Effects Of Rate On EMA-Derived Kinematic Parameters During Syllable and Sentence Productions

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ABSTRACT

This paper is directed towards comparing the articulatory kinematic parameters used to increase speech rate at both the syllable and sentence level. The electromagnetic articulograph (AG100) was used to measure duration, velocity, acceleration and distance of tongue movements during speech produced by a group of young adults with perceptually acceptable speech. The speech tasks involved repetitions of the syllable /ta/ and /ka/ separately and also in the sentence "A tarp will cover a car". Each of these tasks was carried out at a moderate rate and then "as fast as possible". Different kinematic strategies were utilized to increase speech rate in syllable repetitions and sentences. A reduction in the distance travelled appeared to be the principal strategy involved in increasing rate at the syllable level. At the sentence level, the combination of a decrease in distance and an increase in maximum velocity were associated with the increase in speech rate.

1. INTRODUCTION

Investigations of kinematic strategies used for syllables with variations in rate have been growing steadily [1], [2], but have rarely been extended to real word sentences. Further the limited investigations on rate effects in connected speech have examined only a small number of kinematic parameters (duration and/or velocity) [3], [4], rather than a comprehensive set of kinematic parameters. In that speech rate is dependent on several neural processes, knowledge of the kinematic parameters used in varying speech rates is important for understanding the basis of speech rate changes seen in various neurological speech disorders, which are assumed to be a result of dysfunction in central neural coding and motoneuron activity [4]. Also speech rate manipulation forms the basis of several treatment approaches for dysarthria and hence prompts the need for a thorough understanding of the kinematic strategies underlying speech rate variations.

The aim of the study was to carry out an investigation comparing the kinematic strategies used for the production of syllables and sentences at various rates.

2. METHODS

2.1 SUBJECTS

Ten Australian native English speakers, of which, five were male (mean age= 27.6, SD= 3.6) and five were female (mean age= 25.8, SD= 2.3) participated in the study. All the subjects had perceptually normal speech with no history of any neurological, speech or language disorder or oro-maxillo-facial surgery**.**

2.2 ASSESSMENT

The effect of rate manipulations on articulatory kinematics during sentence and syllable productions was assessed using the Electromagnetic Articulograph AG100 EMA system (Carstens Medizinelektronik GmbH, Germany). The subjects were fitted with a plastic helmet on which were mounted three transmitter coils that generated alternating electromagnetic fields at different frequencies. These magnetic fields, in turn, induced electrical signals in five miniature receiver coils affixed to each subject's nose, gingiva above the upper central incisors (reference coils), tongue back (4cm from the tongue tip), tongue tip (1cm from the tongue tip) and jaw. In this study a sampling rate of 200 Hz provided a 2D representation of articulator movement along with quantitative kinematic information on distance, duration, maximum velocity and maximum acceleration (see [5] for further details on EMA instrumentation, method of measurement and recording procedures).

The subjects were required to perform six different speech tasks namely syllable repetitions of /ta/(alveolar) and /ka/(velar) at a moderate rate (approximately 3syllables/sec) and then as fast as possible and repetitions of the sentence "A tarp will cover a car", incorporating both the above mentioned syllables at both rate conditions. Sentence repetitions were divided into four blocks for each rate condition and interspersed with syllable repetitions at both rates. The order of the speech tasks was randomised. Two recordings of syllable repetitions for each consonant and 12 recordings of the sentence were made for each rate condition.

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2.3 EMA ANALYSIS

Firstly the EMA analysis program, Tailor, was used to modify the EMA kinematic data to make it suitable for analysis. The modification procedures included i) smoothing of the reference channels (nose and gingiva above the upper central incisors) using a digital filter, Filter 40 (cut off =10Hz), ii) dynamic position correction of the reference channels to ensure that the reference coils stayed at a fixed position for each sample eliminating any unintentional helmet movements relative to the head; iii) rotating the data such that the occlusional plane was parallel to the X-axis (for further details on EMA analysis refer to [5]).

Once the data was modified, the examiner used rate in syllables per second as a selection criteria to choose a single syllable repetition trial for each rate condition, such that the production closest to 3syllables/sec for the moderate rate and the faster of the two trials for the fast rate was retained for further analysis. Both the productions were screened for perceptual acceptability. The middle seven syllables in each selected production were then annotated to obtain various kinematic measures. Out of the twelve repetitions for the sentence, seven perceptually normal utterances were selected excluding utterances at the beginning of each block of sentences taking into account the time it took the subject to become accustomed to the speech task itself.

Approach and release phases for /ta/ and /ka/ in the syllable and sentence repetition tasks were marked and the following kinematic parameters were calculated for both phases: maximum velocity (mm/s), maximum acceleration (m/s^2), duration (ms) and distance (mm) using a Matlab based analysis program (see [5] for further details on kinematic parameter analysis).

3. RESULTS

A linear mixed effects model with subject as a random factor and the within subject factors, sound (t/k), condition (syllable/sentence), rate (moderate/fast) and phase (approach/release) and their interactions was utilized to compare the effects of rate manipulations on kinematic variables namely duration, maximum velocity, distance and maximum acceleration during syllable repetitions of the above mentioned sounds and sentence productions incorporating the same syllables. It was necessary to transform the means using the log transformation to stabilize the variance. The significance of the factors was determined using the F statistic and by examining the ANOVA table for each outcome. A probability level of .05 was adopted for all significance testing.

For the parameter, duration, a significant main effect was observed for condition [F (1, 1095) = 142.7, p<. 0001] and rate [F (1, 1095) = 1771.4, p<. 0001]. A significant interaction effect was observed between condition and rate [F (1, 1095) =660.6, p<. 0001] characterized by significantly shorter durations in the fast rate condition for both sentences and syllables. For the fast rate condition a greater reduction in the duration of the syllables was observed compared to sentences (refer to Tables 1and 2). A significant main effect was observed for condition [F (1, 1095) =193.0, p<. 0001] and rate [F (1, 1095) =33.204, p<. 0001] for maximum velocity. A significant interaction effect was observed between condition and rate [F (1, 1095) = 71.6, p<. 0001]. A significant reduction in maximum velocity from the moderate to the fast rate condition was observed for syllables. In contrast, a slight (close to significant) increase in maximum velocity from the moderate to the fast rate was observed for sentences (see Tables 1 and 2).

No significant main effect was observed for rate but was evident for condition [F (1, 1095) =35.137, p<. 0001] for maximum acceleration. A significant condition by rate interaction was observed for maximum acceleration [F (1, 1095) =6.9, p=0.0085] characterized by no significant change in maximum acceleration for sentence productions and a significant reduction in maximum acceleration in syllables for the fast rate.

For the parameter, distance, a significant main effect was observed for condition [F (1, 984) =342.6, p<. 0001] and rate [F (1, 984) =471.5, p<. 0001]. A significant interaction effect was observed between condition and rate [F (1, 984) =362.3, p<. 0001] characterized by smaller distances being travelled in the fast rate condition compared to the moderate rate condition for both sentences and syllables (see Tables 1and 2). For syllables, however, the distance travelled in the moderate rate was approximately twice as much as the distance travelled in the fast rate condition. For sentences, the distance travelled in the fast rate condition was only slightly lower than the distance travelled in the moderate rate condition.

To summarize, significant reductions in distance, duration, maximum velocity and maximum acceleration were observed for the fast rate condition compared to the moderate rate condition for syllables. For sentences, however, only a moderate reduction in duration, an increase (just outside significance) in maximum velocity and decrease in distance (just outside significance) were observed from the moderate to the fast rate condition.

	Moderate		Fast			
Syllable	Mean	SD	Mean	SD	t	p-value
Duration	211.9	54.2	87.0	19.2	25.268	< 0.001
Max.Vel	109.6	47.3	82.9	32.6	8.367	< 0.001
Distance	11.8	3.9	5.4	2.3	18.791	< 0.001
Max.Acc	8.7	6.1	7.8	4.4	2.609	< 0.05

TABLE 1:Mean duration, maximum velocity, maximum acceleration and distance across rates for syllables

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Sentence	Moderate		Fast		t	p-value
	Mean	SD	Mean	SD		
Duration	180.2	52.5	145.1	43.6	11.390	< 0.001
Max.Vel	123.7	57.6	126.6	48.0	-1.888	0.059
Distance	12.0	4.7	11.3	4.3	1.871	0.062
Max.Acc	9.9	7.1	10.1	6.3	-0.729	0.466

TABLE 2:Mean duration, maximum velocity, maximum acceleration and distance across rates for sentences

4. DISCUSSION

The aim of the study was to compare the kinematic strategies used to increase speech rate in sentence and syllable productions. It was observed that to increase rate in the two conditions speakers used different strategies. For syllables, it appeared that one main kinematic strategy was employed to increase speech rate, namely a reduction in the distance travelled. Distance could be proposed to be the principal kinematic parameter whose manipulation had a substantial effect on duration, maximum velocity and maximum acceleration, leading to reductions in all three kinematic parameters. This could be because the subjects reduced the linguapalatal distance during the approach and release phases of the syllable to form shorter durations to achieve rapid speech rates for the fast condition, possibly leading to undershooting of articulatory targets at fast rates [1]. The decrease in distance and duration may have resulted in the decrease in velocity as the speakers may have been restricted by insufficient distance and/or time, to increase velocity, with fast rates. The subjects seemed to decrease rather than actively increase velocity possibly in order to economize effort (decrease distance and maximum velocity attained) during fast syllable repetitions.

For sentences, a significant decrease in duration between the moderate and fast rate conditions, could be attributed to the interaction between an increase in maximum velocity, and a decrease in distance (just outside significance). Since speakers are restricted by the need to produce perceptually acceptable utterances during the sentence tasks to ensure that they are understood correctly they could be increasing articulatory effort (velocity) in the fast rate condition to retain perceptually acceptable consonants and vowels. Similarly, the greater reduction in distance for syllables compared to sentences in the fast condition could be attributed to the speaker's inability to drastically decrease linguapalatal distances for real words in sentences at fast rates since speech intelligibility has to be retained [1]. This in turn prevents speakers from undershooting articulatory targets and preserves clarity of speech.

Although the reduction in duration for the syllables /ta/ and /ka/ in the fast sentence productions was less than that for the fast syllable repetition sequences; a syllables per second comparison between the entire sentence "A tarp will cover a car" at a fast rate and fast syllable repetitions revealed that the fast sentences (6.1syllables/sec) were similar in rate to the fast syllables (6.0 syllables/sec). This could be because temporal overlap, and in turn, duration reduction may not be distributed evenly across the entire sentence and may be limited to certain consonants and vowels and syllable positions [3]. The actual tongue movements involved in syllable repetitions of the same consonant and vowel are comprised of presumably one discreet part of the tongue reaching specific articulatory targets potentially making it possible to carry out kinematic strategies efficiently, whereas sentence productions require movement of different parts of the tongue almost simultaneously and sequentially and hence could make it difficult to employ efficient kinematic strategies to increase speech rate.

CONCLUSION

In summary, the kinematic strategies used by individuals to increase speech rate were dependent on the condition (sentence/syllable). These findings have the potential to better inform clinicians as to the kinematic strategies underlying alterations in speech rate in neurological speech disorders.

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