An analysis of speech rate strategies in aging

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Abstract

Effects of age and speech rate on movement cycle duration were assessed using electromagnetic articulography. In a repetitive task syllables were articulated at eight rates, obtained by metronome and self-pacing. Results indicate that increased speech rate is associated with increasing movement cycle duration stability, while decreased rate leads to a decrease in uniformity of cycle duration, supporting the view that alterations in speech rate are associated with different motor control strategies involving durational manipulations. The relative contribution of closing movement durations increases with decreasing speech rate, and is a more dominant strategy for elderly speakers.

Index Terms: aging, speech rate, kinematics, speech motor control

1. Introduction

Aging has been known to bring changes in the production of speech sounds. Smith, Wasowicz and Preston [1] compared sentence-, syllable- and segment durations between younger adults and older adults in a series of repetition tasks at self chosen habitual and fast rates. It was found that for both groups durations were significantly shorter at fast rates, compared to the habitual rates. In addition, the older participants consistently produced longer durations than the younger adults for both speech rates. Amerman and Parnell [2] investigated consonant duration in VCV syllables produced at habitual speech rate by young and older adults. Durational measurements show that consonants durations were significantly longer for the older adults, as compared to the younger group. Benjamin [3] investigated the phonological performance of young and older adults in voiced and unvoiced stop consonants. Voice onset time (VOT) and length of consonants and vowels were measured in speech samples obtained from a reading task. Vowel durations and silent intervals in stop consonants were longer for older adults, while VOT values were shorter. These studies suggest that an important strategy in increasing speech rate is to decrease segment duration, irrespective of age. In addition, it seems that older speakers generally produce longer segment durations, resulting in a decreased speech rate compared to younger speakers.

As to what causes these effects of age on speech production, the picture remains unclear. One possibility is that they might be induced by change in the anatomical structures of vocal tract organs. In particular, it has been proposed that the structure and function of the tongue changes with aging. Atrophy and fibrosis of the tongue muscle may lead to a decrease in muscle strength [4], and a decreased regularity in rhythmic tongue movements [5], resulting in reduced speech rates and affected articulatory precision. Another possible cause of age-related changes in speech production is of neurological nature. A slowing of nerve conduction velocities in the peripheral nervous system and a decrease of central neurotransmitters may account for a general slowing of speech articulation [4]. However, Bennet, van Lieshout and Steel [6] did not find an effect of age on tongue movement duration in speech tasks.

One way to study how the aging process affects the timing and execution of articulatory movements is by using speech rate as an experimental parameter. Adams, Weismer and Kent [7] investigated the effect of speaking rate on the velocity profiles of lower lip and tongue movements. Five speaking rates were obtained by means of a magnitude production procedure, where subjects were asked to produce speaking rates in ratios of four, two, one half and one quarter of their habitual speech rate. Movement duration effectively increased with decreasing speech rate. At the slower speaking rates, median durations of tongue tip movements were larger than lower lip movements. Furthermore, the effects of rate on the movement duration were more consistent for the opening movements than the closing movements. Goozee, Lapointe and Murdoch [8] used electromagnetic articulography (EMA) to analyze how kinematic parameters change with increasing speech rate. A group of healthy adults produced the syllable /ta/ and /ka/ at a self-chosen habitual- and fast rate. Results showed that increasing speech rate from habitual to fast led to a reduction in the duration of tongue movements. In a subsequent study, Goozee, Stephenson, Murdoch, Darnell and Lapointe [9] carried out a detailed analysis of individual articulatory movements in the speech of older as compared to younger adults. The two groups performed a repetition task, while lip- and tongue movements were recorded by EMA. Participants repeated the syllables

/ka/ and /ta/ at around three syllables per second, and as fast as possible. It was found that movement cycle durations for younger adults were generally significantly shorter for the closure and opening phase at both fast and moderate rates, but no further interaction effects of rate and age were found. Their findings suggested that older adults are more restricted to go faster, or alternatively, opt for a motor control strategy which favours accuracy over speed. If one assumes that the rate differences observed between young and older speakers in previous studies are due to such monitoring strategy rather than physiological changes, then one might expect that older speakers are capable of producing speech at a rate similar to those usually realized by younger speakers, if they are forced to do so.

The current study was designed to evaluate the influence of age on the movement cycle durations during the production of reiterated non-word utterances with a controlled timing of speech rate by the use of an auditory metronome. The first question was whether the rate of articulation modeled by an external metronome could be matched equally well by younger and older adults. In addition, it was investigated how movement cycle duration is used as a strategy to increase and decrease syllable repetition rates in both young and older adults, and whether opening and closing movements are differentially affected by this process, as Adams et al. [7] (among others) found.

2. Method

2.1. Participants

Sixteen adults participated in the study, eight young and eight elderly speakers. All participants were native speakers of Dutch and neurologically unimpaired, without self-reported previous or current speech problems. The group of young adults included two males and six females aged 21-27 with a mean of 23.3 years. The group of older adults included four males and four females aged 66-84 with a mean of 74.4 years. In the group of older adults, four subjects had full or partial dental plates or prosthesis. They had been fitted for a period longer than one year, and participants wore them during the study. Two participants had a hearing aid, but reported to use them only rarely. Neither used their hearing aid during the experiments.

2.2. Instrumentation and procedures

Articulatory and acoustic data were collected using an AG100 Carstens Electro-Magnetic Midsaggital Articulograph (EMMA) with time-aligned audio signal (Carstens Medizinelektronic, GmbH, Germany). Position data were sampled at 400Hz, while acoustic data were sampled at 16kHz.

The transducer coils were attached following the procedure described by van Lieshout, Bose, Square and Steele [10]. Micropore tape was used to attach coils to the midline positions of the vermillion border of upper lip and lower lip. Surgical tissue glue (Indermil, Henkel) and micropore tape was used to attach coils to gums of the lower and upper incisors, of which the latter coil served as a reference coil. A second reference coil was placed on the nose bridge using micropore tape. The remaining coils were glued to the tongue blade (approximately 1 cm behind tongue tip), the tongue body (approximately 2 cm behind tongue blade coil), and the tongue dorsum (approximately 3 cm behind tongue blade coil). Subjects were given speaking practice time for around 5 minutes in a casual conversation, to get used to the transducer coils attached to their articulators.

2.3. Task

The participants repeated three different syllables (/pa/, /sa/, and /ta/) in a single trial of 12 seconds. There were two pacing conditions: self-pacing and metronome timing. For the self-paced condition, participants were instructed to produce the items at their self chosen habitual, slow and fast but still intelligible rate. For the metronome condition, a digital auditory metronome (Adobe Audition v1.5) was used to model speech tempo, in order to obtain controlled speech rates at 2, 2.5, 3, 3.5, and 4 beats per second (bps). Participants were instructed to repeat the test items at the dictated speed of the metronome, one syllable to a beat. Prior to recording, the metronome was started and the subjects were instructed to mentally tune into the rhythm of the beats. When the subjects deemed to be tuned into the metronome beat, a hand or thumb up signal was given. Subsequently, the experimenter switched off the metronome and started the recording, after which the subjects repeated the stimulus. Before starting actual recordings, the subject practiced the procedure of timing with the metronome beat for all test items, until the experimenter deemed that the subject was able to do so. Metronome speed was set at 2, 2.5, 3, 3.5, and 4 bps. The participants were instructed to take a deep breath prior to repeating the stimulus for around 12 seconds. An orthographic description of the actual stimulus was visible on the screen, and if necessary, the experimenter modeled the syllable once or twice. After the recording of a trial finished, the acoustic speech sample was played back automatically over a speaker system. The experimenter judged the trial on phonemic production errors, pauses, interruptions, rate accelerations and decelerations, and if present, the trial was repeated at the end of the series. The presentation of test items was blocked for speech task, in the order /pa/ - /sa/ - /ta/. Of each speech task, first the self-paced conditions were recorded, in the order habitual - slow - fast. Subsequently the metronome paced conditions were done, linearly ordered from slow to fast rate.

2.4. Analysis

The speech task /pa/ involves a bilabial closure gesture for the voiceless plosive /p/. For this speech task, movement data were analyzed of the principal articulator, represented by the transducer coil attached to the lower lip. The alveolar plosive /t/ in speech task /ta/ and the alveolar fricative /s/ in speech task /sa/ involve a tongue tip constriction gesture. For these speech tasks, movement data were analyzed of the transducer coil attached to the tongue blade. All movement signals were filtered using the Tailor Data Processing Program v1.3 (Carstens Medizinelektronic, GmbH, Germany). The data for articulator lower lip and tongue blade were sampled down to 100Hz. The reference data nose bridge and upper jaw incisor were sampled down to 40Hz. Subsequently, movement data were corrected, to compensate for subject-specific anatomical differences and variations in helmet positions, as well as rotational misalignments i.e. ‘twist’ and ‘tilt’ movements [11]. Head movements relative to the helmet position were corrected for each participant, using information of the two reference points from the first error-free speech trial. After normalizing, the data were processed in Matlab, following standardized procedures [12, 13, 10]. For the kinematic measurements of the lower lip channel, signals were corrected for jaw movement [14]. Positional information over time for individual articulators was used to automatically identify and mark peaks and valleys of the movements. When

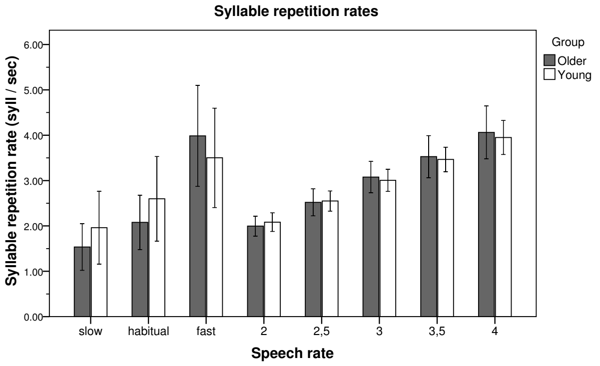

Figure 1: *Means and standard deviations of syllable repetition rates across speech tasks, broken down by group and speech rate.*

necessary, manual peak correction was applied. The peak-to-peak or valley-to-valley segment is referred to as a movement cycle. Movement duration was derived from the position data for every cycle.

For each of the recordings, syllable repetition rate was calculated based on the acoustic waveforms. Only fluent, error-free parts of the recordings were selected, yielding a string of seven to ten repetitions per syllable for each participant. For each syllable the movement duration (in sec) of closing (valley-to-peak) and opening (peak-to-valley) phases of tongue blade movements in syllables /sa/ and /ta/ and lower lip movements in syllable /pa/ were analyzed.

3. Results

3.1. Syllable repetition rates

Syllable repetition rate was analyzed using a repeated measurement model. The younger and older adults formed the between-subject factor ‘group’. Within-subject factors were ‘rate’ (slow, habitual and fast in the self-paced rate condition and 2, 2.5, 3, 3.5 and 4 bps in the metronome condition) and ‘task’ (/pa/, /sa/, and /ta/). An Huynh-Feldt epsilon correction was applied where the sphericity assumption was not met. In the self-paced condition, a significant effect for rate was found [F(1.51,21.13) = 233,91, $p < .001$], as well as interaction effects of rate*group [F(1.51,21.13) = 15,83, $p < .001$] and task*group [F(1.65,23.15) = 5,272, $p < .05$]. Both groups changed their articulation rate in the self-paced conditions, but the older adults were faster in the fast condition, and slower in the slow and habitual condition, relative to the young adults. Across speech rates, the older adults were systematically faster in speech task /pa/, but slower in /sa/ and /ta/, compared to the young adults.

In the metronome condition, a significant effect for rate was found [F(1.67,23.33) = 413.37, $p < .001$], indicating that both groups were equally succesful in increasing speech rate across rate conditions, irrespective of speech task. Figure 1 shows the mean syllable repetition rate across speech tasks broken down by group and speech rate.

3.2. Duration

In the analysis of syllable repetition rate no significant main or interaction effects for task were found in this condition, unlike the self-paced condition. Therefore, movement duration was analyzed for the metronome paced condition only. No differences were found in mean movement cycle duration across speech task, which allowed for collapsing movement durations over speech task. A repeated measurement model was used to analyze movement cycle duration. The younger and older adults formed the between-subject factor ‘group’. Within-subjects factors were ‘rate’ (2, 2.5, 3, 3.5 and 4 bps) and ‘direction’ (opening and closing movements). A between-subject effect of group was found [F(1,46) = 7.11, $p < .05$], along with within-subject effects of direction [F(1,46) = 70.01, $p < .001$], rate [F(1.89,87.01) = 878.14, $p < .001$], and interaction effects of direction*group [F(1,46) = 4,2, $p < .05$], rate*group [F(1.89,87.01) = 5.75, $p < .01$], direction*rate [F(1.60,73.41) = 84.87, $p < .001$] and a three-way interaction effect of direction*rate*group [F(1.60,73.41) = 5.53, $p < .05$]. Inspection of the data reveals that, for both groups, an increase in speech rate was associated with a decrease in movement cycle duration. Cycle durations were longer for closing movements, compared to opening durations. This effect was significantly more present in the group of older adults. Across speech rate and direction of movement, the results indicate that mean cycle durations are higher for younger adults. The relative contribution of the duration of closing movements compared to opening movements increases with decreasing speech rate, while the 3-way interaction indicates this effect is significantly more present in older adults. These effects are visible in figure 2, where mean movement cycle duration is plotted against the five metrome rates broken down by age group and direction of movement.

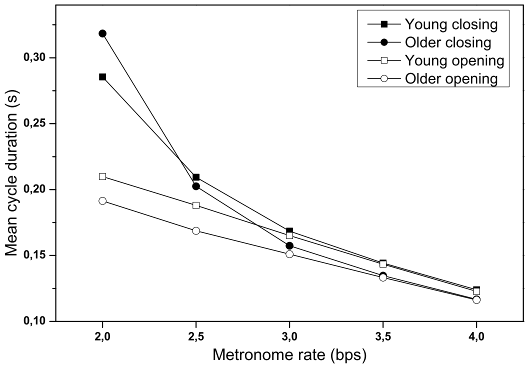

Figure 2: *Mean movement cycle duration per metronome pacing rate, broken down by group and direction of movement.*

The relation between realized syllable rate and corresponding movement cycle duration is presented in figure 3. The data are merged for the results of both young and older adults, and both pacing conditions (self-paced and metronome), broken down by direction of articulation (opening or closing movements). As shown in the figure, with an increasing realized repetition rate, movement duration is decreasing, both for opening and closing movements. For the closing movements of both speaker groups, a decrease in articulation rate below two syllables per second corresponds to a dramatic increase in movement duration. This trend is absent in the opening movements.

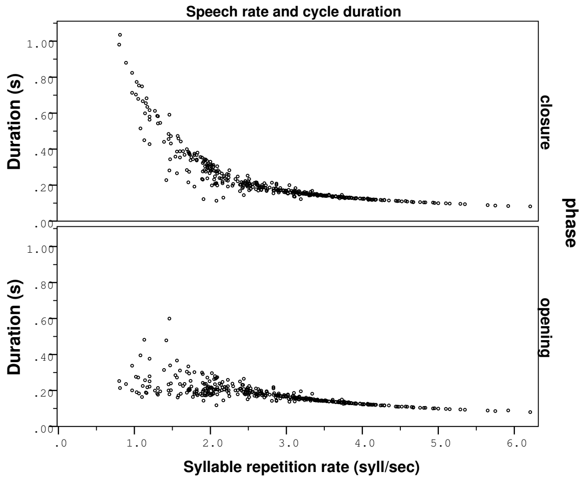

Figure 3: *Scatterplot of syllable repetition rate versus movement cycle durations of the speech of young and older speakers, broken down by direction of articulation.*

4. Discussion and Conclusions

In this study, the influence of speech rate on movement cycle durations of younger and older adults was investigated. Mean syllable repetition rates obtained in the self-paced condition yielded differences between age groups: for habitual and slow rate young adults were significantly faster, while in the fast rate, the older adults were faster. Older adults were capable of reaching syllable repetition rates equal to younger adults, but seem to prefer slower rates at their habitual and slow rates however, which points at a possible speed-accuracy trade-off. In other words, they could go as fast as young speakers, if they have to, but they preferred not to if they can. This is in line with Bennett et al. [6], but goes against Goozee et al. [8], who found that older adults were slower at fast self-paced rate.

In the metronome condition, syllable rates were comparable between the groups of young and older adults, indicating that using an auditory metronome cue as pacer was successful in controlling speech rate.

Both groups effectively reduced duration of the movements of lower lip and tongue tip with increasing articulation rate in respectively the syllables /pa/, and /sa/ and /ta/. The reduction of duration as a strategy to increase articulation rate has also been found by Ostry et al. [15], Smith et al. [1] and Goozee et al. [9]. For both groups, the durations of closing movements were longer than for opening movements. A difference in opening and closing movements has also found by Adams et al. [7]. When decreasing articulation tempo from habitual rate, the difference between the duration of opening and closing movements became larger, indicating that closing movements are more important in speech rate changes. In the metronome-paced condition, where the five different speech rates did not significantly differ across groups, this asymmetrical effect was significantly stronger for the older adults, and points at an age-related change of strategy in speech motor control when decreasing speech rate. Since the use of a metronome was successful in controlling speech rate, possible speech-accuracy trade-off effects were eliminated. On this basis it can be argued that the age-related durational effects in increasing speech rate found by Goozee et al. [9] cannot be explained in terms of differences in strategy or neurological or physiological limitations, as a possible speed-accuracy trade-off might have interfered. In contrast, the use of an external speech rate pacer in this study could eliminate this factor. The age-related differences found in relative contribution of opening and closing movements therefore represent an age-related difference in strategy.

5. Acknowledgements

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