Published in final edited form as:

Respir Physiol Neurobiol. 2008 December 31; 164(3): 323–330. doi:10.1016/j.resp.2008.08.007.

Effects of Utterance Length and Vocal Loudness on Speech Breathing in Older Adults

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Abstract

Age-related reductions in pulmonary elastic recoil and respiratory muscle strength can affect how older adults generate subglottal pressure required for speech production. The present study examined age-related changes in speech breathing by manipulating utterance length and loudness during a connected speech task (monologue). Twenty-three older adults and twenty-eight young adults produced a monologue at comfortable loudness and pitch and with multi-talker babble noise playing in the room to elicit louder speech. Dependent variables included sound pressure level, speech rate, and lung volume initiation, termination, and excursion. Older adults produced shorter utterances than young adults overall. Age-related effects were larger for longer utterances. Older adults demonstrated very different lung volume adjustments for loud speech than young adults. These results suggest that older adults have a more difficult time when the speech system is being taxed by both utterance length and loudness. The data were consistent with the hypothesis that both young and older adults use utterance length in premotor speech planning processes.

1. INTRODUCTION

Typical aging affects respiratory function. Chest wall compliance decreases, and pulmonary compliance may increase (Frank et al. 1957; Mittman et al. 1965). As a result of increased lung compliance, lung elasticity and elastic recoil forces are reduced. Additionally, in typical aging, inspiratory and expiratory muscle strength is reduced (Enright et al. 1994; Berry et al. 1996).

Age-related reductions in elastic recoil of the lungs, compliance of the chest wall, and strength of the respiratory muscles are likely to affect how the respiratory system is used to generate the required air pressure for speech production. Previous studies have demonstrated that older adults initiate speech at a higher lung volume, use a greater percent of their lung volume per speech breath and per syllable, and produce fewer syllables per breath than younger adults (Hoit et al. 1987; Hoit et al. 1989; Sperry et al. 1992; Huber et al. 2008). One study demonstrated that older women inhaled more often and more deeply when reading a standard passage than young women did (Sperry et al. 1992).

Young adults use the mid-lung volume range (35–60% VC) when speaking (Hixon et al. 1973; Stathopoulos et al. 1997; Huber et al. 2005; Huber 2007). This is efficient because recoil pressure in the mid-lung volume range is close to the required pressure for speech production at comfortable loudness, so little respiratory muscle activity is required (Hixon et al. 1973).

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However, in older adults, recoil pressure is reduced, so the recoil pressures available in the mid-lung volume range are lower. Therefore, older adults must compensate to ensure adequate pressure for speech is generated.

Initiating speech at higher lung volumes allows older adults to take advantage of the higher recoil pressures available to generate subglottal pressure for speech. However, this strategy obviously requires greater inspiratory muscle effort. Data from Enright et al (1994) reported that expiratory muscle strength declines more with aging than inspiratory muscle strength. From age 65 years to over 85 years, maximum inspiratory pressure, a measure of inspiratory muscle strength, decreased by 19 cmH₂O for women and 28 cmH₂O for men (Enright et al. 1994). However, in the same group, maximum expiratory pressure, a measure of expiratory muscle strength, decreased by 31 cmH₂O for women and 57 cmH₂O for men (Enright et al. 1994). It may be that it is easier for older adults to use the better preserved inspiratory muscle effort to achieve higher lung volumes at speech initiation, rather than to use expiratory muscle effort to go to lower lung volumes. Also, increasing lung volume before speaking would reduce the likelihood than an individual would need to speak at volumes below resting or end expiratory level, where recoil pressure is negative (inspiratory). At volumes below end expiratory level, the speaker would need to generate muscular pressure to overcome the negative recoil pressure to produce the required subglottal pressure. Given that older adults expend larger volumes during speech due to poor laryngeal valving (Hoit et al. 1987; Hoit et al. 1989), initiating speech at higher lung volumes may also simply help them to have longer breath groups.

Due to changes in strength and compliance in the respiratory system older adults may have less functional reserve (Tolep et al. 1993), and therefore, will have more difficulty when the system is taxed. One way the respiratory system is taxed during everyday speaking situations is by the production of longer utterances. Older adults, particularly men, produce shorter breath groups than young adults during reading, monologue, and conversation tasks (Hoit et al. 1987; Sperry et al. 1992). Both young and older women increased the amount of air inhaled and exhaled as utterance length increased (Sperry et al. 1992; Winkworth et al. 1994); however, the difference between older and younger adults was greater for longer utterances than for shorter utterances (Sperry et al. 1992). Similarly, we have shown that age-related differences in utilization of lung, rib cage, and abdominal volumes were greater when subjects produced a longer utterance (13 syllables) compared to a shorter one (6 syllables) (Huber et al. 2008).

Several studies have reported that adults adjust speech breathing for the length of the upcoming utterance, particularly when reading (Sperry et al. 1992; Winkworth et al. 1994). This suggests that utterance length is a critical variable in premotor planning for speech. The production of shorter utterances by older adults may be a compensatory mechanism for their reduced functional reserve (Tolep et al. 1993). While taking more breaths may be a good physiological compensation for age-related changes, more frequent breath pauses may have unintentional consequences. Utterances are more likely to be “chunked” into shorter linguistic units, potentially degrading linguistic cues. Also, listeners use speech and voice characteristics to make judgments about competence of the speaker to perform everyday activities and maintain independence (Blood et al. 1979). Several investigations have established that listeners associate negative characteristics such as slow thinking, forgetfulness, and frailty with voices perceived to be old (Ryan 1978; Hummert et al. 1994; Hummert et al. 1999). It is possible that listeners may perceive older adults as less competent if they pause to breathe more often while speaking.

A systematic investigation of age-related changes in respiratory kinematics with increasing utterance length has not been undertaken using an extemporaneous speech task like a monologue. Sperry et al.'s (1992) study directly assessed the effects of utterance length in older

adults; however, the participants did not include males and the only connected speech task was a reading task. It is reasonable to hypothesize the neural processes involved in pre-speech planning are different when reading a prepared passage compared to a more natural, extemporaneous speech task.

This hypothesis derives from several lines of evidence. Hoit and colleagues (1987, 1989) reported that utterance lengths were longer on average during reading than during monologue, but these differences were not tested statistically. Also, Hoit et al. (1987) reported that age-related changes in respiratory kinematics were more evident in extemporaneous speech than in reading. We also note that producing a monologue requires the online formulation of language, which suggests that allocation of and demand for cognitive resources differ during more natural speech than during reading. Mitchell and colleagues (1996) found that discussing a topic without a prepared outline resulted in more pauses, fewer syllables produced per breath group, decreased speech rate, and increased volume excursion compared to discussing a topic after preparing an outline. The authors hypothesized that the differences between the two tasks was due to cognitive-linguistic demands (Mitchell et al. 1996). Although almost no differences in respiratory kinematics were reported by Mitchell and colleagues (1996), the tasks may not have been different enough to alter kinematics. The authors hypothesize that kinematic differences may have been more evident if the tasks had been more divergent in cognitive-linguistic load (Mitchell et al. 1996). Due to language formulation processes required for extemporaneous speech, the entire utterance may not be completely pre-planned in a monologue in the way it may be during reading. In support of this suggestion, in two studies of young female speakers, Winkworth and colleagues found less evidence of pre-planning for longer utterances during monologue than during reading (Winkworth et al. 1994; Winkworth et al. 1995).

Another natural way the respiratory system is taxed during everyday speech production is talking in background noise which requires the speaker to increase vocal loudness. This increase in loudness in noisy environments, called the Lombard Effect, is automatic and has been shown to be difficult to suppress (Lane et al. 1971; Siegel et al. 1974; Pick et al. 1989). Reductions in functional reserve in the elderly may result in difficulty with increasing vocal loudness to meet everyday communicative needs. Increasing loudness requires speakers to generate more subglottal pressure (pressure generated to drive the vocal folds) for speech, using both the respiratory and laryngeal systems (Isshiki 1964; Isshiki 1969; Holmberg et al. 1988; Stathopoulos et al. 1997), although the respiratory system is likely to play the primary role in increasing pressure (Finnegan et al. 2000). While several studies have examined changes in respiratory kinematics with increased loudness in young adults and children, little is known about how older adults produce loud speech. Young adults begin speaking at higher lung volumes and sometimes continue speaking into lower lung volumes when increasing loudness (Hixon et al. 1973; Stathopoulos et al. 1993; Stathopoulos et al. 1997; Dromey et al. 1998; Huber et al. 2005; Huber 2007). Use of higher lung volumes at speech initiation allows speakers to generate higher recoil pressures and therefore use less muscular pressure to increase subglottal pressure for speech (Stathopoulos et al. 1993; Stathopoulos et al. 1997; Huber et al. 2005; Huber 2007; Huber et al. 2008). The need for greater subglottal pressure requires the expenditure of larger lung volumes, resulting in larger lung volume excursions. Relative to older adults and increasing loudness, in one study from our laboratory, we asked subjects to repeat sentences and used several different cues to elicit louder speech. For some cues, older adult used similar mechanisms, but different volumes, than young adults (Huber et al. 2008) to produce louder speech. For other cues, older adults used very different mechanisms and volumes than young adults (Huber et al. 2008).

Few studies of subjects of any age have utilized connected speech tasks to study the production of loud speech, and none have systematically examined changes in respiratory kinematics with

increasing utterance length in loud speech. It may be that either loudness goals are not met as the utterance progresses, or utterances are shortened, particularly in older adults. Understanding the effects of reduced functional reserve on speech breathing is important, because such a reduction could result in fatigue if older adults were speaking over longer periods of time. This also may make it difficult for older adults to compensate for diseases that affect speech and respiration, such as Parkinson's disease, cerebrovascular accidents, and Chronic Obstructive Pulmonary Disease (COPD), many of which are more prevalent in older adults (Vinters 2001). The purpose of the present study was to examine age-related changes in speech breathing by manipulating utterance length and loudness during connected speech.

2. METHODS

2.1 Participants

Twenty-three older adults (14 women and 9 men) and 28 young adults (15 women and 13 men) participated in the current study. The mean age of the older women was 72 years (range = 66 to 76 years), and the mean age of the older men was 72 years (range = 66 to 82 years). The mean age of the young women was 23 years (range = 20 to 33 years). The mean age of the young men was 23 years (range = 20 to 25 years). Data from the young adults were published previously (Huber 2007); however, analyses of these data differed in the current paper. The young adult data were included in the present paper as a comparison for the older adults in order to elucidate the effects of aging on respiratory support for speech, and the data for both the young and older adults were analyzed for utterance length, an analysis which was not conducted for the Huber (2007) paper.

At the time of the experiment, all participants reported being free from colds, infections, and allergy symptoms, having been non-smoking for at least the past five years, no history of respiratory problems (including asthma), no history of neurological disease, no head or neck cancer or surgery, and no formal training in singing or speaking. All participants lived independently in the community and were ambulatory, demonstrated normal hearing (Ventry et al. 1983), and were determined by the author, a certified speech-language pathologist, to have normal speech, language, and voice. Older adults had to pass the Mini-Mental State Exam by achieving a score of 24 or higher (Folstein et al. 1975). All participants demonstrated normal lung function by producing vital capacity (VC), forced VC, and forced expiratory volume in one second at greater than or equal to 80% of expected values based on age, sex, height, weight, and ethnicity (VacuMed Discovery Handheld Spirometer).

2.2 Equipment

The equipment set-up for data collection is depicted in Fig. 1. The acoustic signal was transduced by a condenser microphone (model: Bruel & Kjaer (B&K), type 4936), maintained at a constant 6-inch mouth-to-microphone distance. The microphone signal was recorded to a digital audiotape (DAT) (model: Tascam DA-P1) and later digitized using a computer software program, Praat (Boersma et al. 2003). A sound level meter, coupled to the microphone, amplified the microphone signal during the study. The sound level meter was set for c-weighting. The gain provided by the sound level meter to the microphone signal varied depending on how loudly a subject spoke and was factored in when calibrating the acoustic signal for sound pressure level measurements.

Respiratory kinematic data were transduced with the Resptrace (Ambulatory Monitoring, Inc.). An elastic band placed around the rib cage (RC), just under the axilla, transduced RC movement. A second band placed around the abdomen (AB), below the last rib at the level of the participant's belly button, transduced AB movement. Signals from the Resptrace bands were digitized through the analog-to-digital converter in the Optotrak system (Northern Digital

Inc.) with a second microphone (model: SHURE, Beta 87) which picked up sound from the experimental chamber. The acoustic signal from this second microphone was used to determine where speech started and ended for the respiratory kinematic measurements.

2.3 Procedures and Speech Stimuli

Purdue University's Committee on the Use of Human Research Subjects approved the procedures for data collection.

2.3.1. Calibration of Kinematic Signals—Several non-speech tasks were performed by all participants. Participants performed at least 3 trials of the vital capacity (VC) task, with the Resptrace bands in place to estimate maximum lung capacity (VC) for each participant. Participants also produced 1 minute and 30 seconds of rest breathing and 1 minute and 30 seconds of “speech-like” breathing. For “speech-like” breathing, participants were asked to read the sentence “You buy Bobby a puppy now if he wants one” silently to themselves, one time per exhalation.

Since the combined effect of changes in the RC and AB volumes reflect the change in lung volume (LV) (Konno et al. 1967), the sum of the RC and AB movements during speech were used to estimate LV. To calibrate the RC and AB signals for LV change, the sum of RC and AB movement signals were compared to a digital spirometer signal (SP), collected simultaneously with the RC and AB signals, during the rest breathing and “speech-like breathing” tasks (Huber et al. 2005; Huber 2007; Huber et al. 2008). A least squares analysis was used to determine the best correction factors (k_1 and k_2) for the RC and AB signals as in Eq. 1 (Huber et al. 2005; Huber 2007; Huber et al. 2008):

$$SP = k_1(RC) + k_2(AB) \quad \text{Eq. 1}$$

Estimated lung volume was computed during the speech tasks by summing the RC and AB volumes after the correction factors were applied, using Eq. 2:

$$LV = k_1(RC) + k_2(AB) \quad \text{Eq. 2}$$

2.3.2. Speech Tasks—Participants were asked to talk about a topic of their choice for 3 minutes. For the first minute and a half, the room was quiet. During the second minute and a half, the background noise was played to elicit loud speech. Background multi-talker noise (AUDiTEC of St. Louis) was introduced at 70 dBA through free-field speakers positioned in front of the participant at a distance of approximately 40 inches. The multi-talker noise sounded like many people talking at once, but it was impossible to make out any of the individual speakers or words spoken. The participants were instructed to talk, without instructions as to how loud to talk. The background noise acted as a natural cue for speakers to talk louder, eliciting the Lombard Effect (Lane et al. 1971; Siegel et al. 1974; Pick et al. 1989), just as most individuals speak more loudly when at a party or in a noisy room. At all times, participants were instructed to be sure they were clear and audible to an experimenter sitting about four feet away.

2.4 Measurements

A breath group was defined as all of the words produced on one breath. The average SPL in decibels (dB) for each breath group was measured using Praat (Boersma et al. 2003). The number of syllables produced on each breath group was counted. The speech rate was measured

in syllables per second (syl/sec) by dividing the number of syllables produced in each breath group by its duration.

Respiratory kinematic measurements were made from each breath group using algorithms written to run in Matlab (Mathworks, Inc.). The lung volume (sum) signal was displayed along with a time-locked acoustic signal. Lung volume initiation (LVI) was measured at the point where voicing started, based on the acoustic signal. Lung volume termination (LVT) was measured at the point that voicing ended, based on the acoustic signal. Accuracy of selection of speech initiation and termination points was verified by listening to the audio signal. Initiations and terminations were expressed as a percentage of vital capacity (%VC) and relative to the end expiratory level (EEL). EEL was defined by the trough of each rest breathing cycle. The average EEL was computed from at least three consistent troughs of rest breathing preceding the production of the speech task, and the EEL level was computed separately for the two loudness conditions (comfortable and loud). However, as expected, EEL level did not change as a result of loudness condition ($F = 2.38$, $p = 0.129$). Lung volume excursion (LVE), expressed as a %VC, was calculated by subtracting the volume at termination from the volume at initiation. Percent VC expended per syllable (%VC/syl) was computed by dividing the LVE by the number of syllables produced for the breath group.

After each condition, participants were shown a line (23.3 cm in length) with “least effort” written on the left side of the line and “most effort” written on the right side of the line. There were no divisions marked in the line. They were asked to indicate how “physically effortful” the speaking task by making an “X” anywhere on the line. The mark from the comfortable condition was visible on the line when they rated the loud condition. As a measure of effort, the distance in centimeters from the start of the line to the individual’s mark was measured for each condition (comfortable and loud).

2.5 Statistical Analysis

For the analysis of effort ratings, two-factor repeated measures analyses of variance (ANOVAs) were conducted on the dependent measurements. The between-subject factor was age (young adults versus older adults). The within-subject factor was loudness condition (comfortable and loud). For the speech production measurements, utterances were grouped into four categories, based on the length of the utterance: 1) 10 syllables or less, 2) 11–20 syllables, 3) 21–30 syllables, or 4) more than 30 syllables, similar to the technique used by Sperry et al. (1992). Three-factor repeated measures ANOVAs were conducted on the dependent measurements. The between-subject factor was age (young adults versus older adults). The within-subject factors were loudness condition (comfortable and loud) and utterance length category (#1–#4). Tukey HSD tests were used as post-hoc tests when a factor or interaction in the ANOVA was significant. The level of significance was adjusted for the number of ANOVAs completed (0.05/8) and set as $p \leq 0.006$ for all statistical tests.

To establish inter-measurer reliability, two men and two women from each group (older adults and young adults) were randomly chosen for remeasurement (total of 8 subjects). An ANOVA was used to examine differences across the two sets of measurements. All tests were statistically non-significant, with alpha levels ranging from 0.125 to 0.952, indicating good measurement reliability.

3. RESULTS

Both age groups produced utterances in each utterance length category for both loudness conditions (see Table 1). Statistical summaries for main effects are presented in Table 2 and for interaction effects in Table 3. Post-hoc alpha levels are presented in Appendix 1.

3.1 Sound Pressure Level (SPL)

There were significant main effects of condition and utterance length and a significant age by condition effect. Large differences in SPL (greater than 5 dB) were a result of loudness condition. Both older and younger adults increased SPL significantly from comfortable to loud, and there were no significant group differences within conditions (see Fig. 2). Relative to the main effect of utterance length, SPL was significantly higher in utterance length group #3 than in utterance length group #1, but the difference was small (see Table 4).

3.2 Number of Syllables per Breath Group

There were significant main effects of age, utterance length, and a significant age by utterance length interaction effect. For both older and younger adults, the number of syllables per breath group increased significantly as utterance length category increased (see Fig. 3). There were no differences in length across the age groups for utterance length groups #1, #2, and #3, but for utterance length group #4, young adults produced significantly longer utterances than older adults (see Fig. 3).

3.3 Speech Rate

There were significant main effects of age, utterance length, and a significant age by utterance length interaction effect. Older adults spoke significantly more slowly than young adults for all utterance length categories except the shortest one (#1) (see Fig. 3). Older adults spoke significantly more slowly for the shortest utterances (category #1) as compared to longer ones (categories #2, #3, and #4) (see Fig. 3). Younger adults spoke more slowly for the two shorter utterance length categories than for the two longer ones (categories #1 vs. #2, #3, and #4 and #2 vs. #3 and #4) (see Fig. 3).

3.4 Lung Volume Initiation (LVI)

There were significant main effects of age, loudness, and utterance length and a significant age by loudness interaction effect. For the utterance length effect, LVI increased significantly as utterance length category increased (see Table 4). For the age by loudness effect (see Fig. 4), at comfortable loudness, older adults used a significantly higher LVI than young adults, but there was no significant difference in LVI between the two groups in the loud condition. Young adults increased LVI significantly in the loud condition as compared to the comfortable condition, but older adults did not significantly change LVI with increased loudness.

3.5 Lung Volume Termination (LVT)

There were significant main effects of age, loudness, and utterance length and a significant age by loudness interaction effect. For the utterance length effect, LVT decreased significantly as utterance length category increased (see Table 4). For the age by loudness effect, older adults significantly *decreased* LVT in the loud condition as compared to the comfortable condition, while young adults significantly *increased* LVT in the loud condition as compared to the comfortable condition (see Fig. 4).

3.6 Lung Volume Excursion

There were significant main effects of age, loudness, and utterance length and a significant age by utterance length interaction effect. For the loudness effect, LVE was significantly larger in the loud condition ($\bar{M} = 18.5\% \text{ VC}$, $\text{SD} = 13.2\% \text{ VC}$) as compared to the comfortable condition ($\bar{M} = 16.6\% \text{ VC}$, $\text{SD} = 11.3\% \text{ VC}$). For the age by utterance length interaction, LVE increased significantly as utterance length increased for both age groups (see Fig. 5). Older adults had a significantly larger LVE than young adults for longer utterances (#3 and #4), but not for the shorter ones (#1 and #2) (see Fig. 5).

3.7 %VC Expended per Syllable (%VC/syl)

There were main effects of age and utterance length and a significant age by utterance length interaction effect. For both older and younger adults, %VC/syl was significantly larger for the shortest utterances (category #1) as compared to the other categories, and there were no significant differences among the three longer utterance length categories (#2, #3, and #4) (see Fig. 6). Older adults used a significantly larger %VC/syl as compared to younger adults in the shortest utterance length category (#1) only (see Fig. 6).

3.8 Effort Ratings

There was a significant main effect of condition. Effort was rated significantly higher by both groups in the loud condition ($\bar{M} = 10.1$ cm, $\underline{SD} = 4.64$ cm) as compared to the comfortable condition ($\bar{M} = 6.1$ cm, $\underline{SD} = 4.41$ cm).

4. DISCUSSION

Utterance length and loudness both had considerable influence on the effects of typical aging on speech respiration. Older adults had a more difficult time when the respiratory system was taxed, as demonstrated by larger age-related effects present for longer utterances and when participants were speaking loudly.

Confirming earlier studies (Hoit et al. 1987; Sperry et al. 1992), our data make it clear that typical aging affected utterance length. Regardless of loudness levels, older adults produced shorter utterances than young adults (see Table 1). When older adults did produce longer utterances, age-related differences were larger. For example, older adults spoke more slowly for all but the shortest utterances (category #1) (see Fig. 3). Also, while both groups used more lung volume as utterance length increased, differences in LVE between older adults and young adults were only present at longer utterance lengths (categories #3 and #4) (see Fig. 5). Sperry et al. (1992) similarly reported larger age-related effects at longer utterance lengths.

Overall, longer utterances were more taxing to the respiratory system than shorter ones, for both young and older adults. For example, as utterance length increased, participants initiated speech at higher volumes and continued speaking into lower volumes (see Fig. 4). This is important because it means that greater inspiratory and expiratory muscular forces were required to generate pressure for speech at longer utterance lengths, particularly for the longest categories (#3 and #4). For the longest utterance length category (#4), mean LVT was below EEL (where pulmonary recoil pressures are inspiratory).

These findings regarding utterance length, coupled with the finding that age-related changes were larger for longer utterances, suggests that reduced respiratory reserve affects speech breathing patterns in typical aging. As utterance length increased, older adults needed to use more of their reserve capacity to produce speech, necessitating compensation. So, although older adults can produce long utterances, it is more difficult for them to do so. Reduced functional reserve could result in fatigue if older adults were speaking for extended periods and may make it difficult for older adults to compensate for disease-related changes to the respiratory system.

Our study provides novel evidence that extemporaneous speech in a noisy environment was taxing for both older and young adults. Both young and older adults reported their perception of more physical effort expended during the loud condition than during the comfortable one, yet they were not told explicitly that they were speaking more loudly. The physiological data supports the participants' perception of increased effort. Both young and older adults expended a greater percent of their lung volume (higher LVE) and altered respiratory kinematics when speaking loudly.

Despite the similarities, older adults used different strategies for increasing loudness than young adults. Older adults did not increase LVI when increasing loudness, and older adults terminated speech at lower lung volumes (decreased LVT) in the loud condition. Young adults initiated speech (increased LVI) and terminated speech at higher lung volumes (increased LVT) in the loud, compared to the comfortable, condition. The older adults' pattern of not increasing LVI and using lower LVT was surprising. Louder speech requires the generation of higher pressures, and generally, speakers increase LVI to take advantage of higher recoil pressures available at higher lung volumes, as the young adults did in the present study and in earlier studies (Stathopoulos et al. 1993; Stathopoulos et al. 1997; Huber et al. 2005; Huber 2007).

One potential explanation for the use of lower LVT, rather than higher LVI, by older adults in the loud condition is that the task was difficult for older adults at comfortable loudness. As demonstrated in Fig. 4, at comfortable loudness, older adults used a significantly higher LVI than young adults. Older adults may not have increased LVI further when increasing loudness since LVI was already so high at comfortable loudness. If it can be assumed that end expiratory level is about 35–40 %VC, then older adults' lung volume would have been about 75 %VC at speech initiation during the comfortable condition. It may not have been efficient to increase lung volume above that, given that increasing lung volume requires even greater inspiratory muscular force at higher lung volumes (Rahn et al. 1946). However, speaking into lower lung volumes also requires significant muscle force; it has been documented that more expiratory muscle activation is used when individuals are at lower lung volumes (Estenne et al. 1990). Given the lung volumes used by older adults at comfortable loudness levels, either mechanism (increasing LVI or decreasing LVT) employed to increase loudness during extemporaneous speech would require additional muscular force and could lead to fatigue. There was no age difference in the effort ratings, potentially because each individual was rating on the basis of what they perceived their effort to be, relative to their own daily experience. As we age, we may adjust our view of our own effort to some extent, particularly for activities of daily living, like talking. Therefore, both groups may have perceived a similar proportional increase in effort, despite the fact that in real physiological terms, the older participants were taxing their respiratory systems to a greater extent.

In addition to the questions about aging, the data demonstrate some interesting findings relative to speech motor planning. Speakers planned in advance for longer utterances. The observed increased LVI with longer utterances suggests that speakers knew before beginning to speak that the utterance would be longer and inhaled more to ensure the ability to complete that utterance. Winkworth and colleagues (1994, 1995) found similar effects for young women. However, speakers did not use higher LVI as the only means for increasing respiratory drive. As shown by the utterance length effect on LVT, speakers still needed to continue to speak at lower lung volumes with longer utterances.

In summary, utterance length and loudness both had considerable influence on the effects of typical aging on speech breathing. Larger and clearer age-related effects were present for longer utterances and when participants were speaking loudly, suggesting that older adults have a more difficult time when the speech system is being taxed. However, the data demonstrate that longer utterances and louder speech are more of a challenge for both young and older adults. Finally, both young and older adults demonstrated pre-planning of speech respiration for utterance length. This suggests an interaction at higher cognitive levels between language formulation and speech motor control processes.

Acknowledgements

This research was funded by the National Institutes of Health, National Institute on Deafness and Other Communication Disorders, grant # 1R03DC05731, and a Research Support Incentive Grant from the Center on Aging and the Life Course at Purdue University.

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Figure 1.
Schematic of equipment set-up for data collection.

Figure 2.

Sound pressure level (SPL) in dB: Age (OA = older adults, YA = young adults) by loudness (COMF and LOUD). Bars represent mean SPL, measured in decibels (dB). Lines indicate standard errors.

Figure 3.

Number of syllables per breath group and speech rate: age (OA = older adults, YA = young adults) by utterance length effect. Bars represent mean number of syllables. Circles represent mean speech rate, measured in syllables per second. Lines indicate standard errors.

Figure 4. Lung volume initiation and termination: age condition interaction effect. Top of bars represent initiation. Bottom of bars represent termination. Lines indicate standard errors for initiation and termination. All data measured in percent vital capacity (%VC) and relative to end expiratory level (EEL).

Figure 5.

Lung volume excursion (LVE): age by utterance length interaction effect. Bars represent mean LVE, measured in percent vital capacity (%VC). Lines indicate standard errors.

Figure 6.
Percent vital capacity (%VC) expended per syllable (%VC/syl): age by utterance length effect.
Bars represent mean %VC/syl. Lines indicate standard errors.

Table 1

Number of utterances in each utterance length category as a function of age and loudness.

Age Group	ULC	Monologue Comf	Monologue Loud
OA	1	264	248
OA	2	239	206
OA	3	100	86
OA	4	37	33
YA	1	198	160
YA	2	265	260
YA	3	147	150
YA	4	82	74

ULC = utterance length category, Comf= comfortable condition, Loud = loud condition (speaking in noise); OA = older adults, YA = young adults

Table 2

Statistical summary for main effects. Format for results: F-ratio (alpha level), df = degrees of freedom, asterisks denote significant effects at $p \leq 0.006$.

Meas	Age (<u>df</u> = 1)	Loud (<u>df</u> = 1)	ULC (<u>df</u> = 3)
SPL	1.22 (0.274)	7655.70 (<0.001)*	5.32 (0.002)*
#SYL	11.65 (0.001)*	0.01 (0.919)	5930.05 (<0.001)*
Speech Rate	47.45 (<0.001)*	3.13 (0.084)	97.67 (<0.001)*
LVI	9.79 (0.003)*	11.22 (0.002)*	50.70 (<0.001)*
LVT	2.50 (0.120)	0.46 (0.503)	138.77 (<0.001)*
LVE	17.12 (<0.001)*	30.64 (<0.001)*	664.82 (<0.001)*
%VC/Syl	8.94 (0.004)*	5.98 (0.018)	35.27 (<0.001)*
Effort Ratings	1.21 (0.279)	36.09 (<0.001)*	N/A

Meas = Dependent Measure, ULC = utterance length category, Loud = loudness condition. #SYL = number of syllables, SPL = sound pressure level, LV = lung volume, I = initiation, T = termination, E = excursion, %VC/Syl = percent vital capacity expended per syllable.

Table 3

Statistical summary for interaction effects. Format for results: F-ratio (alpha level), df = degrees of freedom, asterisks denote significant effects at $p \leq 0.006$.

Meas	Group $\times$ Cond (<u>df</u> = 1)	Group $\times$ ULC (<u>df</u> = 3)	Cond $\times$ ULC (<u>df</u> = 3)	Group $\times$ Cond $\times$ ULC (<u>df</u> = 3)
SPL	35.70 (<0.001)*	0.17 (0.915)	1.80 (0.152)	4.11 (0.008)
#SYL	1.06 (0.310)	5.26 (0.002)	0.39 (0.758)	1.02 (0.388)
Speech Rate	1.31 (0.258)	4.87 (0.003)	1.03 (0.383)	2.07 (0.108)
LVI	33.60 (<0.001)*	2.01 (0.116)	0.66 (0.578)	0.55 (0.650)
LVT	36.81 (<0.001)*	2.70 (0.048)	0.79 (0.504)	0.41 (0.747)
LVE	0.06 (0.808)	7.48 (<0.001)*	3.59 (0.016)	0.38 (0.769)
%VC/Syl	0.01 (0.915)	5.62 (0.001)*	0.40 (0.753)	0.03 (0.994)
Effort Ratings	0.48 (0.493)	N/A	N/A	N/A

Meas = Dependent Measure, ULC = utterance length category, Loud = loudness condition. #SYL = number of syllables, SPL = sound pressure level, LV = lung volume, I = initiation, T = termination, E = excursion, %VC/Syl = percent vital capacity expended per syllable.

Table 4

Means and standard deviations (in parentheses) for main effects of utterance length.

Measurement	Category #1	Category #2	Category #3	Category #4
SPL (dB)	81.0 (6.9)	80.8 (6.6)	80.5 (6.4)	80.6 (7.5)
LVI (%VC)	19.2 (18.0)	22.7 (18.6)	24.7 (18.2)	30.4 (17.7)
LVT (%VC)	10.1 (17.3)	5.2 (17.6)	-0.8 (15.8)	-2.3 (14.4)

SPL = sound pressure level in decibels (dB), LVI = lung volume initiation in percent vital capacity (%VC) and relative to end expiratory level (EEL), LVT = lung volume termination in %VC and relative to EEL.

Appendix 1

Post-hoc p-values for comparisons of interest from the Tukey analysis on significant effects from ANOVA, asterisks denote significant effects at $p \leq 0.006$.

Measure	Effect	Comparison	p-value
Sound Pressure Level	Utterance Length Category	ULC 1 – ULC 2	0.126
		ULC 1 – ULC 3	<0.001*
		ULC 1 – ULC 4	0.932
		ULC 2 – ULC 3	0.120
		ULC 2 – ULC 4	0.896
		ULC 3 – ULC 4	0.147
	Age by Loudness	OA Comf – OA Loud	<0.001*
		YA Comf – YA Loud	<0.001*
		OA Comf – YA Comf	0.355
		OA Loud – YA Loud	0.949
Number of Syllables per Breath Group	Age by Utterance Length Category	OA 1 – OA 2	<0.001*
		OA 1 – OA 3	<0.001*
		OA 1 – OA 4	<0.001*
		OA 2 – OA 3	<0.001*
		OA 2 – OA 4	<0.001*
		OA 3 – OA 4	<0.001*
		YA 1 – YA 2	<0.001*
		YA 1 – YA 3	<0.001*
		YA 1 – YA 4	<0.001*
		YA 2 – YA 3	<0.001*
		YA 2 – YA 4	<0.001*
		YA 3 – YA 4	<0.001*
		OA 1 – YA 1	0.315
		OA 2 – YA 2	0.328
		OA 3 – YA 3	0.413
		OA 4 – YA 4	<0.001*
		OA 1 – OA 2	<0.001*
Speech Rate	Age by Utterance Length Category	OA 1 – OA 3	<0.001*
		OA 1 – OA 4	<0.001*
		OA 2 – OA 3	0.444
		OA 2 – OA 4	0.085
		OA 3 – OA 4	0.854
		YA 1 – YA 2	<0.001*
		YA 1 – YA 3	<0.001*
		YA 1 – YA 4	<0.001*
		YA 2 – YA 3	0.001*
		YA 2 – YA 4	<0.001*
		YA 3 – YA 4	0.929
		OA 1 – YA 1	0.007
		OA 2 – YA 2	<0.001*

Measure	Effect	Comparison	p-value
Lung Volume Initiation	Utterance Length Category	OA 3 – YA 3	<0.001*
		OA 4 – YA 4	<0.001*
		ULC 1 – ULC 2	<0.001*
		ULC 1 – ULC 3	<0.001*
		ULC 1 – ULC 4	<0.001*
		ULC 2 – ULC 3	0.003*
		ULC 2 – ULC 4	<0.001*
		ULC 3 – ULC 4	<0.001*
	Age by Loudness	OA Comf – OA Loud	0.510
		YA Comf – YA Loud	<0.001*
Lung Volume Termination	Utterance Length Category	OA Comf – YA Comf	0.001*
		OA Loud – YA Loud	0.141
		ULC 1 – ULC 2	<0.001*
		ULC 1 – ULC 3	<0.001*
		ULC 1 – ULC 4	<0.001*
		ULC 2 – ULC 3	<0.001*
		ULC 2 – ULC 4	<0.001*
		ULC 3 – ULC 4	0.001*
	Age by Loudness	OA Comf – OA Loud	0.003*
		YA Comf – YA Loud	<0.001*
Lung Volume Excursion	Loudness	OA Comf – YA Comf	0.061
		OA Loud – YA Loud	0.949
		Comf – Loud	<0.001*
		OA 1 – OA 2	<0.001*
		OA 1 – OA 3	<0.001*
		OA 1 – OA 4	<0.001*
		OA 2 – OA 3	<0.001*
		OA 2 – OA 4	<0.001*
		OA 3 – OA 4	<0.001*
		YA 1 – YA 2	<0.001*
	Age by Utterance Length Category	YA 1 – YA 3	<0.001*
		YA 1 – YA 4	<0.001*
		YA 2 – YA 3	<0.001*
		YA 2 – YA 4	<0.001*
		YA 3 – YA 4	<0.001*
		OA 1 – YA 1	0.194
		OA 2 – YA 2	0.095
		OA 3 – YA 3	0.003*
		OA 4 – YA 4	<0.001*
		OA 1 – OA 2	<0.001*
Percent Vital Capacity Per Syllable	Age by Utterance Length Category	OA 1 – OA 3	<0.001*
		OA 1 – OA 4	<0.001*

Measure	Effect	Comparison	p-value
Effort Ratings	Loud	OA 2 – OA 3	0.898
		OA 2 – OA 4	0.893
		OA 3 – OA 4	0.999
		YA 1 – YA 2	0.001*
		YA 1 – YA 3	<0.001*
		YA 1 – YA 4	<0.001*
		YA 2 – YA 3	0.816
		YA 2 – YA 4	0.557
		YA 3 – YA 4	0.996
		OA 1 – YA 1	<0.001*
		OA 2 – YA 2	0.208
		OA 3 – YA 3	0.580
		OA 4 – YA 4	0.865
		Comf – Loud	<0.001*

ULC = utterance length category, Comf= comfortable condition, Loud = loud condition (speaking in noise); OA = older adults, YA = young adults