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Abstract:

The costs of doing two things were assessed for a group of healthy older adults and older adults who were tested at least six months after a stroke. A baseline language sample was compared to language samples collected while the participants were performing concurrent motor tasks or selective ignoring tasks. Whereas the healthy older adults' showed few costs due to the concurrent task demands, the language samples from the stroke survivors were disrupted by the demands of doing two things at once. The dual task measures reveal long-lasting effects of strokes that were not evident when stroke survivors were assessed using standard clinical tools.

Text of paper:

Revealing language deficits following stroke:
The cost of doing two things at once

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Revealing language deficits following stroke: The cost of doing two things at once

Advances in stroke rehabilitation have led to significant improvements in outcome for stroke survivors over the last several decades (Heinemann, Roth, Cichowski, & Betts, 1989; Ottenbacher & Jannell, 1994). Even so, recovery is rarely complete, and residual deficits may take a variety of forms. However, some of these deficits may go undetected because of the nature of post-stroke assessment. Most assessments of recovery are conducted in contextually impoverished environments where the individual is able to concentrate solely on the task at hand. However, such an environment is rarely present in real life where tasks must be performed in a variety of contexts. Thus typical assessments may underestimate the residual deficits that stroke survivors experience when they are faced with a variety of concurrent demands. The present investigation examined this possibility in the cognitive domain, focusing on expressive language during the performance of simple concurrent motor and selective ignoring tasks.

Expressive language skills are often key to successful integration into regular family, work, and community life. Stroke frequently affects these skills, making the recovery of language abilities critical to quality of life following stroke (Clarke, Marshall, Black, & Colantonio, 2002; Mackenzie & Chang, 2002). Frustration with expressive abilities can lead stroke-survivors to withdraw from social situations and limit their participation in family and community activities. Much work has been carried out on stroke-related aphasia in an effort to understand the condition and improve quality of life for individuals with aphasia. However, it is also important to understand the impact of stroke on language abilities for individuals whose deficits are not as severe. The present study was undertaken to determine if residual language deficits exist among stroke survivors who do not meet clinical criteria for aphasia. This work was conceptualized using the idea of cognitive reserve capacity (Kinsbourne & Hicks, 1978; Satz, 1993) to capture the notion that subtle deficits may be revealed only when the language task is performed under sufficiently challenging conditions.

The concept of cognitive reserve capacity reflects an individual's ability to meet difficult task demands. Although individual and group differences in reserve capacity may not be obvious when performing simple tasks, they become apparent as task demands become increasingly difficult or complex and there is less reserve available to meet those demands. In previous work, the concept of reserve capacity has proved useful for characterizing cognitive functioning in clinical conditions such as dementia (e.g. Basso & Bornstein, 2000; Schmand, Smit, Geerlings, & Lindeboom, 1997; Timiras, 1995) and HIV/AIDS (e.g. Stern, Silva, Chaisson, & Evans, 1996;). For example, Stern et al. (1996) found that neuropsychological impairments among those with HIV-1 infection were greater for individuals who had lower cognitive reserve (as indexed by factors such as years of education and premorbid intelligence). Timiras (1995) presents evidence that reduced reserve capacity lowers the threshold for experiencing cognitive deficits in aging. We have applied the same logic to stroke, using cognitive reserve capacity as a theoretical framework within which to assess language functioning.

The idea that stroke survivors may have less cognitive reserve than their healthy counterparts is consistent with Vandvoort, Kappelee, Algra, and DeHaan's (1998) neuropsychological assessment of stroke survivors. They concluded that stroke "patients have to invest more effort to reach the same level of performance as controls. This is not a problem on low demand tasks but as soon as the task or the context becomes more strenuous, performance decreases" (p. 700-701). For the notion of cognitive reserve to be useful in the present context, we must demonstrate that although stroke survivors may appear to be "recovered" when performing simple tasks, they are not able to meet the demands of more

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complex tasks. Toward this end we used a series of secondary tasks that were each performed individually, and then in conjunction with an expressive language task. Cognitive reserve capacity is commonly assessed by measuring dual task costs, the costs of performing two tasks in combination relative to the performance of each task independently.

Healthy older adults have been shown to have reduced cognitive reserve using simple walking and balance tasks in conjunction with memory tasks. Lindenberger, Marsiske, & Baltes (2000) and Li, Lindenberger, Freund, & Baltes (2001) compared young and older adults' balance and gait as they memorized lists of words. Dual task costs, measured in terms of memory accuracy, walking rate, and walking accuracy, increased with age. Li et al. extended this paradigm to investigate the use of compensatory walking or memory aids. Participants could grasp a handrail to assist with balance or use a control box to slow the presentation of to-be-remembered words. Under dual task conditions, they found that older adults prioritized walking at the expense of memory performance and utilized the handrail to compensate for walking difficulties. When the walking task was made difficult by the presence of obstacles in the path, young adults could accommodate the additional demand with little effect on their memory performance. Older adults, however, could not accommodate the additional demand without a significant decline in memory performance, suggesting reduced reserve capacity among the older adults.

Postural stability, like walking, is also affected by cognitive reserve capacity (Brown, Shumway Cook, & Woollacott, 1999; Shumway Cook, Woollacott, Kerns, & Baldwin, 1997). Maylor and Wing (1996) examined dual task costs to postural stability while participants performed a number of different cognitive tasks. Dual-task costs were significantly greater for the older adults when they were performing visuo-spatial tasks, such as remembering the location of digits assigned to a 4 – by - 4 grid, than non-spatial tasks, such as random number generation. Using closely matched spatial and nonspatial tasks, Maylor, Allison, & Wing (2001) replicated these results, showing that the older adults experienced greater costs due to the spatial tasks and have less reserve capacity to meet the dual task demands .

These studies of dual tasks costs confirm a linkage between cognition and sensory-motor control of behavior (Lindenberger et al., 2000; Lundin-Olsson, Nyberg, & Gustafson, 1998; Nutt, Marsden, & Thompson, 1993; Welford, 1958) and suggest simple tasks such as walking and maintaining balance become increasingly dependent on cognitive reserve capacity in order to compensate for sensory losses, attentional lapses, slowing of response times, and other age-related deficits. As cognitive reserve capacity declines, dual task costs increase. Kemper, Herman, and Lian (2003) have extended the argument to assess the effects of simple motor and selective ignoring tasks on expressive language. The effects of three motor tasks were compared: simple finger tapping, complex finger tapping, and walking. Two selective ignoring tasks were also compared: ignoring concurrent noise and ignoring concurrent speech. Surprisingly, Kemper et al. report that young adults exhibited *greater* dual tasks costs than the older adults. Analyses of young adults language sample revealed reduced sentence length, grammatical complexity, and propositional content when talking while performing the motor tasks or concurrent selective ignoring tasks. In contrast, the older adults spoke more slowly during the dual task conditions but their grammatical complexity and propositional content did not vary with dual task demands. In addition, the expressive language of older adults was less grammatically complex and less propositionally dense even under baseline, single-task conditions. Based on these findings, Kemper et al. hypothesized that older adults, in response to age-related loss of processing speed and working memory capacity, have developed a simplified speech register that is buffered from many dual task costs associated with simple motor and concurrent selective ignoring tasks. Whereas young adults' faster, more complex speech is affected by simultaneously performing simple motor and selective ignoring tasks, older adults are able to combine these tasks by speaking more slowly without suffering further declines in grammatical complexity or propositional density. The question under investigation in the present study is whether an additional decline in reserve capacity following stroke will produce deficits in expressive language function among stroke survivors relative to healthy older adults.

In the present series of experiments, we employed the same tasks and methods as reported in Kemper et al. (2003). Healthy older adults and stroke survivors were asked to provide expressive language samples in response to elicitation questions (e.g., what was the most important invention of the 20th century?) while concurrently carrying out a variety of different tasks. The language samples were scored on a several dimensions including measures of fluency, grammatical complexity, and propositional content. Fluency, grammatical complexity, and propositional content were hypothesized to vary with concurrent task demands, reflecting dual task costs involved in selecting, coordinating, sequencing, and executing the complex demands of conversational speech while performing the concurrent tasks. Two types of concurrent tasks were used. In the first series, three motor tasks were compared: simple finger tapping, complex finger tapping, and walking. In the second series of tasks, the participants attempted to ignore concurrent noise or concurrent speech. Two groups of closely matched participants were compared, healthy older adults with no history of stroke or other debilitating medical condition, and older adults who had experienced a stroke at least 6 months prior to their participation in the study. The stroke survivors were considered to be functionally recovered, using standard clinical assessments.

Our hypothesis was as follows: if a stroke reduces cognitive reserve capacity, then as secondary task complexity increases, language deficits affecting fluency, grammatical complexity, and propositional content will begin to appear relative to the matched group of healthy older adults. Data supporting our hypothesis would indicate that cognitive reserve capacity following stroke should be examined more closely, more sensitive measures of function should be developed, and interventions pursued for ameliorating deficits that may only be apparent when performance is particularly demanding.

Method

Participants

Ten older adults who had experienced a stroke (*M* = 77.2 years, *SD* = 5.8) were tested. The stroke survivors were recruited from the University of Kansas Medical Center registry of stroke survivors. The stroke survivors had experienced a stroke 24 to 36 months prior to testing. Three had right hemisphere infarcts, 5 left hemisphere, and 2 bilateral, based on medical examination and neurological scanning. The participants were paid a modest honorarium; this honorarium also included compensation for their travel to campus to participate in this research. Each stroke survivor was matched to a participant (*M* = 76.3 years, *SD* = 5.4) from the Kemper, Herman, & Lian (in press) study on the basis of gender, age (+/- 2 years), educational level (+/- 1 year), and performance on the Short Portable Mental Status Questionnaire (+/- 1 point) (Pfeiffer, 1975). All participants were living at home alone or with family.

Screening

All participants were screened for hearing acuity and those who had experienced clinically significant hearing loss were excluded from participation in this study. A hearing loss was defined as (i) a

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threshold greater than 40 dB at 250, 500, 1000, or 2000 using pure tone audiometry or (ii) self-report of 6 or more problems on the Hearing Handicap Inventory (Ventry & Weinstein, 1982).

> The healthy participants were also screened for a variety of health conditions that might limit their performance on the walking and finger tapping tests. These exclusionary conditions included: failing 4 or more questions on the Short Portable Cognitive Status Questionnaire (Pfeiffer, 1975), any health condition that interfered "a great deal" with daily activities such as arthritis, high blood pressure, heart trouble, or diabetes; self-report of a history of stroke, polio, cerebral palsy, emphysema, or other disabling condition; or a history of taking any medication for angina, pain, seizure, vertigo, or any neurological or psychotropic medication.

The stroke survivors were screened for functional recovery and for aphasia. Those scoring below 90 on the Barthel Index (Collin, Wade, Davies, & Horne, 1988; Mahoney & Barthel, 1965) of motor impairment during self-care activities, e.g., dressing, bathing, were excluded from participation. In addition, they were given the Fugl-Meyer Assessment (Duncan, Propst, & Nelson, 1983; Fugl-Meyer, 1980) which assess motor recovery, balance, sensation, range of motion, and pain, the Duke Mobility Scale (Hogue, Studenski, Duncan, 1990) which assesses ability to, e.g., retrieve objects from the floor, stop abruptly, or navigate steps, and the Berg Balance Scale (Berg, Wood-Dauphinee, & Williams, 1995; Berg, Wood-Dauphinee, Williams, & Maki, 1992) which evaluates balance in sitting and standing. The stroke survivors were required to score within normal limits on these tests in order to participate in this experiment. Hence, all participants were considered to be functionally recovered from the stroke. The stroke survivors also were given the Reading, Writing, Fluency, Personal Information, Naming, and Auditory Comprehension tests from Aphasia Diagnostic Profiles (Helm-Estabrooks, 1992); all scored within normal limits on these tests. Thus, none of the stroke survivors evidenced any sign of aphasia or other expressive language impairment. The healthy older adults were not given the functional and aphasia screening tests.

All participants were given a battery of cognitive tests designed to assess individual and age-group differences in verbal ability, working memory, inhibition, and processing speed. These tests included the Shipley (1940) Vocabulary Test, the Digits Forward, Digits Backwards, and Digit Symbol tests from the Wechsler Adult Intelligence Scales-Revised (Wechsler, 1958), and a Stroop test. The Stroop test required participants to name the color of blocks of X's printed in colored inks or to name the color of color words printed in contrasting colored inks, e.g., RED printed in blue ink; participant were given 45 s to complete the tasks; the participant's score is the number of colors correctly named in 45 s. The stroke survivors and healthy older adults did not differ on any of these tests with one exception; see Table 1. The stroke survivors had higher pure tone hearing thresholds than their healthy counterparts although the two groups did not differ in self-reported hearing problems on the Hearing Handicap Inventory. An alpha level of .05 was set for these and all subsequent *t* and *F* tests.

Insert Table 1 here

Tasks

Each participant completed nine tasks: talking alone, talking while ignoring concurrent speech and talking while ignoring concurrent noise, walking alone and walking while talking, simple finger tapping alone and while talking, complex finger tapping alone and while talking. All tasks were administered in a fixed order and interspersed with the cognitive tests. Following cognitive, health, and hearing screening, the participants were given the digit span tests and a baseline language sample was collected. The talking while ignoring concurrent noise task was next administered, followed by the

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vocabulary test and the baseline complex finger tapping and baseline walking tasks. Following a break, participants were given the Stroop baseline color naming task and the talking while ignoring noise task. Simple tapping while talking, the Digit Symbol, and Stroop color word naming tasks were administered followed by the reading span test and the complex tapping while talking and walking while talking tasks. The entire testing session lasted approximately 2 hours.

The Noldus Video Observer (Noldus, 1997) system was used to analyze all walking and tapping tasks. Participants were digitally video- and audio-recorded as they performed these tasks. The Noldus system enables the researcher to play back these recordings while inserting behavioral codes to mark critical behavioral events such as each foot step or tap of a finger. These codes are automatically time-locked to the recording. A hierarchical system of codes can be used so that critical events may be nested within larger behavioral segments. The Noldus system then computes rates, intervals, and durations for coded events based on the time-locked codes. Multiple coders can analyze each recording to establish reliability and reliability can be defined with ms accuracy if desired.

Ignoring Concurrent Speech or Noise. Two listening conditions were used: ignoring concurrent speech and ignoring cafeteria noise. In the ignoring concurrent speech condition, the participants listened through headphones with binaural presentation to a speaker of the same sex as the participant. In the ignoring noise condition, the participants listened to binaural presentation of a recording made in a public cafeteria. The AUDiTEC (AUDiTEC, 1998) recordings of concurrent speech or cafeteria noise were used. The presentation was first adjusted to a comfortable listening level between 40 dB – 60 dB and the same dB level was used for both concurrent speech and concurrent noise conditions. Individual levels were set approximately 20 dB louder than the participant's pure tone hearing threshold. The participants first listened to 30 s of speech or noise and then they were then shown a prompt card with an elicitation question and asked to begin to respond orally.

Walking. Participants were asked to walk at a "brisk but comfortable" pace around an irregular elliptical pathway, approximately 18 ft in diameter and 2 feet wide for 3 to 5 min. The participants were permitted to walk clockwise or counter-clockwise, as preferred. During the concurrent walking and talking segment, the participants were handed a prompt card with the elicitation question and asked to complete 1 "lap" or about 30 s of walking before beginning to respond orally.

> The walking or walking + talking segments were coded using the Noldus system and then analyzed to determine the average walking rate, in steps per s, starting 30 s after the participant began walking. Stumbles, mis-steps, and footsteps outside of or inside of the boundaries of the path were coded separately. The walking "errors" were of extremely low frequency and were not analyzed further. During the concurrent walking + talking task, codes were inserted to mark the onset of speech and all discernable speech interruptions or pauses; additional codes marked the onset of walking and all pauses or interruptions of walking. Speech interruptions and pauses while walking were rare and were not analyzed further. The percentage of time each participant was actually walking or walking while talking simultaneously was computed as a measure of "time-on-task."

Finger Tapping. Two tapping tasks were used. Simple tapping required participants to tap "as rapidly as possible" with the index finger of the preferred hand for 5 min. Complex tapping required the participants to tap "as rapidly as possible" a four-finger sequence (if the fingers are numbered beginning with the index finger, the sequence is 1-3-2-4) for 3 to 5 min. During the concurrent tapping + talking tasks, participants were asked to tap for 30 s; then they were shown a prompt card with an elicitation

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question and asked to respond orally.

The participants were video- and audio-recorded while tapping and the Noldus system was used to compute tapping rates and time – on – task. Simple tapping was analyzed to determine taps per min; all pauses or interruptions were also coded. Complex tapping was analyzed to determine complete 4-tap sequences per min. Sequencing errors and pauses or interruptions were also coded. During the concurrent simple tapping + talking or complex tapping + talking tasks, codes were also inserted to mark the onset of speech and any speech pauses or interruptions; time-on-task was computed as the percentage of time the participants were simultaneously tapping accurately while talking. Speech interruptions and errors or pauses while tapping were rare and were not analyzed further. Two coders independently coded video recordings from 10 young and 10 older participants; they agreed at better than 90% accuracy on all rate measures.

Language Sample Elicitation. A baseline language sample was collected from each participant at the beginning of the testing session and additional language samples were collected while the participants were performing each of the five concurrent tasks. Each language sample was approximately 3-5 min duration and included at least 50 utterances. Language samples were elicited using a variety of questions requiring participants to describe people or events that have influenced their lives, recent vacations, significant inventions of the 20th Century, individuals they admire, and so forth. Six different elicitation questions were counter-balanced across conditions. Each elicitation question was printed on a card which was shown to the participant. During concurrent tasks, participants were first instructed to initiate the concurrent activity (walking, simple or complex tapping, ignoring concurrent speech or noise) and after a 30-s start-up interval, the participant was shown the elicitation question and asked to respond without interrupting the concurrent activity. Participants were instructed that they were to respond to the elicitation question without disrupting their performance on the current task. When a participant first paused or stopped responding, a standard prompt such as "can you tell me more about….?" or ""would you like to add anything?" was used to ensure that an adequate language sample of at least 50 utterances was obtained from each participant in each condition.

The samples were analyzed following the procedures described by Kemper, Kynette, Rash, Sprott, and O'Brien (1989). The samples were transcribed and coded by first segmenting each into utterances and then coding each utterance. Utterances were defined by discernable pauses in the participant's flow of speech; therefore, 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. Although typically considered to be disfluencies or speech errors, fillers may serve pragmatic and discourse functions. Non-lexical fillers, such as "uh," "umm," "duh," etc., were excluded from the transcript as they are not reliably segmented and transcribed. 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.

Three dimensions of language were then assessed: fluency, grammatical complexity, and propositional density. Fluency is commonly assumed to involve both 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; fluency is commonly assessed by examining utterance length and grammaticality, speech rate, and the occurrence of fillers. Four measures of fluency were computed: (i) Mean Length of Utterance (MLU) was obtained automatically using the Systematic Analysis of Language Transcripts (SALT) software (Chapman & Miller, 1984). (ii) A word-per-minute (WPM) speech rate was also computed by timing the duration of 10 different segments of 5 to 10 words and computing an average. (iii) All grammatical sentences were identified and the percentage of utterances that were grammatical sentences was computed for the entire language sample. (iv) The percentage of utterances without lexical fillers was determined. These measures of fluency are not highly correlated (Cheung & Kemper, 1992), suggesting that they are differentially modifiable aspects of fluency.

Grammatical complexity reflects the 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 (D-Level), an index of grammatical complexity, was scored on a scale originally developed by Rosenberg and Abbeduto (1987). Grammatical complexity ranges from simple one-clause sentences to complex sentences with multiple forms of embedding and subordination. Each complete sentence was scored and the average D-Level for each language sample was then calculated. MCU treats all forms of embedding and subordination alike. D-Level assumes a left-to-right processing model of language production such that embedded constructions that occur in the subject, such as relative clauses modifying the subject, impose more processing demands than those occurring in the predicate. Consequently, subject embeddings are worth more points than predicate embeddings. Both measures of grammatical complexity are highly correlated and both correlate highly with measures of working memory span (Kemper & Sumner, 2001).

Finally, the content of the language samples was assessed. Content can be measured by identifying and tallying individual idea units or by assessing lexical redundancy and repetition. Two measures of propositional content were obtained from each language sample: (i) Propositional Density (P-Density) was calculated according to the procedures described by Turner and Greene (1977). Each utterance was decomposed into its constituent propositions, which represent propositional elements and relations between them. The P-Density 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. P-Density can be considered a measure of processing efficiency whereas TTRs may reflect working memory limitations affecting lexical repetition (Kemper & Sumner, 2001).

Two trained coders independently scored 10% of the language samples to establish reliability. Agreement exceeded r (15) > .90 for all measures.

Results

The initial analyses compared walking rates, simple and complex finger tapping rates, and percentage of time – on – task in the baseline and dual task conditions for the two groups using ANOVA. The second series of analyses compared baseline performance of the two groups on the language sample measures of fluency, grammatical complexity, and content. The final series of comparisons computed dual task costs (DTC) for the language sample measures following Lindenberger et al. (2001) and used MANOVAs to compare DTCs for the two groups for the language sample measures of fluency, grammatical complexity, and content.

Walking and Finger Tapping

Figure 1 compares baseline and dual task walking, simple tapping, and complex tapping rates. Walking and tapping rates were analyzed with Group x Condition (baseline versus dual task) ANOVAs. The two groups had equivalent walking rates and walking rates for the dual task condition were equivalent to those for the baseline condition for both groups, all $F(1, 18) \le 2.28$, $p \ge .148$.

In order to investigate the possibility of fatigue effects, a secondary analysis examined walking rates for the participants, comparing rates for the first 45 s of walking to the last 45 s of walking. Whereas walking and walking while talking rates for healthy older adults were unchanged, both $t(9) < 1.0$, walking rates for stroke survivors declined by 60% from the first to last 45 s interval, $t(9) = 115.728$, $p = .000$, and those for walking while talking declined by 65%, $t(9) = 13.347$, $p = .000$. Simple tapping rates were slower for the stroke survivors, $F(1,18) =7.150$, $p = .015$, $\eta^2 = .284$. The condition main effect was not significant, $F(1,18) < 1.0$, $p = .496$, $\eta^2 = .026$, although the Group x Condition interaction was significant for simple tapping rates, $F(1,18) = 5.754$, $p = .028$, $\eta^2 = .242$. Whereas the dual task condition did not affect simple tapping rates for the healthy older adults, simple tapping rates for the stroke survivors were slower in the dual task condition than in the baseline.

A secondary analysis examined simple tapping rates for the participants, comparing rates for the first 45 s of tapping to the last 45 s of tapping. Whereas simple tapping and simple tapping while talking rates for healthy older adults were unchanged, both $t(9) < 1.0$, simple tapping rates for stroke survivors declined by 25% from the first to last 45 s interval, $t(9) = 17.972$, $p = .000$, and those for simple tapping while talking declined by 65%, $t(9) = 7.527$, $p = .000$. Complex tapping rates for the two groups did not differ, $F(1,18) = 3.814$, $p = .067$, $\eta^2 = .974$. The condition main effect was significant, $F(1,18) = 10.423$, $p = .005$, $\eta^2 = .367$, indicating that complex tapping by both groups was slower in the dual task condition than in the baseline. The Group x Condition interaction was not significant, $F(1,18) = 1.642$, $p = .216$, $\eta^2 = .084$, indicating that the dual task condition affected healthy older adults and stroke survivors equally.

A secondary analysis examined complex tapping rates for the participants, comparing rates for the first 45 s of tapping to the last 45 s of tapping. Complex tapping and complex tapping while talking rates for healthy older adults were unchanged, both $t(9) < 1.0$, complex tapping rates for stroke survivors showed a 45% decline from the first to last 45 s interval, $t(9) = 15.821$, $p = .000$, and complex tapping while talking showed a 50% decline, $t(9) = 12.539$, $p = .000$.

Time-on-Task. Figure 2 compares baseline and dual task walking, simple tapping, and complex tapping for the percentage of time – on- task. For the baseline conditions, this measure is the percentage of time the participants actually engaged in the tapping or walking task. For the dual task conditions, this measure reflects the percentage of time spent actually engaged in both behaviors. Time - on - task was analyzed with a Group x Task x Condition (baseline versus dual task) ANOVA. All main effects and two-way interactions were significant as was the three-way interaction of group, task, and condition, $F(2, 17) = 23.716$, $p = .000$, $\eta^2 = .754$. Time - on - task did not vary for healthy older adults with task or condition, all $p > .50$. Further, the two groups had equivalent time - on - task rates, all $p > .20$, in all three baseline conditions. Stroke survivors had a significant reduction in time - on - task for all three tasks in the dual task conditions compared to the baseline conditions: simple tapping: $t(9) = 3.476$, $p = .007$, complex tapping: $t(9) = 6.280$, $p = .000$, walking: $t(9) = 14.529$, $p = .000$.

A secondary analysis examined time-on-task rates for both groups of participants by comparing rates for the first 45 s of the task to the last 45 s of the task. Time-on-task rates were unchanged across the 3 min interval for both groups of participants, both $t(9) < 1.0$.

Baseline Language Sample Measures

Table 2 presents baselines fluency, grammatical complexity, and language sample measures for the two groups. Three multivariate ANOVAs were conducted to compare the groups. The corresponding univariate *t*-tests are also reported in Table 2. The MANOVAs for fluency, $F(2,17) < 1.0$, $p = .574$, $\eta^2 = .166$, and grammatical complexity, $F(2,17) =1.439$, $p = .265$, $\eta^2 = .145$, were nonsignificant, indicating similar baseline levels for the healthy older adults and the stroke survivors. The MANOVA for content was significant, $F(2,17) =15.662$, $p = .00$, $\eta^2 = .648$, indicating that baseline content measures, PDensity and TTR, were higher for the healthy older adults than for the stroke survivors.

Dual Task Costs

Dual task costs for each language sample measure were first computed as a percentage of the baseline for the two selective ignoring tasks (ignoring noise and speech) and for the three motor tasks (simple tapping, complex tapping, and walking). These dual task costs for the fluency, grammatical complexity, and content measures were submitted to a 2-way multivariate analysis of variance to determine if there were age group differences in dual task costs. Figures 3 – 8 summarize the results; they are organized by task and measure. Asterisks (*) mark DTCs that are significantly different from zero.

Selective ignoring Tasks. Dual task costs for the selective ignoring tasks were computed by first averaging the language sample scores for the talking + ignoring noise and talking + ignoring speech conditions:

$$\mathrm{DTC}_{\mathrm{attention}} = (\mathrm{Condition} - \mathrm{Baseline}) / \mathrm{Baseline} * 100. \qquad (1)$$

Fluency: MLU, the percentage of grammatical sentences, the percentage of sentences without fillers, and WPM were considered to be measures of fluency. Note that an increase in the use of fillers relative to the baseline level produces a negative "cost." The multivariate effect for group was significant, $F(4, 15) = 29.480$, $p = .000$, $\eta^2 = .887$. The multivariate effect for task, $F(4,15) = 1.785$, $p = .184$, $\eta^2 = .323$, and the Group x Task interaction, $F(4,15) = 1.636$, $p = .217$, $\eta^2 = .304$, were both nonsignificant. DTCs for the stroke survivors exceeded those for the healthy older adults for both ignoring noise and ignoring speech. See Figure 3.

Grammatical Complexity: D-Level and MCU were considered to be measures of grammatical complexity. The multivariate effect for group was significant, $F(2,17) = 26.200$, $p = 000$, $\eta^2 = .755$. The multivariate effect for task, $F(2,17)$ 2.094, $p = .154$, $\eta^2 = .198$, and the Group x Task interaction, $F(2,17) = 1.99$, $p = .167$, $\eta^2 = .190$ were not significant. DTCs for the stroke survivors were greater than those for the healthy older adults and did not vary for the two selective ignoring tasks. See Figure 4.

Content: TTR and P-Density were considered to be measures of the content of the language samples. The multivariate effect for group was significant, F2,17) = 23.427, p_= .000, $\eta^2 = .734$. In addition, the multivariate effect for task, $F(2, 17) =14.064$, $p = .000$, $\eta^2 = .623$, and the Group x Task multivariate interaction, $F(2,17) = 10.090$, $p = .001$, $\eta^2 = .543$, were significant. DTCs for stroke survivors exceeded those for healthy older adults, DTCs for ignoring speech were greater than those for ignoring noise, and this difference was greater for stroke survivors than for healthy older adults. See Figure 5.

Motor Tasks. For each of the three tasks, talking + simple tapping, talking + complex tapping, and talking + walking, the percentage of decline for each language sample measure relative to that obtained in the baseline language sample was computed according to the formula:

$$\text{DTC}_{\text{motor tasks}} = (\text{Task} - \text{Baseline}) / \text{Baseline} * 100. \qquad (2)$$

Fluency: The multivariate effect for group was significant, $F(4, 15) = 38.264$, $p = .000$, $\eta^2 = .911$. The multivariate effect for task was not significant, $F(8,11) = 1.183$, $p = .462$, $\eta^2 = .315$, nor was the Group x Task interaction, $F(8,11) = 1.166$, $p = .459$, $\eta^2 = .311$. Stroke survivors experienced greater costs due to the dual task demands for all three motor tasks and this group difference did not vary across tasks. See Figure 6.

Grammatical Complexity: The multivariate effect for group was significant, $F(2,17) = 28.533$, $p = .000$, $\eta^2 = .770$. Neither the multivariate effect for task, $F(4,15) < 1.0$, $p = .475$, $\eta^2 = .198$, nor the Group x Task multivariate interaction, $F(4, 15) < 1.0$, $p = .450$, $\eta^2 = .107$, were significant. DTCs for stroke survivors were larger than those for healthy older adults on all three motor tasks, simple tapping, complex tapping, and walking. See Figure 7.

Content: The multivariate effect for group was significant, $F(2,17) = 101.697$, $p = .000$, $\eta^2 = .923$. Neither the multivariate effect for task, $F(4,15) = 1.199$, $p = .352$, $\eta^2 = .242$ or the Group x Task multivariate interaction, $F(4, 15) = 1.471$ $p = .260$, $\eta^2 = .282$, were significant. DTCs for stroke survivors exceeded those for healthy older adults for the three motor tasks, walking, simple tapping, and complex tapping. See Figure 8.

Discussion

Doing two things at once poses considerable challenge to post-stroke survivors. Unlike healthy older adults, these individuals experienced considerable difficulty speaking while performing selective ignoring tasks or simple motor tasks. Their difficulties were apparent in two regards: first, they were unable to perform simultaneously the motor tasks while speaking, affecting the time – on – task measure as well as their ability to sustain their walking or finger tapping rates over the 3 min interval; second, their speech was severely affected by simultaneous tasks demands imposed by the selective listening tasks or by the motor tasks. It is striking that all linguistic measures show greater DTCs for stroke survivors than for healthy older adults for both selective ignoring tasks and all three motor tasks.

Kemper, Herman, & Lian (2003) suggested that the speech of healthy older adults is buffered from competing task demands because older adults have shifted to a simplified speech register. This speech register itself reflects age-related reductions in working memory capacity that restrict older adults' production of complex grammatical constructions and propositionally dense sentences. As a result, older adults can draw upon sufficient cognitive reserve capacity to perform simple motor tasks or selective ignoring tasks simultaneously while speaking without a further loss of grammatical complexity or propositional density. Kemper et al. did observe that healthy older adults do speak more slowing in dual tasks situations, suggesting that their simplified speech register is not entirely buffered from competing working memory demands.

The results of the present study suggest that post-stroke survivors are unable to draw upon sufficient cognitive reserve capacity to successfully perform these tasks while speaking. Thus, stroke survivors are able to perform each task well in isolation yet unable to do two things at once without experiencing considerable disruption to each task.

Given the importance of language function to quality of life following stroke (e.g., Mackenzie & Chang, 2002), findings from the present study suggest that rehabilitation efforts may be beneficial to individuals even though they may not present with aphasia. Most clinical aphasia tests, including the Aphasia Diagnostic Profiles used to evaluate the stroke survivors in the present study, assess language function in isolation. The tasks employed in the present study reveal residual language deficits when speaking is combined with simple motor tasks or with selective ignoring tasks. These tasks are not unlike those commonly encountered in the home or social environment – such as conversing while strolling through a shopping mall, watching television or knitting. It is clear from the present study that stroke survivors will experience considerable difficulty "doing two things at once" and will be forced by competing task demands to alternative between the two tasks or to experience considerable disruption to both tasks.

A related issue concerns identifying appropriate measures to assess post-stroke function. It is important to administer assessments that are sufficiently challenging in order to reveal performance deficits should they exist. This issue has been raised in the domain of physical function following stroke; Duncan and colleagues (Duncan, Goldstein, Horner, Landsman, Samsa, & Matchar, 1994) have suggested that existing physical function measures do not adequately assess potential residual deficits of stroke survivors. They have observed that individuals may obtain the maximum score on many common measures of physical functioning, while also experiencing continued performance difficulties. Together with the present findings, it appears that stroke survivors would be best served by the use of assessment tools that index functional abilities even in challenging situations. In this way, rehabilitation services might be tailored to address problems that may arise in complex situations common in daily life.

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Table 1: Comparison of Stroke Survivors to Healthy Older Adults. Exclusion criteria and maximum possible scores are given where appropriate.

	Stroke Survivors	**Healthy Elders**	***t*(18)**
Age	77.2 (5.8)	76.3 (5.4)	.359
Education	14.3 (3.1)	14.9 (2.8)	.422
Hearing Handicap, exclude > 12	5.6 (5.5)	4.0 (5.6)	.822
Average dB, exclude > 40 dB	37.3 (5.6)	31.5 (2.3)	4.923*
Mental Status maximum = 10, exclude < 6	8.9 (1.1)	9.5 (0.9)	1.365
Shipley Vocabulary	34.0 (3.4)	32.4 (4.9)	.851
Digits Forwards	6.1 (2.0)	6.0 (1.7)	.120
Digits Backwards	5.9 (1.4)	4.9 (1.2)	1.738
Digit Symbol	16.7 (5.2)	21.6 (6.5)	1.866
Stroop			
Colors	53.8 (15.1)	60.2 (15.2)	.928
Color words	27.0 (7.8)	30.8 (11.7)	.856
Difference	26.8 (10.7)	29.4 (8.2)	.610
Barthel Index maximum = 100, exclude < 90	96.5 (5.3)	not administered	
Fugl-Meyer Assessment maximum = 123	110.9 (9.4)	not administered	
Berg Balance Scale maximum = 54	47.2 (4.1)	not administered	
Duke Mobility Scale maximum = 26	20.8 (2.6)	not administered	
Aphasia Diagnostic Profiles		not administered	
Writing maximum = 30, exclude < 20	28.6 (2.2)		
Reading maximum = 30, exclude < 22	27.3 (2.2)		
Fluency no maximum, exclude < 16	19.4 (2.7)		
Personal Information maximum = 24, exclude < 20	20.9 (2.1)		
Naming maximum = 36, exclude < 30	34.8 (2.1)		
Auditory Comprehension maximum = 28, exclude < 24	25.6 (1.2)		

**$p < .01$

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Table 2: Language Sample Measures for Baselines for Healthy Older Adults and Stroke Survivors.

	Healthy Elders	**Stroke Survivors**	***t*(18)**
Fluency			
WPM	145.7 (21.6)	121.7 (46.6)	1.482
% Grammatical	35% (.18)	40% (.20)	1.320
MLU	6.52 (2.37)	5.79 (2.29)	1.635
% without Fillers	24% (.01)	19% (.15)	0.736
Grammatical Complexity			
MCU	0.96 (.31)	1.04 (.22)	2.803
D-Level	3.05 (1.06)	2.42 (0.74)	1.539
Semantic Content			
TTR	0.51 (.14)	0.36 (.07)	2.929**
P-Density	4.47 (.43)	3.31 (.51)	5.455**

** $\underline{p} < .01$

Note. MLU = mean length of utterance; WPM = word per minute speech rate; % Grammatical = percentage of grammatical sentences; % w/out Fillers = percentage of sentences without fillers; MCU = mean clauses per utterance; D-Level = Developmental Level; TTR = type-token ratio; P-Density = propositional density.

Figure Captions

Figure 1. Comparison of Walking and Finger Tapping Rates for Stroke Survivors and Healthy Older Adults in the Baseline and Dual Task Conditions.

Figure 2. Percentage of Time - on - task for Stroke Survivors and Healthy Older Adults in the Baseline and Dual Task Walking and Finger Tapping Conditions.

Figure 3. Dual Task Costs (DTCs) (and standard errors) for the Language Sample Fluency Measures while Ignoring Noise and Ignoring Speech.   Asterisks (*) mark DTCs that are significantly different from zero.

Figure 4. Dual Task Costs (DTCs) (and standard errors) for the Language Sample Grammatical Complexity Measures while Ignoring Noise and Ignoring Speech. Asterisks (*) mark DTCs that are significantly different from zero.

Figure 5. Dual Task Costs (DTCs) (and standard errors) for the Language Sample Content Measures while Ignoring Noise and Ignoring Speech. Asterisks (*) mark DTCs that are significantly different from zero.

Figure 6. Dual Task Costs (DTCs) (and standard errors) for the Language Sample Fluency Measures during Simple Tapping, Complex Tapping, and Walking. Asterisks (*) mark DTCs that are significantly different from zero.

Figure 7. Dual Task Costs (DTCs) (and standard errors) for the Language Sample Grammatical Complexity Measures during Simple Tapping, Complex Tapping, and Walking. Asterisks (*) mark DTCs that are significantly different from zero.

Figure 8. Dual Task Costs (DTCs) (and standard errors) for the Language Sample Content Measures during Simple Tapping, Complex Tapping, and Walking. Asterisks (*) mark DTCs that are significantly different from zero.

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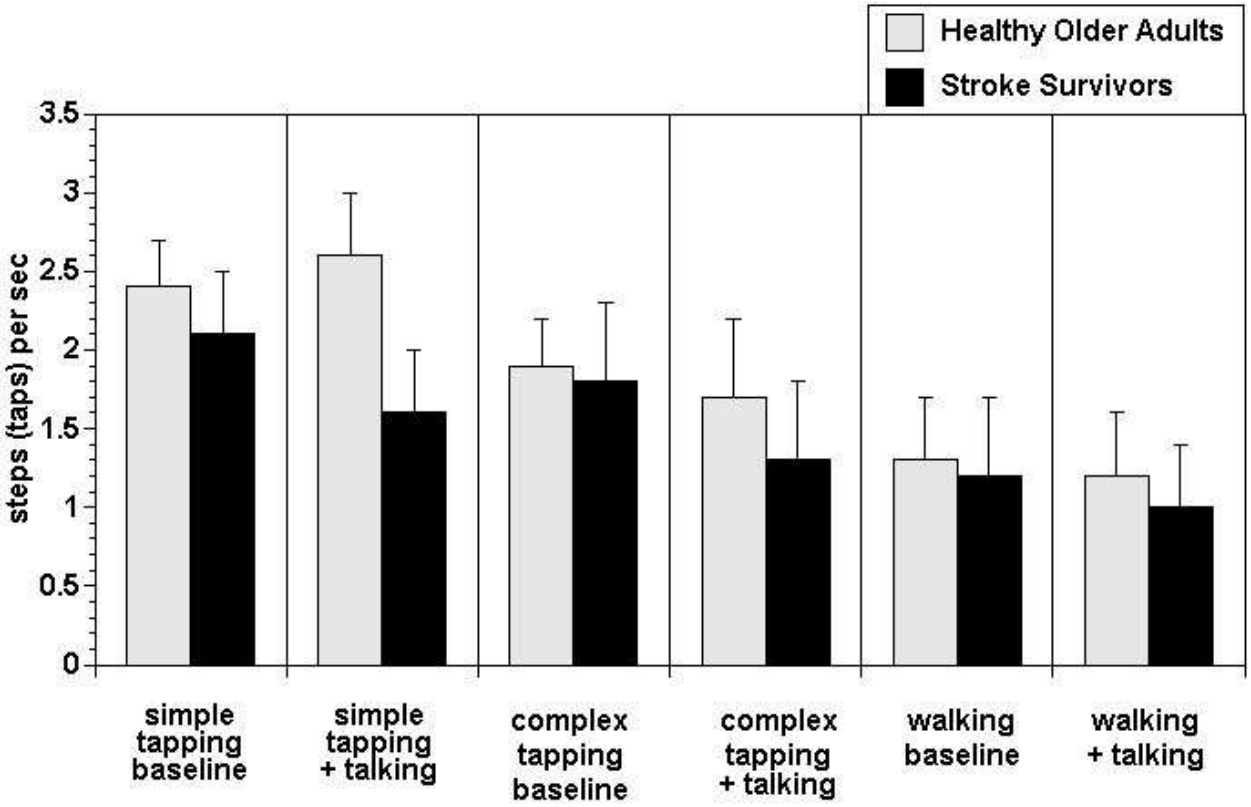
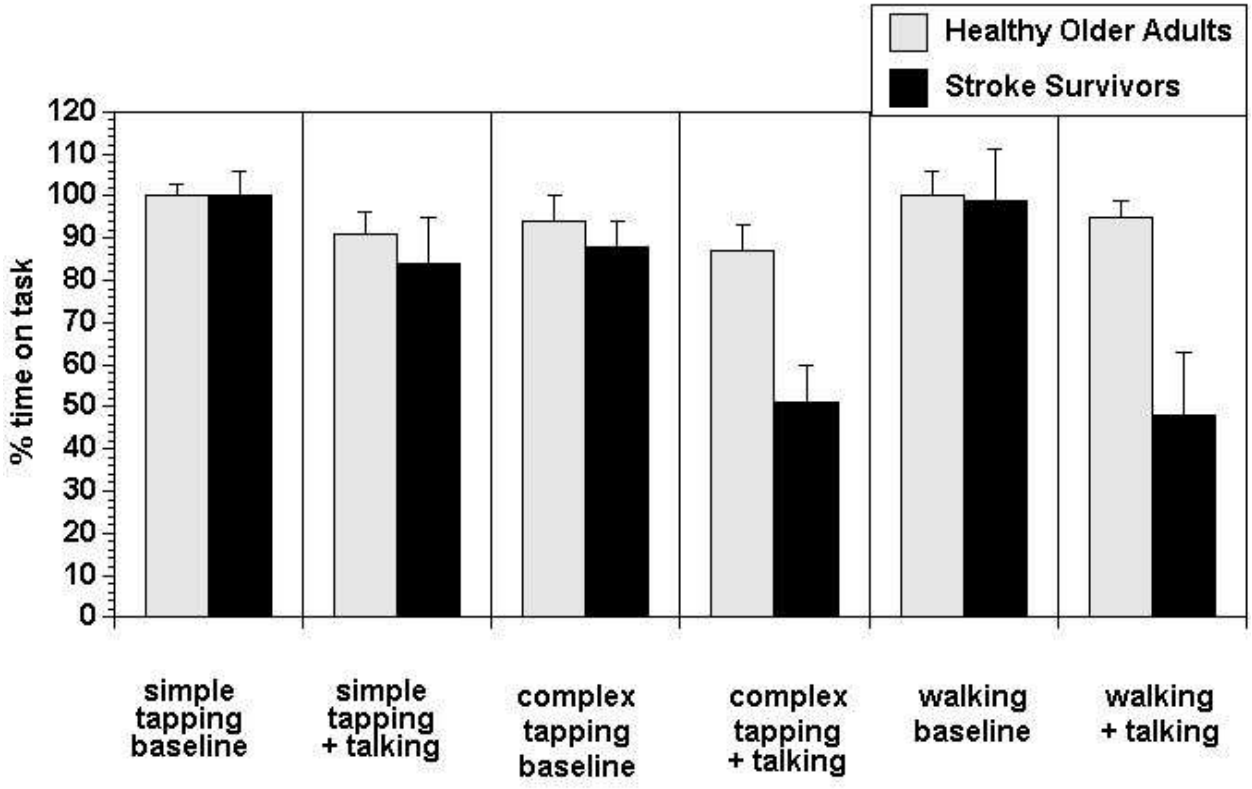
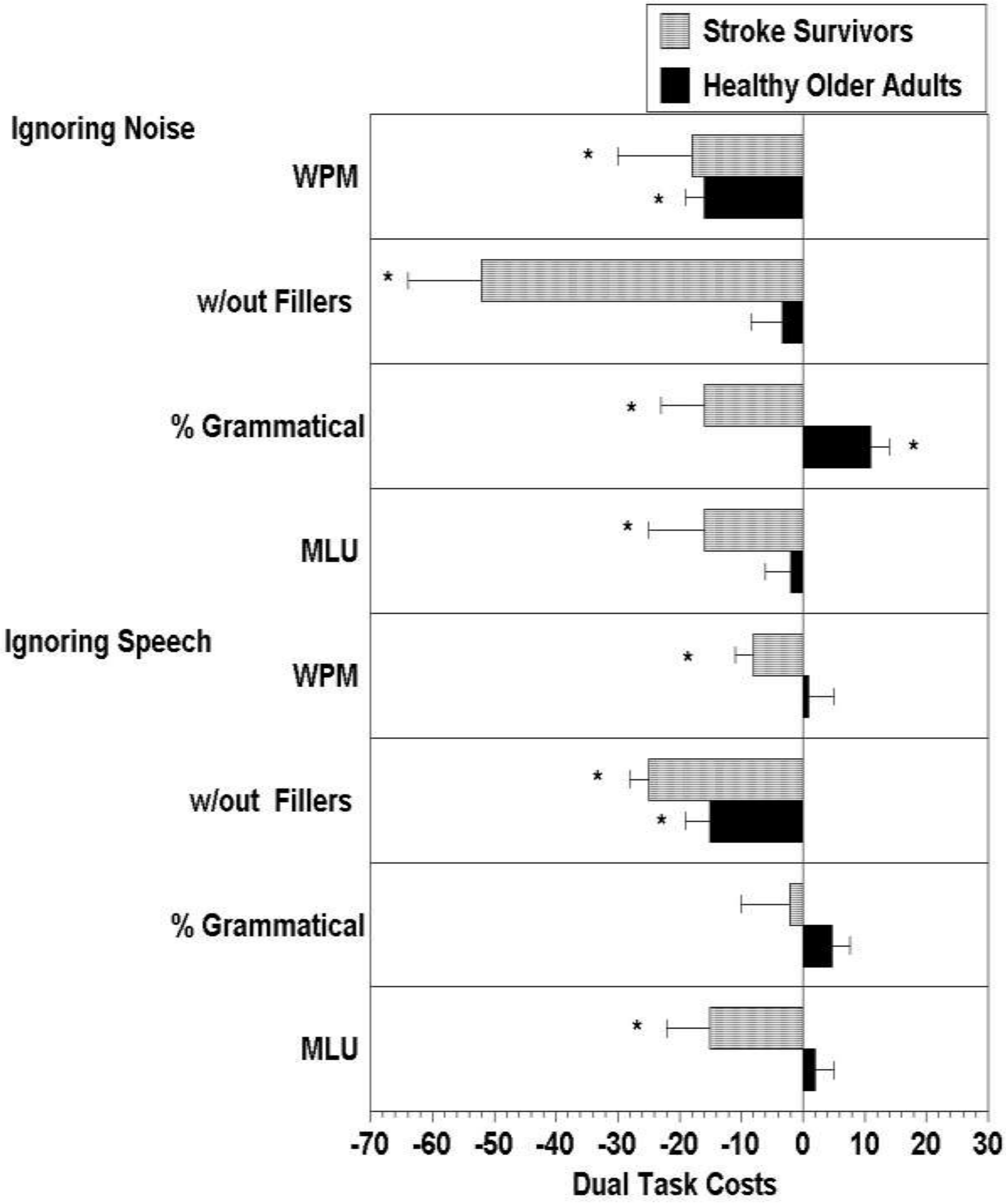



Healthy Older Adults
Stroke Survivors
% time on task
120
110
100
90
80
70
60
50
40
30
20
10
0
simple tapping baseline
simple tapping + talking
complex tapping baseline
complex tapping + talking
walking baseline
walking + talking

Kemper, S., McDowd, J., Pohl, P., Herman, R., & Jackson, S. (2006). Revealing language deficits following stroke: the cost of doing two things at once. *Aging, Neuropsychology, and Cognition, 13,* 115-139. PM#16766346. Publisher's official version: http://dx.doi.org/ 10.1080/13825580500501496. Open Access version: http://kuscholarworks.ku.edu/dspace/.



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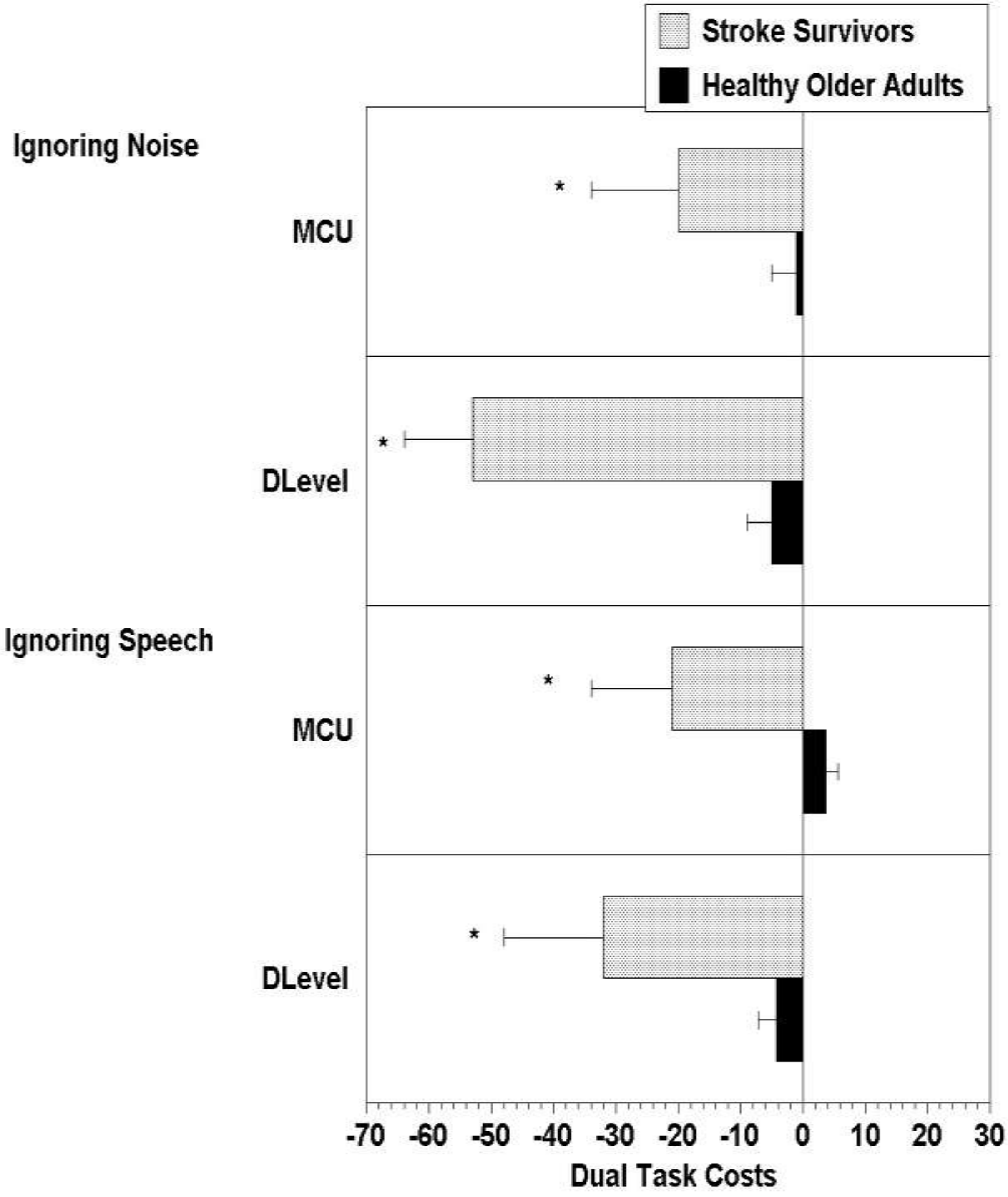

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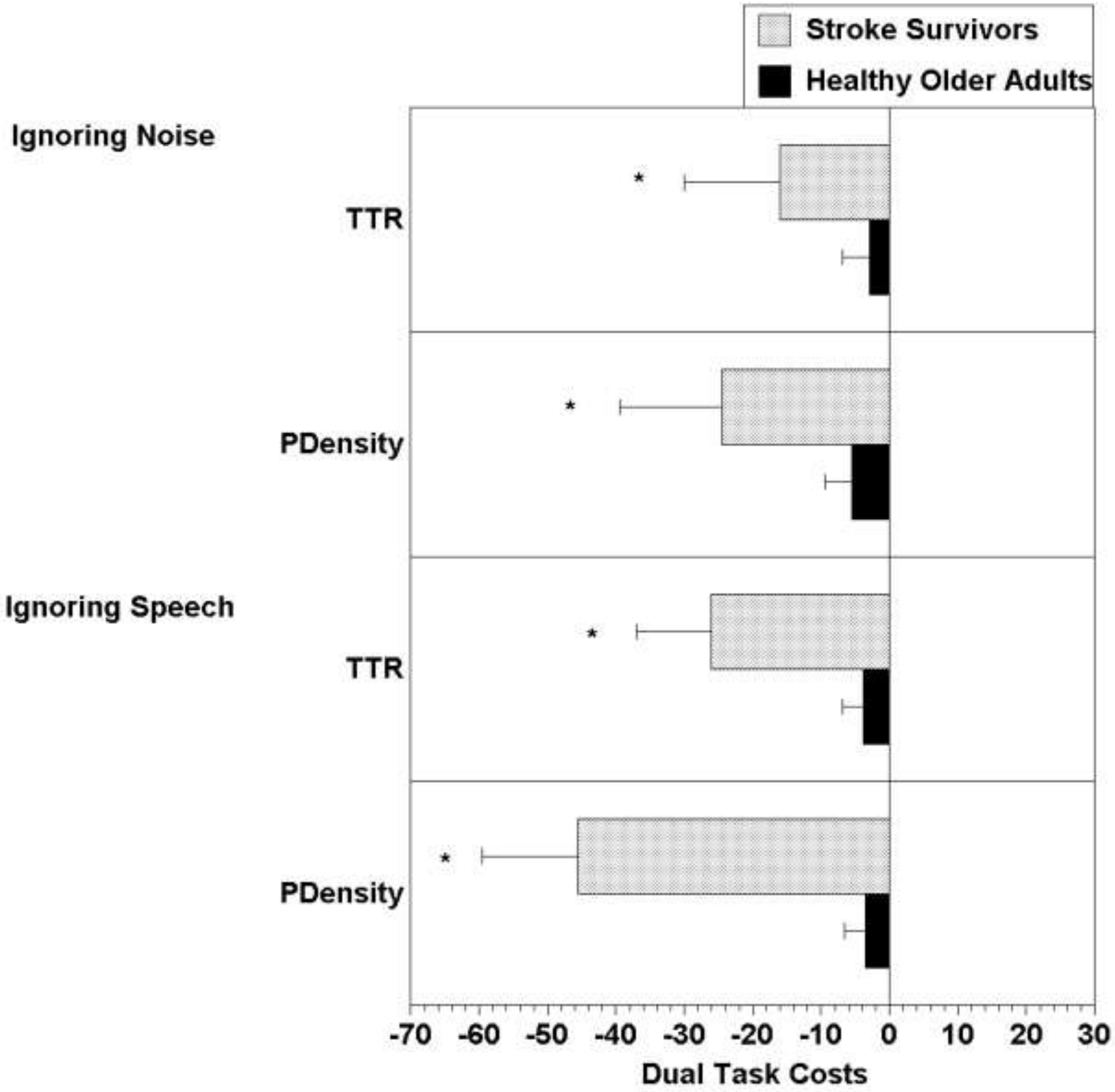

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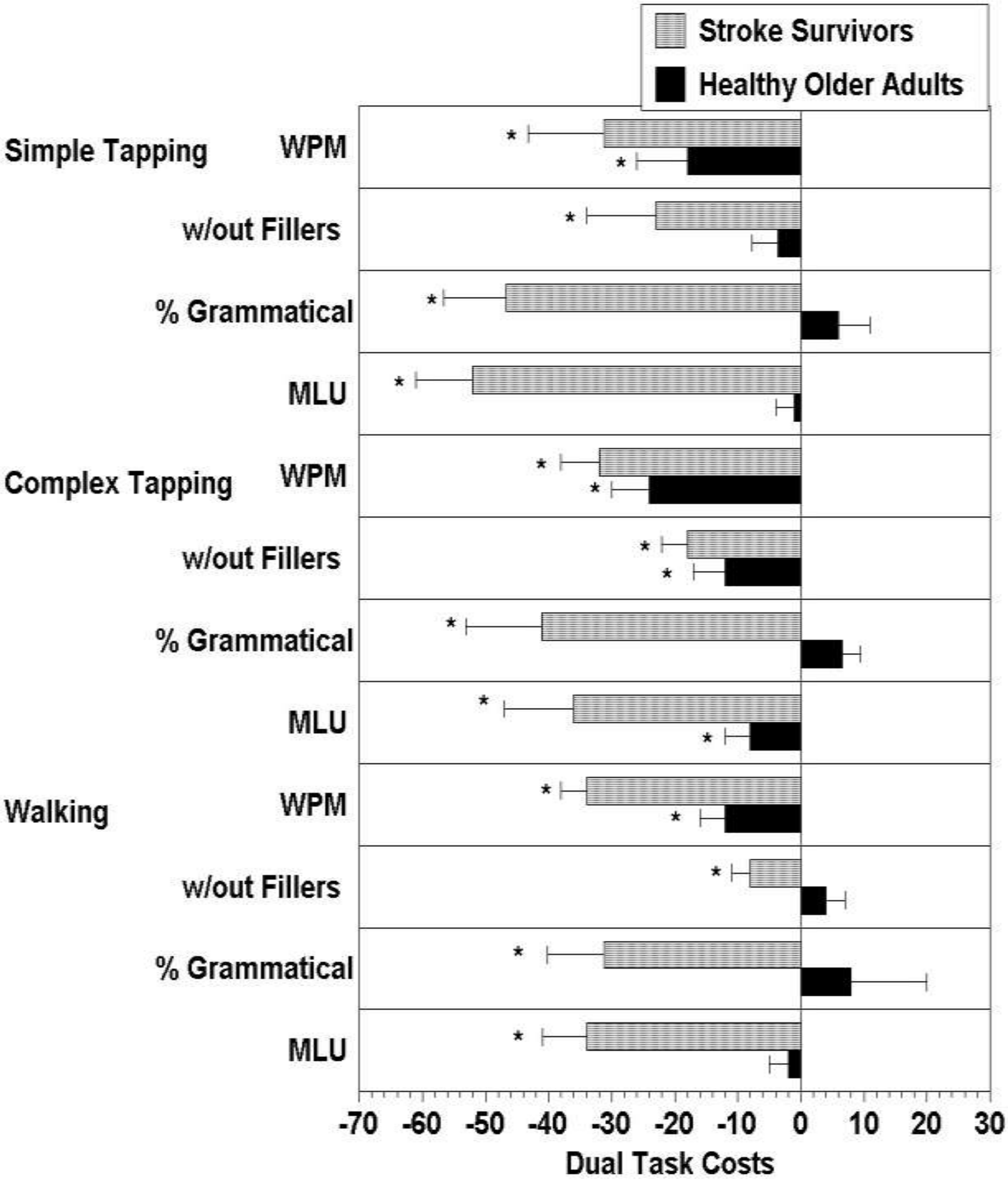

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