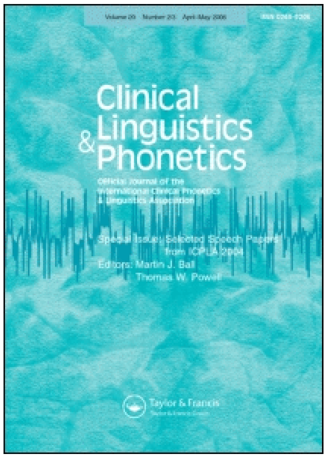


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## Lingual kinematic strategies used to increase speech rate: Comparison between younger and older adults

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# Lingual kinematic strategies used to increase speech rate: Comparison between younger and older adults

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**Abstract**
The primary objective of this study was to assess the lingual kinematic strategies used by younger and older adults to increase rate of speech. It was hypothesised that the strategies used by the older adults would differ from the young adults either as a direct result of, or in response to a need to compensate for, age-related changes in the tongue. Electromagnetic articulography was used to examine the tongue movements of eight young (M=26.7 years) and eight older (M=67.1 years) females during repetitions of /ta/ and /ka/ at a controlled moderate rate and then as fast as possible. The younger and older adults were found to significantly reduce consonant durations and increase syllable repetition rate by similar proportions. To achieve these reduced durations both groups appeared to use the same strategy, that of reducing the distances travelled by the tongue. Further comparisons at each rate, however, suggested a speed-accuracy trade-off and increased speech monitoring in the older adults. The results may assist in differentiating articulatory changes associated with normal aging from pathological changes found in disorders that affect the older population.

**Keywords:** *Aging, lingual dynamics, speech motor control, speech rate, electromagnetic articulography (EMA)*

## Introduction

Many physiological, anatomical and neurological changes occur in the human body as one ages. Common are reports of decreased skeletal muscle strength, muscle atrophy and increased muscle fatigability (Campbell, McComas, & Petito, 1973; Price, & Darvell, 1981; Wilder, 1984; Sonies, 1991; Crow, & Ship, 1996; Martini, 1998). Declines in sensory and motor nerve conduction velocity, motor unit loss, and a slowing of fine and gross motor movements (LaFratta, & Canestrari, 1966; Brown, 1972; Sonies, 1991) have also been observed, as have changes to the skeletal system, with bone loss and changes in bone composition (Sonies, 1991). Limited research has been carried out specifically to ascertain whether the same changes occur in the supralaryngeal structures (i.e., tongue,

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lips, jaw) with age. Changes in these structures and, in particular, the tongue, would likely affect speech.

Age-related changes in tongue structure and function include findings of muscle atrophy (Bassler, 1987), reductions in strength (Price, & Darvell, 1981; Robbins et al., 1995; Crow, & Ship, 1996), slower movements and reduced regularity in the rhythm of tongue movements (Hirai, Tanaka, Koshino, & Yajima, 1991). Increases in fatty tissue (lipomatosis) in the musculature of the tongue (Bassler, 1987), together with a narrowing of muscle fibres and fibrosis of the perimysium (Bassler, 1987) have also been found with increased age. In regards to the size of the tongue, Sonies, Baum, and Shawker (1984) noted that the tongues of older individuals (aged over 63 years) were reduced in thickness. Bassler (1987), however, noted that the loss of muscle fibres in the tongue is largely compensated by increased deposits of fatty tissue, which maintains the form and size of the tongue in older adults.

Contradictory evidence also exists to suggest that the tongue fails to show the same age-related physiological changes that are exhibited in other voluntary muscles throughout the body (Price, & Darvell, 1981; Crow, & Ship, 1996; Youmans, Stierwalt, & Clark, 2002). These studies suggest that age-related changes in the tongue are minimal to non-existent. In post-mortem sections of aged human tongues, Price and Darvell (1981) found no evidence of expected age-related changes. Tongue endurance has been reported to be maintained with age (Crow, & Ship, 1996; Youmans et al., 2002) and, in the case of older edentate denture wearers, significantly increased tongue forces have been recorded compared to younger dentate subjects (Price, & Darvell, 1981). It has been suggested that maintenance of tongue structure and function with aging can be attributed to the tongue's abundant vascular supply, which has been suggested to remain constant irrespective of age, and the constant high level of activity required of the tongue through such activities as mastication (Price, & Darvell, 1981; Breustedt, 1983; Crow, & Ship, 1996). This is particularly the case for those who wear dentures, where the tongue is required for retention and stabilisation of the prosthesis (Price, & Darvell, 1981; Breustedt, 1983; Crow, & Ship, 1996; Koshino, Hirai, Ishijima, & Ikeda, 1997).

In regards to the tongue's sensory function and feedback mechanisms, age-related reductions have been reported. Truex (1940) showed that a particular group of sensory cells in the oral epithelium undergo fatty degeneration and proposed that the loss of these sensory cells contributed to the reduced vibrotactile sensitivity found to be experienced in the oral and facial regions of older adults (cited in Kahane, 1981). Other researchers have specified a reduced ability to recognise form and shape intraorally and affected perception of lingual pressure associated with aging (Ostericher, & Hawk, 1982; Breustedt, 1983; Sonies, 1991). Proprioceptors have also been suggested to undergo alterations as a result of age induced submucosal changes in the oral epithelium (Kahane, 1981). Little research has been carried out to investigate oral sensory integrity despite its important role in articulatory feedback for speech and swallowing (Kahane, 1981; Wilder, 1984; Sonies, 1991).

A number of studies have reported age-related changes in oro-facial structures surrounding the tongue, which may have an effect on tongue function. Such changes include atrophy or absorption of the maxillary and mandibular alveolar bone and associated tooth loss (Kaplan, 1971; Zemlin, 1988). Bone growth has also been reported, resulting in a lengthening of the mandible body (Israel, 1973). The temporomandibular joint undergoes changes including a hardening and loss of elasticity of the capsular ligament and the interarticular disk, with the articular zone becoming increasingly fibrous (Kaplan, 1971; Kahane, 1981). Remodelling of the jaw and degradation of the temporomandibular joint may alter the lines of force of the articulators (Wilder, 1984) and could require coordination between the articulators to be reorganised (Weismer, & Liss, 1991). General changes with age in the oral mucosa include thinning or thickening, keratinisation, and increased dryness due to diminished salivary gland function (Kaplan, 1971; Kahane, 1981; Price, & Darvell, 1981; Sonies, 1991; Weismer, & Liss, 1991). Drying of the tongue and oral cavity's surface epithelium may lead to increased resistance of tongue movement across the palate when articulating speech sounds (Kahane, 1981).

Despite the contradictory findings regarding age-related changes to the tongue, a number of authors have argued that the age-related changes in tongue physiology that have previously been found, could lead to changes in speech production (e.g., Bassler, 1987; Sonies, 1991; Weismer, & Liss, 1991; Caruso, Mueller, & Shadden, 1995). The findings of changes to the tongue's environment in which it functions would also lend support to this conjecture. Specifically, for example, Bassler (1987) suggested increased amounts of fatty tissue and muscular atrophy of the tongue could result in speech output that was less energetic, while Kahane (1981) suggested that a reduction in the extent and speed of tongue movement could be anticipated.

Indeed, age-related changes in perceptual speech characteristics and acoustic measures have been reported in adults typically over 60 years, including the production of imprecise consonants and vowels (Ryan, & Burk, 1974; Parnell & Amerman, 1987; Shuey, 1989; Amerman, & Parnell, 1990), decreases in diadochokinetic (DDK), speech and reading rates (Ptacek, & Sander, 1966; Ptacek, Sander, Maloney & Jackson, 1966;Ryan, 1972; Ryan, & Burk, 1974; Ramig, 1983; Oyer, & Deal, 1985; Amerman, & Parnell, 1992; Flanagan, & Dembowski, 2002), and increased phoneme, syllable and sentence durations (Smith, Wasowicz, & Preston, 1987; Parnell, & Amerman, 1996). In a study conducted by Ryan and Burk (1974), imprecise consonants and a slow rate of articulation were found to be two of five speech characteristics that were strong predictors of perceived age. It should be noted, however, that as reported above for age-related physiological changes, conflicting results have also been reported regarding the effects of aging on speech performance (Shanks, 1970; Kruel, 1972).

Those age-related changes that have been found to occur in previous perceptual and acoustic studies of older adults' speech provide an indication of how tongue movements for speech may change with age. There is, however, a need for direct, objective, physiological investigations of these changes. This is particularly important given Sonies and Caruso's (1990) proposal that even for older adults who appear to be able to produce normal-sounding speech, the manner of producing this speech may differ from younger subjects (cited in Caruso, McClowry, & Max, 1997). Sonies et al. (1984) used the technique of ultrasound to study tongue movements in older versus younger speakers. She found significant differences in the direction and extent of tongue displacement during the production of /a/, with the older speakers minimising tongue retraction. Flanagan and Dembowski (2002) studied the relationship between articulator speed, range of articulatory movement, and syllable rate in groups of young and older adults using the X-ray microbeam technique. No significant differences in tongue speed or range of motion were found between the young and older adults during /tʌ/ and /kʌ/ diadochokinetic tasks. Further research concentrating on articulatory movements is necessary to understand how the aging process affects the force of movement and timing of the articulators during speech (Kahane, 1981). Parnell and Amerman (1996) highlighted that a profile detailing the characteristics of elderly adults' motor speech control is still needed.

Research on speech rate is an optimal way to study sensorimotor control of the speech mechanism (Hall, & Yairi, 1997). It is also an ideal parameter for studying the motor control changes that occur with age. There have been a number of studies that have investigated the articulatory kinematic strategies used to increase speech rate; that is, how articulatory movements change to affect an increased rate of speech (Gay, Ushijima, Hirose, & Cooper, 1974; Ostry, & Munhall, 1985; Flege, 1988; McClean, 2000; Goozée, LaPointe, & Murdoch, 2003). There has, however, been limited research focused on the articulatory kinematic mechanisms involved in speaking rate changes specifically in older adults.

The technique of electromagnetic articulography (EMA; Carstens Medizinelektronik GmbH, Germany) allows a range of articulatory kinematic parameters, such as the velocity, acceleration, duration and amplitude of articulatory movements during speech production to be calculated. Articulatory movements are tracked safely and non-invasively making it suitable for use with large numbers of subjects. This technique, therefore, has the potential to provide important insights into the effects of age on speech motor control and the mechanisms involved in speech rate changes.

The aim of this study was to use EMA to assess the articulatory kinematic strategies used by younger and older adults to increase rate of speech. It was hypothesised that the kinematic strategies used by older adults would differ from younger adults either as a direct result of, or in response to a need to compensate for, age-related physiological and anatomical changes to the tongue and its oral environment.



## Method

### *Participants*

Two groups of eight healthy, community-dwelling, non-neurologically impaired women participated in the study. One group was comprised of young adults aged 21.2 to 32.3 years (M=26.7), while the second group comprised older adults aged 62 to 73.2 years (M=67.1). The women included had perceptually normal speech as judged by a qualified speech language pathologist, and reported no substantial hearing difficulties. Three of the older adults had dentures and were asked to wear them during the EMA assessment. Each of these participants had been wearing dentures for over forty years and was included in the study to reflect a representative sample of older adults for investigation.

Women who had undergone oro-maxillo-facial surgery or who, in the past or presently, had any form of speech or neurological impairment were excluded from the study. All participants were native speakers of English. For this initial, preliminary study, only one gender was selected for investigation to avoid possible confounding effects of gender.

### *Procedure*

An EMA system (AG-100, Carstens Medizinelektronik GmbH, Germany) was used to track and record movements of the tongue along the mid-sagittal plane during a set of syllable repetition tasks. The EMA system is comprised of three transmitter coils that are housed within a plastic helmet and positioned around the participant's head in the mid-sagittal plane. The coils are arranged in an equilateral triangle (i.e., in front of the chin, in front of the forehead and behind the neck) and transmit alternating electromagnetic fields at different frequencies (range 10–20 kHz). The magnetic fields, in turn, induce alternating electrical signals in five miniature receiver coils (approximately $2 \times 2 \times 3$ mm in size) affixed to the articulators along the mid-sagittal plane. The size of the signals induced in the receiver coils is used by the system to calculate the distance between each transmitter coil and receiver coil (i.e., magnitude of signal inversely proportional to cube of distance from the transmitter coil) and, in turn, the position of the receiver coils within the two-dimensional mid-sagittal measuring plane. All testing was conducted in an electrically shielded, quiet laboratory room, and all participants were seated in a straight-backed chair. Prior to each assessment, the AG-100 system was switched on for at least 2 hours to allow time for the coils to warm. Once the system temperature had stabilised, the AG-100 system was calibrated in strict accordance with the procedures outlined in the AG-100 operating manual.

In the present study, receiver coil positions were sampled at a rate of 500 Hz. Two receiver coils were placed on the midline of the tongue (1cm and 4cm from the tongue tip) with a biologically-safe adhesive (Cyano Veneer Fast, a cyanoethyl liquid), while the tongue was in a resting position inside the mouth. Another two receiver coils were fixed in reference positions (i.e., points which did not move in relation to the head) on the bridge of the nose (using micropore tape) and on the gingiva above the two upper central incisors (using the adhesive). Each of the receiver coils were positioned with their axes perpendicular to the mid-sagittal plane, parallel with the axes of the transmitter coils. Once the receiver coils had been attached, the EMA helmet was lowered over the participant's head using a pulley system, which suspended and stabilised the helmet. A lapel microphone, which was connected to the EMA system, was attached to the participants to record their speech at a sampling rate of 16 kHz during the EMA testing.

A trace was first recorded of the occlusional plane using an unfixed receiver coil attached to the midline of a small custom-made plastic T-bar. The ends of the T-bar were run over the upper teeth, from the molars to the first or second bicuspid, to produce a midsagittal line plot of the occlusional/bite plane.

Before further recordings, participants were given approximately five minutes practice speaking time, or until the researchers deemed that there was no significant perceptual change in speech production that may be attributed to the coils being affixed to the tongue. Following this desensitisation period, the participants were then asked to produce twelve repetitions of both /ta/ and /ka/ at a moderate rate of three syllables per second that was modelled by one of the researchers (rate monitored using a stopwatch), and then at a rate as fast as possible. A rate of three syllables per second was chosen as this rate has been deemed to be closest to an average rate of speech (Higgins, Netsell, & Schulte, 1998). It was regarded as important to ensure that the participants produced the syllables in the moderate rate condition at a rate that was comfortable for them, rather than impose a strict syllable repetition rate that may have taxed their speech system. Rather than being strictly controlled by a metronome then, the moderate rate was modelled by the researcher simply as a guide for the participants. Each syllable and rate condition trial was repeated twice during the testing. The syllable repetitions of /ta/ and /ka/ and the receiver coil placements on the tongue tip and back were selected to examine anterior and posterior tongue movements, respectively. A syllable repetition task was favoured over a more natural speech task as other segments in a word or phrase may have been altered to increase rate of speech instead of the target syllable, thereby, concealing, in this study, the articulatory kinematic strategies used to increase rate of speech.

## Analysis

The data recorded using the EMA system was initially modified using the Tailor program (Carstens Medizinelektronik) to make it suitable for analysis. First, the sampling rate was down sampled from 500 to 250 Hz. The reference channels recorded from the receiver coils positioned on the bridge of the nose and above the two upper central incisors were then filtered (Filter 40, cutoff=8 Hz). Third, dynamic position correction was carried out, which corrected for any movements of the head relative to the helmet. Finally, the movement data was rotated to make the alignment of the occlusional plane parallel to the x-axis. This procedure corrected for differences in helmet position across participants and ensured that the orientation of the movement data within the x-y coordinate system was consistent between participants.



### *Kinematic parameter analysis*

For each of the syllable strings (two attempts each of /ta/ and /ka/ at moderate and fast rates), the number of syllables per second was calculated from the acoustic waveforms displayed in the EMA analysis program, Emalyse (Carstens Medizinelektronik). The syllable string closest to three syllables per second (for the moderate rate condition) and the fastest syllable string (for the fast rate condition) were chosen for analysis. All syllable repetitions were first screened for possible consonant distortions by one of the researchers and were deemed perceptually acceptable. For each of the chosen syllable strings, the middle seven repetitions were analysed (the first two syllables and last syllables were removed). The kinematic parameters analysed for each syllable included:

(i) maximum velocity (mm/s) computed for principal receiver coil (i.e., tongue tip coil for /ta/ and tongue back for /ka/) during the consonant approach (tongue movement toward palate) and release (tongue movement away from palate) phases of the two repeated consonants;
(ii) maximum acceleration (m/s$^2$) computed for principal receiver coil during consonant approach and release phases;
(iii) distance (mm) travelled by principal receiver coil during consonant approach and release phases;
(iv) duration (s) of approach and release phases.

These values were all semi-automatically calculated using custom-written Matlab scripts. The kinematic parameter values were averaged over the seven syllable repetitions.

### *Perceptual analysis*

Two qualified speech-language pathologists (SLPs), who were unrelated to the study, independently phonetically transcribed the syllable repetitions produced. The syllable repetitions recorded for each participant were presented in random order to the SLPs. The transcriptions were used to compare the listeners' perceptions of the syllables produced with the actual kinematic tongue movement data.

## Results

### *Syllable repetition rates*

The mean number of syllables per second for each of the conditions (/ta/ and /ka/ at moderate and fast rates) produced by the younger and older adults and mean percent increases in syllable rates from the moderate to the fast rate condition are presented in

Table I. Mean number of syllables per second and mean percent increase in rate for/ta/ and /ka/ from moderate to fast rate conditions for younger (n=8) and older adults (n=8).

| | /ta/ | | | /ka/ | | |
|---|---|---|---|---|---|---|
| | Rate | | | Rate | | |
| Subject Group | Moderate | Fast | % Increase | Moderate | Fast | % Increase |
| Younger Adults | 2.54 (0.13) | 5.42 (0.83) | 113.39% | 2.5 (0.2) | 4.84 (0.51) | 93.60% |
| Older Adults | 1.85 (0.25) | 4.00 (1.35) | 116.22% | 1.95 (0.31) | 3.09 (0.82) | 58.46% |

Note: Standard deviations appear in parentheses.



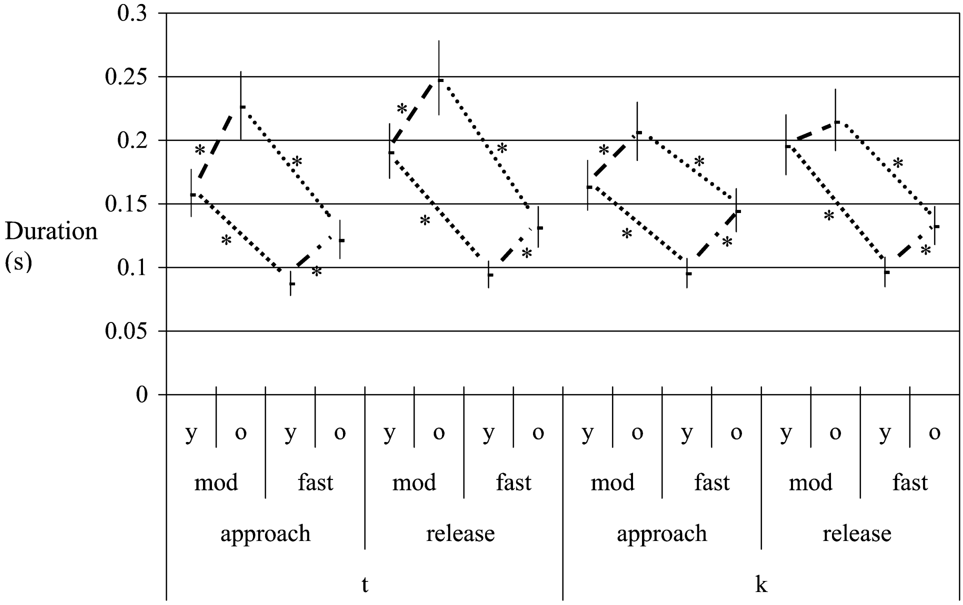
Table I and were compared using the Mann-Whitney U procedure (due to small sample sizes). The comparisons revealed significant ($p<.05$) differences between the younger and older groups for syllable repetition rates recorded for the /ta/ moderate rate condition ($U=0$, $p=.001$), /ta/ at a fast rate ($U=9$, $p=.016$) and /ka/ at a moderate rate ($U=6$, $p=.006$). Non-significant differences between the two groups were found for /ka/ fast rate ($U=13.5$, $p=.052$), and /ta/ ($U=26$, $p=.529$) and /ka/ ($U=25$, $p=.462$) moderate to fast rate percent increases in syllable repetition rate.

### *Kinematic results*

A repeated measurement model incorporating age as a between-subject factor and within-subjects factors of rate (moderate, fast), phase (approach, release) and consonant (/t/, /k/) was used to investigate the effects of rate variation on each of the kinematic variables measured during the syllable repetition tasks (seven repetitions of /ta/ and /ka/ at moderate and fast rates) and to examine whether rate-related kinematic changes differed between the older and younger adults. The model defined subject as a random factor allowing for both subject and measurement variation. Fixed factors included phase, rate, consonant and all their interactions. The model was applied using the R programming language (Ihaka, & Gentleman, 1996). A probability level of .05 was adopted for all significance testing.

Mean duration, mean maximum velocity, mean maximum acceleration, and mean distance values and 95% confidence intervals for the young and older subject groups at moderate and fast speech rates are presented in Figures 1 to 4. The Repeated Measures (RM) ANOVA for the parameter, duration, revealed that only the main effects of age ($p<.0001$), rate ($p<.0001$), and phase ($p=.0035$) were significant with some moderately significant two-factor interactions ($.01<p<.05$) that did not include age. The mean values indicated that the younger adults' durations were significantly shorter (i.e., outside the confidence interval) than the older adults' durations by approximately 27% on average for the approach and release phases of /t/ and /k/ at both fast and moderate rates, with one exception. This exception was for the duration of /k/ release during the moderate rate condition for which the younger and older adults' durations were comparable. In regards to changes with rate, both the younger and older adults significantly reduced duration for the two consonants and across phases by approximately 30 to 50% in the fast rate condition compared to the moderate rate condition (see Figure 1).

For mean maximum velocity, the RM ANOVA revealed a non-significant four-factor (age $\times$ rate $\times$ consonant $\times$ phase) interaction effect ($p=.8915$) and non-significant three-factor



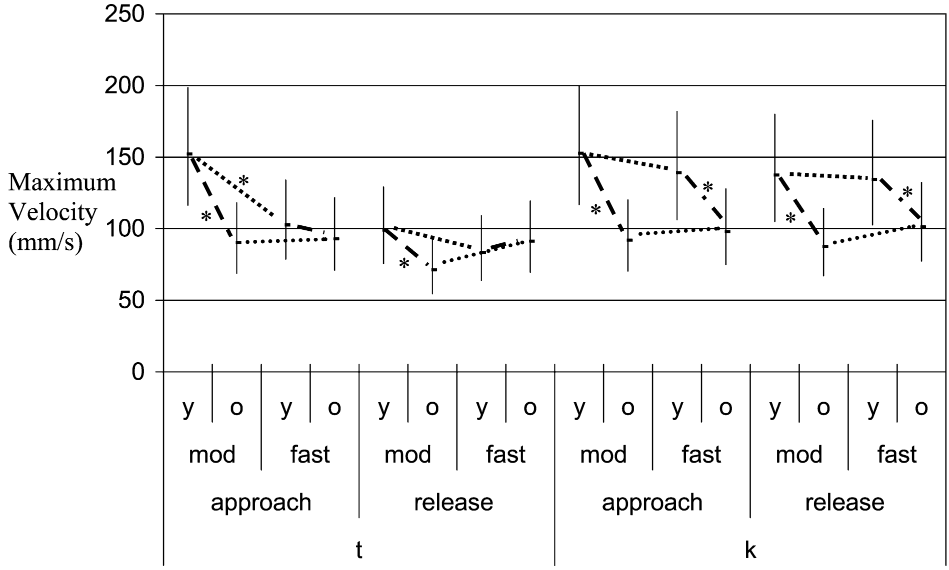

*Note*: Vertical line delineates confidence interval; mean represented as ▪; * significant being outside of confidence interval.

Figure 1. Mean duration and 95% confidence intervals for the younger (n=8) and older (n=8) female groups at moderate and fast speech rates.

interactions (p>.05), with one exception between age, rate and consonant (p=.0005). Figure 2 shows that the younger adults exhibited significantly greater velocities (i.e., outside confidence intervals) compared to the older adults for /t/ and /k/ productions (across both approach and release phases) during the moderate rate condition and during fast rate /k/ approach and release productions. From the moderate to the fast rate condition, maximum velocity was found to only significantly change (i.e., decrease) for the young adults' /t/ approach phase (see Figure 2).

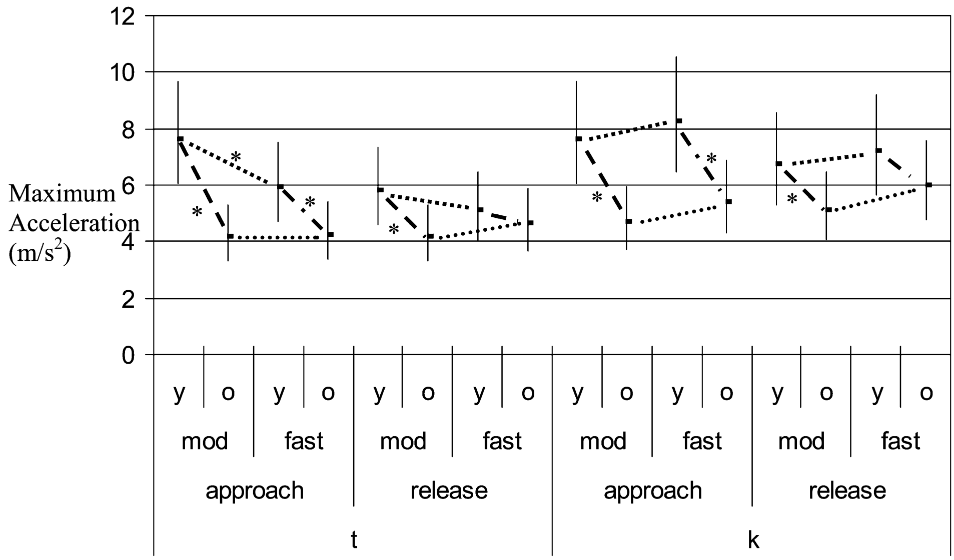
No significant three- or four-factor interactions were revealed by the RM ANOVA for mean maximum acceleration. The only two-factor interaction found to be significant was rate by consonant (p=.0025). The younger adults exhibited significantly higher maximum acceleration values (i.e., outside confidence interval) compared to the older adults for the approach and release phases of /t/ and /k/ during the moderate rate condition and for the /t/ and /k/ approach phases during the fast rate condition (see Figure 3). Similar to maximum velocity, only for the young adults' /t/ approach phase was a significant change (i.e., decrease) noted for maximum acceleration from the moderate rate condition to the fast rate condition (see Figure 3).

For mean distance travelled by the tongue, the RM ANOVA revealed main effects of rate (p<.0001) and consonant (p<.0001), and significant two-factor interaction effects between age and rate (p<.0001), age and consonant (p<.0001), and rate and consonant (p<.0001). Both the younger and older groups significantly decreased distance in the fast rate condition (i.e., outside confidence interval) compared to the moderate rate condition across consonants and phases by 43.5% (younger) and 30% (older) on average, respectively (see Figure 4). For the production of /k/ at a moderate rate (approach and




*Note*: Vertical line delineates confidence interval; mean represented as ▪; * significant being outside of confidence interval.

Figure 2. Mean maximum velocity and 95% confidence intervals for the younger (n=8) and older female (n=8) groups at moderate and fast speech rates.




*Note*: Vertical line delineates confidence interval; mean represented as ▪; * significant being outside of confidence interval.

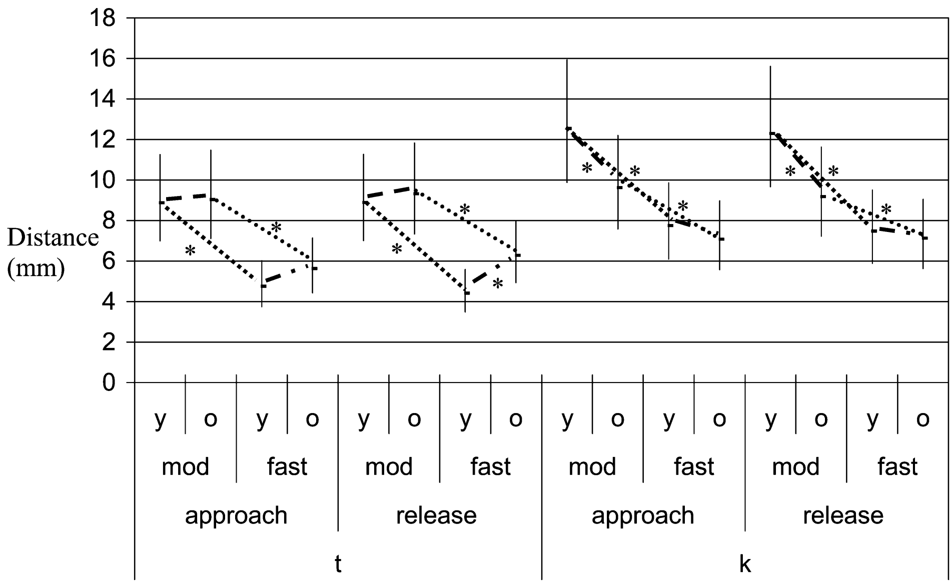
Figure 3. Mean maximum acceleration and 95% confidence intervals for the younger (n=8) and older female (n=8) groups at moderate and fast speech rates.

release phases), the older adults' tongues travelled significantly less distances compared to the younger adults, yet the distances travelled during the fast rate were comparable between the two age groups. This finding indicated that during /k/, the younger adults exhibited a greater decrease (approx. 39%) in the mean distance travelled from the moderate to the fast rate condition compared to the older adults (approx. 24%). Similarly, for /t/ release, the younger adults reduced their distances to a greater extent from the moderate to the fast rate condition (50.4% younger compared to 32.6% older), with significantly shorter distances being exhibited by the younger adults during the fast rate condition compared to the older adults (see Figure 4).

### *Perceptual results*

The two speech-language pathologists who independently phonetically transcribed the syllable repetitions demonstrated 100% agreement for the younger and older adults' consonant productions, but lower agreement for vowel productions (i.e., 80% agreement for younger adults' vowels and 63.33% agreement for older adults' vowels). Agreement was recorded when both raters noted that the phonemes had/had not changed from the target.

Table II displays the proportion of participants who were perceived to change their syllable productions from the targets (i.e., /ta/, /ka/) in the moderate and fast rate repetition conditions. The changes were characterised predominantly as vowel shortening during the fast rate condition, with these changes perceived to be exhibited by similar proportions of younger and older adults (i.e., approx. 60% of participants during /ta/ fast and approx. 40% of participants during /ka/ fast).




*Note*: Vertical line delineates confidence interval; mean represented as ▪; * significant being outside of confidence interval.

Figure 4. Mean distance and 95% confidence intervals for the younger (n=8) and older female (n=8) groups at moderate and fast speech rates.

Table II. Percentage of older and younger females perceived by two speech pathologists (SLPs) to change syllable productions from target.

| | Target syllable | Rate | SLP 1 | SLP 2 |
|---|---|---|---|---|
| Young adults | /ta/ | Moderate | 0 | 0 |
| | | Fast | 62.5 - vowel shortened | 62.5 - /∧/; 12.5 - /a - ∧/ |
| | /ka/ | Moderate | 0 | 0 |
| | | Fast | 42.9 - vowel shortened | 28.6 - /∧/; 14.3 - /a - ∧ / |
| Older adults | /ta/ | Moderate | 0 | 25 - vowel prolonged |
| | | Fast | 57.1 - vowel shortened | 28.6 - /∧/ |
| | /ka/ | Moderate | 0 | 25 - vowel prolonged |
| | | Fast | 37.5 - vowel shortened | 12.5 - /∧/; 25 - /a - ∧/ |

*Note*: /a - ∧/ = varied between /a/ and /∧/; one younger adult's /ka/ data not recorded; one older adult's /ta/ not analysed due to equipment fault.



## Discussion

The focus of this study was directed at examining the articulatory kinematic strategies used to increase rate of speech and whether differences existed between younger and older adults in the use of such strategies. The participants were asked to repeat the syllables /ta/ and /ka/ at a moderate rate (modelled at three syllables/s) and then as fast as possible. Both the younger and older adults were found to significantly reduce consonant approach and release phase durations by similar proportions to increase syllable repetition rate, as evidenced by the finding of a non-significant age by rate interaction effect for duration. This finding is consistent with the percentage increase in syllable repetition rate results, which revealed that the older adults in the study increased their syllable repetition rate from the moderate to the fast rate condition by the same degree as the young adults. It is also consistent with the perceptual findings, which showed that similar proportions of older and younger adults were perceived to shorten their vowels during the fast rate syllable repetitions. Similar findings were presented by Smith et al. (1987) who found comparable reductions in speech durations exhibited between older and younger adults when speech rate increased from normal to fast. The authors postulated on the basis of this result that the older and younger adults were using similar strategies to increase rate of speech. The objective kinematic analyses that were afforded by EMA in the present study appear to confirm this postulate.

It appears that the younger and older adults were using the same strategy to reduce consonant durations and, in turn, increase syllable repetition rate. This strategy involved reducing the distances travelled by the tongue up to and away from the palate during the consonant productions in the fast rate condition compared to the moderate rate condition. The velocity and acceleration parameters were only manipulated by the younger group during the approach phase of /t/, with reductions in velocity and acceleration observed during the fast rate condition. These reductions are likely to be related to the reduced distances being travelled, however, given previous findings which have shown that velocity is positively correlated to the distance travelled (Kuehn, & Moll, 1976; Ostry, & Munhall, 1985). The shorter distances may have prevented large velocities being reached, which additionally may have negated the need for large accelerations. The velocity and acceleration manipulations could be considered "reactive" then to the reductions in distance, rather than "active" mechanisms as would be considered had increases in velocity and acceleration been observed. It appears, therefore, that both the younger and older adults were not utilising an "active" mechanism to increase speech rate, but rather were economising on effort.

Despite the similarity in articulatory strategy being used to increase rate, a difference was observed between the younger and older adults in terms of the extent to which distance was reduced in the fast rate condition compared to the moderate rate condition, with the younger adults showing greater decreases. The reduced decrease in distance found for the older adults may be due to a number of possible factors including a reduction in neuromotor control of the tongue, as has been previously suggested to occur with aging by Sonies et al. (1984). Bose, Van Lieshout, and Square (2001) reported that with smaller articulatory movements comes a decrease in the maintenance of stability. The older adults in this study, therefore, may not have decreased their distances to the same extent as the younger adults in an effort to maintain stability of their tongue movements and counteract potential reductions in neuromuscular control. It is also possible that the older adults may not have reduced distances to the same extent as the younger adults due to potential sensory changes, such as decreased proprioception of the tongue (Kahane 1981), leading to compromised articulatory feedback. The older adults may have had a decreased ability to judge the distances being travelled by the tongue (Weismer, & Liss, 1991), which may have possibly contributed to distances being decreased less in the fast rate condition compared to the younger adults.

Comparisons between the younger and older adults' syllable repetitions rates and kinematic values recorded at the different rates also provide indications of possible age-related changes in neuromotor control of the tongue for speech. At both the moderate and fast rates, the durations of the /t/ and /k/ consonant approach and release phases were significantly shorter for the younger adults compared to the older adults (with the exception of /k/ release in the moderate rate condition), which is consistent with the finding of increased syllable repetition rates exhibited by the younger adults. Greater velocities and accelerations were typically exhibited by the younger adults during the moderate rate condition, which could possibly account for the shorter durations recorded. For the fast rate condition, shorter durations appeared to be achieved by the younger adults by shorter distances being travelled by the tongue during /t/ release and greater velocity values being reached during /k/ approach and release compared to the older adults. For /t/ approach during the fast rate condition, the underlying nature of the shorter durations were unclear given that the younger adults exhibited comparable velocity, acceleration and distance values to the older adults.

Since the rate was not strictly controlled (e.g., via a metronome) during the moderate and fast rate conditions, the possibility that the older adults "chose" to produce syllable repetitions at a reduced and perhaps a more comfortable rate cannot be ruled out. The longer durations, lessened decreases in distance, and reduced velocity and acceleration values found for the older adults all provide support for the notion of a "speed-accuracy trade-off" in the speech of older adults (Welford, 1977; Salthouse, 1988; Amerman, & Parnell, 1992; Parnell, & Amerman, 1996). As expounded by Parnell and Amerman (1996, p. 114), speed-accuracy trade-off is "reflective of effort to maintain accuracy in the face of declining anatomical and physiological support". The strategies of lessened reductions in distances being travelled by the tongue and increased syllable durations would provide time for, or indeed may be the result of, increased speech monitoring (Kent, & Burkard, 1981; Smith et al., 1987; Welford, 1977). Increased speech monitoring would be expected to facilitate accuracy of productions and may be needed to augment afferent feedback in the face of sensory declines or may stem from a general tendency of older adults to exhibit caution in their performances (Welford, 1977). Increased monitoring may have also been required during the speech production performances of the older adults to compensate for potential compromises in the central nervous system (CNS) including a decreased ability to distinguish between purposeful or relevant neural signals and random activity (noise) generated by the CNS (Welford, 1977). Indeed, this proposal of reduced signal-to-noise ratio in the CNS of older adults may account directly for the longer syllable durations and lessened decreases in lingual distance recorded for the older adults in the present study.

## Conclusions and future directions

In conclusion, the results indicated that the articulatory kinematic strategy used by a group of older adult females aged between 62 and 73 years to increase syllable repetition rate was similar to that used by a group of younger adult females aged 21 to 32 years. That is, the distance travelled by the tongue was reduced in order to shorten consonant durations and, in turn, increase syllable repetition rates. A difference in the extent to which distance was reduced was observed, however, with the younger group exhibiting greater reductions in distance compared to the older group. Overall, the older group exhibited slower syllable repetition rates, and typically demonstrated decreased velocity and acceleration values compared to the younger group. These differences may be in part due to age-related physiological, neuromotor, and/or sensory declines, or compensatory techniques to maintain articulatory stability or speech output accuracy.

The findings and proposals generated in this study need further investigation using larger and broader groups of subjects, including males, individuals from older age groups, and individuals of different health status. Only healthy females, aged 73 years and under, were included in the present study. The potential influence of dentures on articulatory movements should also be considered in future studies of aging, with participants with and participants without dentures being examined separately. Articulatory compensations may be made in response to changes to the dimensions of the oral cavity and oral sensation caused by wearing dentures (Hamlet, & Stone, 1978; Kelso, & Tuller, 1983; McFarland, & Baum, 1995; Baum, & McFarland, 1997, 2000). Indeed, the tongue, itself, may change physiologically due to the presence of dentures. Price and Darvell (1981) found an increase in tongue force exhibited by older adults who wear dentures and hypothesised that this increased force may be due to an extended use of the tongue to stabilise the dentures.

The range of articulatory parameters investigated could also be extended to include the positioning and motion paths of the articulators and not solely the quantitative, temporal aspects of speech production, so that the notion of a "speed-accuracy trade-off" in the speech of older adults can be further examined objectively. Further, the range of speech tasks employed should be expanded to include real words and sentences in order to examine articulatory strategies employed during more natural speech.

The articulatory kinematic findings of the present study, which involved comparisons between younger and older adults, provide further insight into the changes that occur with aging in normal, healthy individuals. These results may assist in the differentiation of articulatory changes associated with normal aging from those pathological changes found with diseases such as Parkinson's disease that typically affect the older population.

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