' speech approaches this functional floor and their speech becomes slower, shorter, and less complex than young adults. In dual task conditions, older adults are able to stay above the floor and to maintain the length, complexity, and content of their speech by slowing even further. However, young adults adopted a different strategy to balance the dual task costs of language production and pursuit rotor tracking. In addition to slowing down, young adults sacrifice length and grammatical complexity. However, by reducing length and complexity, young adults were better able to maintain speech rate, experiencing a 16% decrease in speech rate, than older adults, who experienced a 26% reduction in speech rate.

Gőthe, Oberauer, & Kliegl (2007) have suggested that older adults adopt a "conservative" approach to dual-task demands that trades reduced speed for improved accuracy whereas young adults employ a more risky approach that emphases speed over accuracy. In the present context, older adults' conservative strategy may buffer their speech from dual tasks demands whereas young adults' more risky approach may leave them vulnerable to dual-task disruptions of fluency and grammatical complexity. Of interest is determining the limits on older adults' ability to accommodate to dual task demands. It may be that older adults can adapt to a wide range of dual task demands by slowing their speech; however, at some point, slowing may be insufficient and lead to disfluent, fragmented, ungrammatical speech. Disfluent, fragmented, ungrammatical speech may be dysfunctional in that it results in delays, requests for clarifications, confusions, and other forms of communication breakdown.

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weakening illocutionary force. Thus, the young adults may use more fillers in the baseline language samples than older adults in order to appear to be unassertive and it appears that both young and older adults' speech over time may be shifting to a less assertive style, contributing to the overall increase in the use of fillers by both groups. As in prior studies, young adults in this study used significantly fewer fillers in the dual task conditions than in the baseline conditions but this decline in the use of fillers resulted in the slight increase in propositional density in the present study since fillers contribute no propositional content. For young adults, as indicated in Table 3, susceptibility to Stroop interference is associated with the effect of dual task demands on the use of fillers, consistent with the notion that fillers serve a pragmatic function, one that requires executive control. In prior studies, young adults also experienced a decline in propositional density in dual task conditions.

The present study also demonstrates that individual differences in working memory and processing speed not only affected baseline measures of tracking performance and language production but also vulnerability to dual task costs. Faster individuals, as measured by performance on the Digit Symbol test, spoke more rapidly and used longer sentences in the baseline language samples; they were also more vulnerable to dual task costs to speech rate. Individual differences in working memory contributed to the use of grammatically complex sentences in the baseline language samples by young and older adults and provided the young adults some protection from the decline in grammatical complexity during the dual task condition. And the reduction in young adults' use of fillers during the dual task condition was associated with Stroop interference, suggesting that they were unable to manage the pragmatics of "like" and "you know" due to interference from the tracking task.

In summary, language production is vulnerable to dual task demands imposed by pursuit rotor tracking: young and older adults speak more slowly when tracking a rotating target. However, young adults' faster, more complex speech is vulnerable to other dual task demands whereas older adults' slower, less complex speech provides some protection from dual task costs. Pursuit rotor tracking, unlike walking or other gross motor tasks, does not affect speech respiration yet differentially affects how young and older adults accommodate to dual task demands on language production.

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Table 1

Baseline Language Sample Measures For Young And Older Adults.

	Young Adults		Older Adults				
	M	*SD*	*M*	*SD*	*F* (1, 77)	*p*	p_{rep}
Fluency							
MLU	13.9	4.3	12.3	4.6	4.048	=.048	.926
% w/ fillers	65.8	11.4	19.8	10.1	37.829	<.001	.999
fillers/utterance	3.1	0.4	0.7	0.1	20.486	<.001	.999
% Grammatical	64.0	11.1	62.1	15.3	0.438	=.606	.669
WPM	193	47	127	35	53.305	<.001	.999
Grammatical Complexity							
MCU	2.4	0.5	1.2	0.5	51.914	<.001	.999
DLevel	3.9	1.3	3.2	1.1	4.534	=.036	.963
Content							
TTR	.51	0.1	.58	0.1	5.093	=.027	.985
PDensity	4.8	1.0	5.2	0.4	3.483	=.066	.947

Note: MLU = mean length of utterance; fillers/utterance = number of fillers per utterance; % w/fillers = percentage of sentences with fillers; % Grammatical = percentage of grammatical sentences; WPM = words per minute; MCU = mean clauses per utterance; DLevel = developmental level; TTR = type-token ratio; PDensity = propositional density.

Table 2

Dual Task Costs (DTCs) For Young And Older Adults comparing Dual Task Language Samples to Baseline Language Samples. * Mark DTCs Significantly Different From Zero. Correlations between the Baseline Language Sample Measures and those obtained from the Dual Task Sample are Reported Separately for Young and Older Adults.

	Dual Task Costs							Correlation with Baseline	
	Young Adults		Older Adults		*F* (1, 77)	*p*	p_{rep}	Young Adults	Older Adults
	M	*SD*	*M*	*SD*					
Fluency									
MLU	+10.4*	2.4	- 0.4	1.6	1.094	=.299	.645	.58**	.52**
% w/ fillers	+64.4*	8.4	+ 1.6	0.4	47.923	<.001	.999	.64**	.04
fillers/utterance	+74.1*	24.4	+ 0.6	0.3	58.476	<.001	.999	.64**	.16
% Grammatical	+0.5	0.2	+ 0.4	0.3	< 1.0	> .50	.013	.10	.09
WPM	+16.6*	12.4	+26.15*	8.1	7.819	=.007	.959	.77**	.32*
Grammatical Complexity									
MCU	+52.5*	24.1	+ 2.7	6.1	24.344	<.001	.999	.54**	.65**
DLevel	+40.3*	21.1	+ 2.1	3.2	20.486	<.001	.999	.63**	.67**
Content									
TTR	+ 1.1	2.3	+ 1.0	1.1	< 1.0	>.50	.432	.15	.17
PDensity	-10.2*	2.4	+ 3.1	4.2	6.685	=.011	.947	.56**	.68**

*$p < .05$, $p_{rep} \geq .980$; ** $p < .01$, $p_{rep} \geq .995$

Note: MLU = mean length of utterance; fillers/utterance = number of fillers per utterance; % w/fillers = percentage of sentences with fillers; % Grammatical = percentage of grammatical sentences; WPM = words per minute; MCU = mean clauses per utterance; DLevel = developmental level; TTR = type-token ratio; PDensity = propositional density.

Table 3

Correlations between the Cognitive Measures and the Baseline Measures Language Sample Measures and Dual Task Costs to Fluency, Complexity, and Content.

	Stroop Interference		Digit Symbol Speed		Working Memory Composite	
	Young Adults	Older Adults	Young Adults	Older Adults	Young Adults	Older Adults
Baseline Language Sample						
MLU	-.02	-.09	+.40**	+.39*	+.31	+.31
% w/ fillers	+.01	-.16	+.14	+.07	-.17	-.21
fillers/utterance	+.15	-.14	+.12	+.04	-.15	-.12
WPM	+.02	-.17	+.41**	+.44**	-.12	+.01
MCU	-.11	-.19	+.14	+.19	+.54**	+.37*
DLevel	-.11	-.21	+.10	+.19	+.64**	+.41*
Dual Task Costs to Language						
MLU	+.27	+.17	-.18	-.17	-.31	-.23
% w/ fillers	+.48**	+.23	+.11	+.04	-.05	+.01
fillers/utterance	+.44**	+.24	+.09	-.04	-.09	+.04
WPM	-.12	+.24	+.47**	+.54**	+.09	-.04
MCU	+.23	+.24	+.09	+.06	-.39*	-.18
DLevel	+.22	+.28	-.14	-.08	-.44**	-.17

* $p < .05$, $p_{rep} \geq .972$; ** $p < .01$, $p_{rep} \geq .995$

Note: MLU = mean length of utterance; fillers/utterance = number of fillers per utterance; % w/fillers = percentage of sentences with fillers; % Grammatical = percentage of grammatical sentences; WPM = words per minute; MCU = mean clauses per utterance; DLevel = developmental level; TTR = type-token ratio; PDensity = propositional density.