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An EMA analysis of the effect of increasing word length on consonant production in apraxia of speech: A case study

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Abstract
The effect of increasing word length on the articulatory dynamics (i.e. duration, distance, maximum acceleration, maximum deceleration, and maximum velocity) of consonant production in acquired apraxia of speech was investigated using electromagnetic articulography (EMA). Tongue-tip and tongue-back movement of one apraxic patient was recorded using the AG-200 EMA system during word-initial consonant productions in one, two, and three syllable words. Significantly deviant articulatory parameters were recorded for each of the target consonants during one, two, and three syllables words. Word length effects were most evident during the release phase of target consonant productions. The results are discussed with respect to theories of speech motor control as they relate to AOS.

Keywords: *Apraxia of speech, physiological assessment, articulation*

Introduction

Apraxia of speech (AOS) is a neurogenic speech disorder, most commonly caused by single left-hemisphere stroke (Duffy, 2005). McNeil, Robin, and Schmidt (1997) defined AOS as "a phonetic-motoric disorder of speech production caused by inefficiencies in the translation of a well-formed and filled phonologic frame to previously learned kinematic parameters assembled for carrying out the intended movement" (p. 329). As such, disturbances in articulation and prosody are typical of AOS (McNeil et al., 1997; McNeil, Pratt, & Fossett, 2004; Duffy, 2005).

Perceptually-derived characteristics of apraxic speech production include: phoneme prolongation, sound distortions, syllable segregation, a slow rate of speech, and dysprosody (Odell, McNeil, Rosenbek, & Hunter, 1990; 1991; Duffy, 2005). Perceptual (Johns & Darley, 1970; Deal & Darley, 1972) and acoustic (Kent & Rosenbek, 1983; Haley & Overton, 2001) studies of vowel and consonant production in AOS have established that multisyllabic words (in contrast to monosyllabic words) are particularly susceptible to articulatory error.

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Kent and Rosenbek (1983) used spectrographic analysis to investigate vowel and consonant duration in multisyllabic words and phrases, sentences, and monosyllabic words, in a group of participants with AOS (n=7) and a control group (n⩾7). The AOS group exhibited longer consonant durations than the control group for the majority of consonant productions (e.g. /k-, s-, -ɾ-, -dʒ-, -n-, -m-/; NB: dashes are used to indicate word position) in multisyllabic words, but for comparatively few consonant productions (e.g. /s-, -s, -tʃ/) in monosyllabic words. Similarly, although the apraxic speakers, as a group, exhibited longer vowel durations for the mono- and multisyllabic utterances, vowel duration appeared to be substantially longer, compared to the control group, for the multisyllabic words (Kent & Rosenbek, 1983).

Also using spectrographic analysis, Haley and Overton (2001) investigated word stem vowel duration in mono-, di-, and trisyllable words. Unlike in Kent and Rosenbek's (1983) study, Haley and Overton (2001) included three sets of speech stimuli, each of which contained three words with the same word stem, but with an increasing number of syllables (e.g. zip, zipper, zippering). As such, a direct comparison could be made between vowel duration and the number of syllables, the phonetic environment of the vowel remaining constant. Haley and Overton (2001) reported significantly longer (i.e. $p<.05$) vowel durations for the AOS-aphasia group (n=10) for di- and tri-syllable word productions, compared to a control group (n=10); no significant differences were reported for the monosyllabic words.

Despite reporting significantly longer vowel durations for persons with AOS during multisyllabic word productions, Haley and Overton (2001), as well as Collins, Rosenbek, and Wertz (1983), reported a reduction in relative vowel duration in word stem vowels in words with an increasing number of syllables. Vowel reduction in multisyllabic words is considered a common phonological phenomenon that occurs in typical speech production (Lehiste, 1971; Klatt, 1973). Haley and Overton (2001) compared the results of two different measures of relative vowel duration, one of which was comparable to that used by Collins et al. (1983). When vowel duration was expressed as a proportion of total word duration, both Haley and Overton (2001) and Collins et al. (1983) reported a reduction in word stem vowel duration in words of increasing length. When the word stem vowel duration of the two and three syllable words were expressed as a proportion of the monosyllabic word stem vowel duration, however, a slightly different shortening pattern was observed. While there remained a reduction in relative vowel duration in the multisyllabic words, it was notably smaller in the AOS group, compared to the control speakers (Haley & Overton, 2001). The discrepancy in results was attributed to a greater increase in word duration from monosyllabic to multisyllabic words for persons with AOS. Haley and Overton (2001) commented that irrespective of whether or not vowel duration decreases, if word length duration increases, relative vowel duration would automatically decrease (Haley & Overton, 2001). Nevertheless, Haley and Overton (2001) concluded that their results were indicative of a preserved phonological distinction, attributing the abnormal shortening pattern to a deficit at the motoric level of articulatory control.

Accordingly, kinematic investigations of articulatory movement in AOS have revealed deviant lip movement characteristics. Bose, van Lieshout, and Square (2001) and McNeil and Adams (1991) reported longer durations during the closing gesture of bilabial productions (i.e. /p, b/) in multisyllabic stimuli; however, while Bose et al. (2001) also reported larger lip displacements, McNeil and Adams (1991) reported comparable articulatory displacements for the AOS speakers and the control group. In addition, Itoh, Sasanuma, Hirose, Yoshioka, and Ushijima (1980), unlike McNeil and Adams (1991), reported reduced lip movement velocities in their participant with AOS. Larger articulatory displacements, longer closing segment durations, and reductions in peak velocity, could each contribute to increased phoneme durations in AOS. Itoh et al. (1980), in addition to reporting reduced movement velocities, identified inconsistency in the timing relationship between the velum, lip, and tongue during /n/ productions. Acoustic studies of speech production in AOS have also identified variable timing characteristics in AOS (Square-Storer & Apeldoorn, 1991; Seddoh, Robin, Sim, Hageman, Moon, & Folkins, 1996). As it stands, however, no research has investigated the kinematic properties of consonant production, and articulatory variability, in words of increasing length.

Given that prolonged phoneme durations are realized perceptually as distorted speech and contribute to a slow rate of speech and prosodic abnormalities (Odell et al., 1990; McNeil et al., 2004), and that articulatory variability has been reported in AOS (Itoh et al., 1980; Square-Storer & Apeldoorn, 1991; Seddoh et al., 1996), it was considered essential that the articulatory kinematics of consonant production in words of increasing length be investigated. In particular, given that the tongue is considered to be the most important articulator in speech production (Smith, 1992), the aim of the present study was to use electromagnetic articulography (EMA) to investigate the articulatory dynamics of tongue-tip and tongue-back movement during target consonant productions (i.e. /t, s, k) in words of increasing length in persons with AOS. By doing so, it was expected that the parameter/s of tongue movement (e.g. distance, duration, velocity, acceleration, deceleration) that are deviant and contributing to increased consonant durations and articulatory variability in words with an increasing number of syllables would be identified. It was hypothesized that the apraxic speaker would exhibit deviant and highly variable duration, distance, velocity, acceleration, and deceleration values for /t/, /s/, and /k/ during multisyllabic word productions. The articulatory parameters recorded during the monosyllabic word productions, however, were expected to be relatively comparable to those recorded for the control group.

Method

Participants

One female participant (NR) with AOS and co-existing oral apraxia and Broca's aphasia, aged 52 years, participated in the study. NR was 11 years post-onset of left-hemisphere stroke, which involved the deep white matter of the left hemisphere extending from the frontal to the parietal region, caused by a left internal carotid artery dissection.

NR was diagnosed with mild-moderate AOS, as well as a mild oral apraxia, based on the assessment results of the Apraxia Battery for Adults-Second Edition (ABA-2; Dabul, 2000) (see Appendix A). The following diagnostic criteria were also satisfied: slow, syllabic speech production, effortful, visible, and audible searching articulatory movements with attempts to self correct, inconsistent errors across repetitions of the same utterance, initiation difficulties, and dysprosody. NR was diagnosed with Broca's aphasia based on the assessment results of the Boston Diagnostic Aphasia Examination (BDAE; Goodglass, 2001) (see Appendix B). NR had no history of a speech or neurological disorder unrelated to her stroke, nor had she undergone oro-maxillo-facial surgery.

A control group of three non-neurologically impaired participants, matched for age (range=49–54 years; M=51.33 years; SD=2.52) and gender, also participated in the study. Participants were all native English speakers, and had no history of, or any form of speech and/or neurological disorder. Nil participants had undergone surgery of the lips, tongue, or jaw.

Assessment procedures

A series of perceptual speech assessments, and an instrumental physiological assessment, EMA, were used to evaluate articulatory performance in the present study.

Perceptual assessments

A speech sample analysis, the Multiple Word Intelligibility Test (MWIT; Kent, Weismer, Kent, & Rosenbek, 1989), and the Frenchay Dysarthria Assessment (FDA; Enderby, 1983) were administered to all participants. To obtain the speech sample, participants were instructed to read "The Grandfather Passage" (Darley, Aronson, & Brown, 1975) at their usual speaking rate and volume. The speech sample was later analysed independently by two speech pathologists who were unconnected to the study, according to the articulatory features (i.e. precision of consonants, length of phonemes, precision of vowels), intelligibility (i.e. overall intelligibility), and rate (i.e. general rate) sections of the perceptual rating scale, described by FitzGerald, Murdoch, and Chenery (1987). Two additional items were added to the rating scale, "word length" and "length of intersyllabic pauses" (NB: these latter features were rated according to the "length of phonemes" criteria). An equal appearing intervals scale of one to four was used for the articulatory features and intelligibility sections; one indicated normal precision/length/intelligibility, two indicated mild disturbances, three indicated moderate disturbances, and four indicated severe disturbances. For the rate section, a scale of one to seven was used to mark the severity of disturbances. Four indicated a normal rate of speech, one to three indicated a slow rate of speech (1=severe disturbances; 3=mild disturbances), and five to seven indicated a fast rate of speech (5=mild disturbances; 7=severe disturbances). Discrepancies between ratings were discussed among the two speech pathologists, and a single consensus rating was given to each of the seven parameters analysed. The judge's scores never varied by more than one on the rating scale. The MWIT was administered by a speech pathologist in accordance with the instructions outlined in Kent et al.'s (1989) article and overall intelligibility was analysed. Likewise, the tongue component of the FDA was administered by a Speech Pathologist in accordance with the procedures outlined in the FDA testing manual (Enderby, 1983).

EMA assessment

The Electromagnetic Articulograph AG-200 system (Carstens Medizinelektronik GmbH, Germany) was used to track and record tongue movement along the midline during speech production.

Instrumentation and method of measurement. Each participant was required to wear a plastic helmet that comprised three transmitter coils, positioned in front of the participant's jaw, behind their neck, and in front of their forehead, within the mid-sagittal plane. Each of the transmitter coils produced an alternating magnetic field at different frequencies (range 10–20 kHz), which, in turn, induced alternating signals in seven receiver coils (approximately $2 \times 2 \times 3$ mm in size) attached to the articulators within the midline. The magnitude of the signals induced in a single receiver coil reflected the distance between it and a transmitter coil (i.e. magnitude of signal inversely proportional to cube of distance from the transmitter coil). Having been calculated, the location (x-y coordinates) of the receiver coil within the two-dimensional mid-sagittal plane could be established. The position of each receiver coil was sampled at a measurement frequency of 200 Hz.

Assessment preparation. Prior to each assessment, the AG-200 system was calibrated according to the procedures outlined in the AG-200 operating manual. During the EMA assessment, the participants were seated in a straight-backed chair in a laboratory room. Receiver coils were attached to the participant's tongue-tip and tongue-back (1 and 4cm from the tongue-tip in the mid-sagittal plane, respectively), along the midline of their upper and lower lips, and under the mental protuberance of the mandible. Receiver coils were also affixed to the bridge of the nose and to the gingiva above the two upper central incisors, to be used as reference points throughout the assessment (i.e. they do not move in relation to the head). The receiver coils were coated in latex (plasty-late), and were affixed to the articulators using a biologically safe adhesive (Cyano-Vaneer Fast, a cyanoethyl liquid); tape was used to attach the receiver coils to the bridge of the nose and to the jaw. Once all but one of the receiver coils were attached, the plastic helmet comprising the three transmitter coils was lowered from the ceiling via a pulley system. The helmet was subsequently secured to the participant's head via a plastic headband. Before attaching a receiver coil to the tongue-tip, the receiver coil was used to trace the occlusional plane. The receiver coil was positioned in the T-junction at the end of a custom made T-bar, which was ran over the participant's upper teeth, from the molars to the first or second bicuspid, to obtain the trace.

Recording procedure. The participant's were initially given approximately five minutes of speaking time to adjust to speaking with receiver coils on their articulators, after which time they were instructed to read aloud (or repeat after the researcher) a set of phrases that contained the alveolar stop consonant /t/, the alveolar fricative /s/, or the velar stop consonant /k/, in word-initial position in words of increasing length. Each of the target consonants were embedded between the vowels /ʌ/ and /a/. The speech stimuli used in the present study consisted of three sets of words, each of which contained two or three words with the same word stem (i.e. "a tar", "a target", "a targeting"; "a sarge", "a sergeant"; "a car", "a carpet", "a carpenter"). Each of these phrases was randomly repeated seven times within a larger list of phrases. The participants were instructed to read aloud (or repeat after the researcher) the phrases at a habitual rate and loudness level. To ensure that reading difficulties did not influence the results, the researcher modelled each of the phrases prior to the assessment. While the participants read aloud (or repeated after the researcher) the phrases, their tongue-tip and tongue-back movements were recorded. To record the acoustic signals during the assessment session, a lapel microphone which was connected to the AG200 EMA system was attached to the participant's helmet (sampling rate = 16 Hz). The preparation and recording procedures took approximately 40 minutes for each participant.

Analysis procedures

Prior to data analysis, the Tailor program (Carstens Medizinelektronik GmbH, Germany) was used to modify the kinematic data recorded by the AG-200 system. Data modification involved: filtering the reference (Filter 40, cut-off=8 Hz) and data (Filter 160, cut-off=32 Hz) channels; dynamic correction, to correct for any head movement that may have occurred in relation to the helmet; and the rotation of the movement data within the x-y coordinate system (i.e. occlusional plane rotated so that it was parallel to the x-axis) to make certain that the orientation of kinematic data was consistent between the participants.

Kinematic parameter analysis

The participants tongue-tip and tongue-back movements were tracked and recorded while they repeated the /t/, /s/, and /k/ sounds in word stem initial position in words with an increasing number of syllables. The acoustic trace produced by Emalyse (Carstens Medizinelektronik GmbH, Germany) was initially used to isolate the target sounds /t/, /s/, and /k/, after which the y-displacement, velocity, and acceleration profiles created by Emalyse (Carstens Medizinelektronik GmbH, Germany) were used to calculate a number of kinematic parameters during the approach (i.e. the tongue approaching the palate), closure (i.e. the tongue held at the palate), and release (i.e. the tongue moving downward from the palate) phases of the target consonant productions. The kinematic parameters analysed included maximum velocity (mm/s), and maximum acceleration and deceleration (m/s^2) of the principal receiver coil (i.e. that coil attached to the primary articulator involved in consonant production), and the duration (ms) of the approach, closure, and release phases of target consonant productions (see Figure 1). Custom written scripts in Matlab© (version 6.5.1, The Math-Works Inc., 2004) were used to calculate the distance (mm) travelled by the principal receiver coil during the approach, closure, and release phases of target consonant productions.

The values obtained for the aforementioned kinematic parameters were averaged across five of the seven repetitions of each target consonant in the one, two, and three syllable words; the five most typical movement profiles were chosen for analysis. For NR, productions were eliminated from analysis if the approach phase of the target consonant production could not be isolated. For example, NR, on occasion, preceded her utterance with a silent articulatory starter. If her tongue did not assume a neutral position between her silent articulatory starter and actual consonant production, the kinematic values obtained for the approach phase of the target consonant production may have failed to represent full articulatory movement.

Following the analysis of each target consonant, the acoustic trace produced by Emalyse (Carstens Medizinelektronik GmbH, Germany) was used to isolate, and calculate the total duration (ms) of each target word. In addition, the mean consonant release phase duration values recorded for the target consonants during multisyllabic word productions were expressed as a function of those recorded for the target consonants during monosyllabic word productions, to determine *relative* release phase duration values.

Perceptual analysis of EMA words

Each of the EMA target words chosen for kinematic analysis were analysed by one of the researchers according to the rate (i.e. general rate of whole phrase), articulatory features (i.e. precision of consonants, length of phonemes), and intelligibility (i.e. overall intelligibility) sections of the perceptual rating scale described by FitzGerald et al. (1987). As with "The Grandfather Passage", two additional items (i.e. "[target] word length" and "length of intersyllabic pauses") were included. These latter two items were

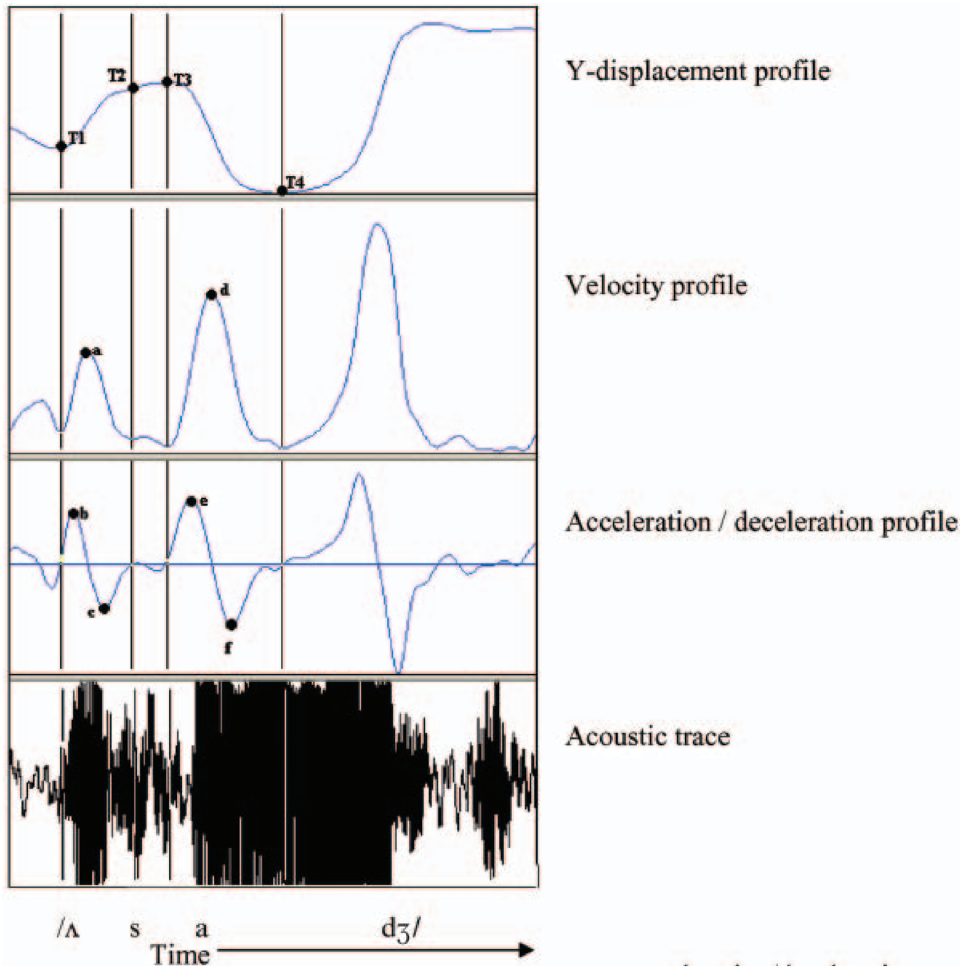

Figure 1. Example y-displacement, velocity, and acceleration/deceleration profiles for the approach, closure, and release phases of /s/, displaying start of approach phase (T1); end of approach phase/start of closure phase (T2); end of closure phase / start of release phase (T3); end of release phase (T4); maximum velocity (a), maximum acceleration (b), and maximum deceleration (c) of approach phase; maximum velocity (d), maximum acceleration (e), and maximum deceleration (f) of release phase; duration of approach phase [5 × (T2–T1)], closure phase [5 × (T3–T2)], and release phase [5 × (T4–T3)], given a sampling rate of 200 Hz.

rated according to the "length of phonemes" criteria. Equal-appearing intervals scales, like those used during the speech sample analyses, were used to rate each of the aforementioned sections (see Method, *Perceptual assessments*). A second speech pathologist who was unconnected to the study rated a sample of 40% of the EMA target words to obtain an inter-judge reliability measure using Spearman's rho (r_s) correlations. Inter-judge reliability was calculated for general rate, precision of consonants, length of phonemes, overall intelligibility, word length, and length of intersyllabic pauses, and the median correlation was .795 (range=.701–.924). The results indicated an acceptable degree of inter-judge reliability. To determine the degree of intra-judge reliability, each of the parameters recorded for a sample of 40% of the EMA stimuli was re-rated by Judge 1. The median correlation was .861 (range=.701–.927). The perceptual ratings obtained for NR during the EMA assessment were related to her articulatory kinematic results.

Results

Perceptual assessment results

Analysis of the speech samples obtained from "The Grandfather Passage" readings revealed perceptually clear speech for the control participants. Precision of consonants, length of phonemes, precision of vowels, and overall intelligibility were judged to be within normal limits for each of the control participants. One control participant presented with an appropriate general rate of speech; however, two control participants exhibited borderline appropriate general rate and just noticeably rapid rate of speech.

NR was unable to read or repeat "The Grandfather Passage" after the researcher as her speech output was largely limited to one, two, or three word utterances. Accordingly, a spontaneous speech sample, as well as her response to a picture description task (i.e. the "Cookie Theft" picture) was rated. NR exhibited a moderately slow rate of speech, slight vowel and consonant imprecision, slightly prolonged length of phonemes, mild to moderately prolonged length of intersyllabic pauses and word length, and normal intelligibility. NR's description of the "Cookie Theft" picture has been transcribed below:

> Falling over. Um. Um. Falling. Chairs. Um. Cups. Two. Two plates. Um. Woman. Falling over. Crashing. Jar. Soap. Falling over.

Each of the control participants was judged to be 100% intelligible on the MWIT. NR, however, presented with 95.7% word intelligibility. NR substituted "write" with "read", "pat" with "hat", and "slip" with "clip". The following errors were also noted: "ache" was substituted with /ɛɪkt/, and "wax" was substituted with /wɛks/ (NB: these errors did not influence her word intelligibility).

According to the tongue component of the FDA, no disturbances in tongue function were exhibited by two of the three control participants. One control participant, however, exhibited mild tongue disturbances at rest (i.e. her tongue occasionally deviated to the right or left side at rest) and moderate disturbances in tongue elevation (i.e. had difficulty coordinating the upward and downward tongue movements). NR exhibited mild or no disturbances in tongue function, with the exception of tongue elevation. NR was unable to coordinate the upward and downward movements of her tongue during this latter task. Slight incoordination was also observed during the alternate tongue movement task.

Perceptual analysis of EMA words

The mean perceptual ratings of each of the target stimuli for the control group and NR are presented in Table I. The control group, on average, exhibited normal or near-normal mean perceptual ratings for each of the target consonants during mono- and multisyllabic word productions. In contrast, NR exhibited a mild-moderate slow rate of speech during her production of each of the EMA phrases (i.e. often inserted a pause between the "a" and the target word; e.g. "a … tar"). NR's target consonants were of relatively normal precision, as was her length of /t/ and /k/ phonemes. NR's /s/ phonemes were mildly prolonged. Inter-syllabic pause length was relatively normal for NR's /t/ and /k/-initial two syllable stimuli, and mild-moderately prolonged for NR's /t/ and /k/-initial three syllable

Table I. Mean (and standard deviation) perceptual ratings of the EMA stimuli for the control group (CG) and NR.

	General rate		Precision of consonants		Length of phonemes		Length of inter-syllabic pause		Word length		Overall intelligibility	
Stimuli	CG	NR	CG	NR	CG	NR	CG	NR	CG	NR	CG	NR
tar	3.67 (.49)	2.40 (.55)	1.00 (.00)	1.20 (.45)	1.00 (.00)	1.00 (.00)	N/A	N/A	1.13 (.35)	1.40 (.55)	1.00 (1.00)	1.20 (.45)
target	3.67 (.49)	2.60 (.55)	1.00 (.00)	1.20 (.45)	1.00 (.00)	1.60 (.55)	1.00 (.00)	1.40 (.55)	1.00 (.00)	1.40 (.55)	1.00 (.00)	1.20 (.45)
targeting	3.80 (.41)	2.60 (.55)	1.00 (.00)	1.40 (.55)	1.00 (.00)	1.20 (.45)	1.00 (.00)	2.60 (.55)	1.00 (.00)	2.60 (.55)	1.13 (.35)	2.20 (.84)
sarge	3.67 (.49)	2.40 (.55)	1.00 (.00)	1.20 (.45)	1.27 (.46)	1.80 (.45)	N/A	N/A	1.27 (.46)	1.20 (.45)	1.00 (.00)	1.40 (.55)
sergeant	3.80 (.41)	2.60 (.55)	1.00 (.00)	1.20 (.45)	1.20 (.41)	1.80 (.45)	1.00 (.00)	2.00 (.00)	1.00 (.00)	2.00 (.00)	1.00 (.00)	1.40 (.55)
car	3.80 (.41)	2.80 (.45)	1.00 (.00)	1.00 (.00)	1.00 (.00)	1.00 (.00)	N/A	N/A	1.27 (.46)	1.00 (.00)	1.00 (.00)	1.00 (.00)
carpet	3.87 (.35)	3.00 (.00)	1.00 (.00)	1.00 (.00)	1.00 (.00)	1.00 (.00)	1.00 (.00)	1.40 (.55)	1.00 (.00)	1.40 (.55)	1.00 (.00)	1.00 (.00)
carpenter	3.67 (.49)	3.00 (.00)	1.00 (.00)	1.00 (.00)	1.00 (.00)	1.00 (.00)	1.00 (.00)	2.20 (.45)	1.00 (.00)	2.20 (.45)	1.00 (.00)	2.00 (.00)

Note: For ‘general rate’ 4=normal, 3=mild deviation, 2=moderate deviation, 1=severe deviation; for all other parameters, 1=normal, 2=mild deviation, 3=moderate deviation, 4=severe deviation.

stimuli. Inter-syllabic pause length was mildly prolonged during NR's /s/-initial two syllable word stimuli. Likewise, word length was of normal length, or mildly prolonged for NR's one and two syllable word stimuli, and mild-moderately prolonged for NR's three syllable word stimuli. NR presented with normal, or mildly reduced speech intelligibility during her production of each of the EMA phrases.

EMA results

The mean kinematic parameter values obtained for the control participants' (n=3) and NR during the approach, closure, and release phases of /t/, /s/, and /k/ in mono-, di- and trisyllable words, as well as their corresponding mean coefficient of variance (CV) values, are presented in tables two through to six. The mean kinematic values and mean CV values calculated for NR were considered to be statistically significant if they were greater than two standard deviations above or below the mean of the control group.

Approach phase

Articulatory dynamics. Significantly greater mean duration values were recorded for NR during the approach phases of /t/, /s/, and /k/ during one, two, and three syllable word productions (see Table II). On the contrary, the mean distance travelled by NR's tongue was only significantly greater during the approach phase of /t/ during "a target" repetitions (see Table II). Significantly reduced mean maximum acceleration values were recorded for NR during the approach phase of /t/ during mono- and multisyllabic word repetitions; however, with the exception of /k/ during "a carpenter" repetitions, the mean maximum acceleration values obtained for NR during the approach phases of /s/ and /k/ appeared to be relatively comparable to those of the control group (see Table II). The mean maximum deceleration values obtained for /t/, /s/, and /k/ during monosyllabic word productions and for /t/ and /k/ during three syllable word productions, were significantly reduced for NR (see Table II). Likewise, the mean maximum velocity values that were obtained for /t/ during one and three syllable word productions and for /k/ during two syllable word productions were significantly reduced (see Table II).

Articulatory variability. NR exhibited significantly more variable mean duration values for /s/, /t/, and /k/ during one, two, and three syllable word productions, respectively (see Table III). In contrast, NR exhibited relatively comparable CV values to those of the control group for distance, with the exception of that recorded for /k/, which was significantly more variable during "a carpet" repetitions (see Table III). The mean maximum acceleration and mean maximum deceleration values recorded during the approach phase of /t/ during three syllable word productions and during the approach phase of /k/ during one and two syllable word productions were significantly more variable for NR (see Table III). Mean maximum velocity values, however, appeared to be significantly more variable during the approach phase of /s/ during "a sarge" repetitions and during the approach phase of /k/ during one, two, and three syllable word productions (see Table III).

Closure phase

Articulatory kinematics. Significantly greater mean duration values were recorded for NR during the closure phases of /t/ and /s/ during mono- and multisyllabic word productions

Table II. Mean (and standard deviation) kinematic parameter values for the control participants' (n=3) and NR during the approach phases of /t/, /s/, and /k/ in one, two, and three syllable words.

		Duration (ms)			Distance (mm)			Acceleration (m/s^2)			Deceleration (m/s^2)			Velocity (mm/s)		
	Target	CG (SD)	NR (SD)	DIFF	CG (SD)	NR (SD)	DIFF	CG (SD)	NR (SD)	DIFF	CG (SD)	NR (SD)	DIFF	CG (SD)	NR (SD)	DIFF
/t/	tar	149.33	311.00	+3.40*	13.27	17.75	+1.40	21.65	5.64	−2.57*	26.69	6.48	−2.37*	204.49	105.92	−2.02*
		(47.58)	(48.40)		(3.21)	(3.72)		(6.22)	(1.64)		(8.54)	(2.22)		(48.83)	(28.80)	
	target	174.67	448.00	+4.69*	15.60	24.80	+2.42*	24.57	6.34	−2.23*	28.94	9.10	−1.98	228.52	121.48	−1.85
		(58.29)	(111.72)		(3.80)	(2.01)		(8.16)	(1.78)		(10.04)	(3.57)		(58.02)	(23.58)	
	targeting	148.00	351.25	+4.82*	13.65	20.85	+1.93	23.44	6.99	−2.55*	30.24	8.42	−3.12*	221.33	114.75	−2.27*
		(42.17)	(33.80)		(3.74)	(3.94)		(6.45)	(3.45)		(7.00)	(3.42)		(47.02)	(22.30)	
/s/	sarge	168.67	472.50	+5.81*	9.23	15.98	+1.58	8.94	4.97	−1.35	9.22	3.94	−2.31*	97.96	67.25	−1.18
		(52.32)	(148.22)		(4.26)	(2.93)		(2.93)	(1.40)		(2.29)	(0.82)		(25.98)	(17.97)	
	sergeant	181.00	296.00	+2.74*	10.31	13.37	+0.98	9.93	4.71	−1.04	11.82	6.13	−1.27	115.85	83.60	−0.98
		(42.05)	(37.15)		(3.12)	(2.46)		(5.00)	(1.42)		(4.47)	(2.28)		(33.06)	(18.98)	
/k/	car	132.00	276.00	+3.21*	13.04	18.07	+1.07	22.60	11.37	−1.81	22.48	10.72	−2.24*	196.29	135.88	−1.36
		(44.91)	(20.43)		(4.71)	(2.47)		(6.21)	(3.37)		(5.24)	(3.53)		(44.46)	(28.92)	
	carpet	133.33	264.00	+2.94*	11.58	15.94	+1.35	19.62	10.56	−1.99	19.38	11.88	−1.49	171.95	135.72	−2.51*
		(44.51)	(22.75)		(3.22)	(2.55)		(4.56)	(3.97)		(5.02)	(5.82)		(14.43)	(28.82)	
	carpenter	129.33	435.00	+8.56*	12.60	19.98	+1.46	22.29	7.91	−3.05*	20.17	7.31	−3.76*	191.64	110.16	−1.82
		(35.70)	(122.37)		(5.05)	(2.52)		(4.72)	(1.75)		(3.42)	(1.76)		(44.73)	(35.75)	

Note: CG=control group; NR=participant with AOS and Broca's aphasia; DIFF=difference, expressed in terms of the number of standard deviations above (+) or below (–) the control group mean; *=significantly different from the control group mean (i.e. DIFF>2 SDs).

Table III. Mean (and standard deviation) coefficient of variance (CV) values for the control participants' (n=3) and NR during the approach phases of /t/, /s/, and /k/ in one, two, and three syllable words.

		Duration (ms)			Distance (mm)			Acceleration (m/s^2)			Deceleration (m/s^2)			Velocity (mm/s)		
	Target	CG (SD)	NR	DIFF	CG (SD)	NR	DIFF	CG (SD)	NR	DIFF	CG (SD)	NR	DIFF	CG (SD)	N	DIFF
/t/	tar	.180 (.086)	.156	−.28	.178 (.066)	.209	+.47	.217 (.125)	.291	+.59	.179 (.201)	.343	+.82	.119 (.093)	.272	+1.65
	target	.143 (.037)	.263	+3.24*	.176 (.077)	.081	−1.23	.203 (.118)	.281	+.66	.201 (.135)	.393	+1.42	.155 (.086)	.194	+.45
	targeting	.156 (.057)	.096	−1.05	.216 (.072)	.189	−.38	.192 (.020)	.494	+15.10*	.144 (.047)	.406	+5.57*	.125 (.067)	.194	+1.03
/s/	sarge	.131 (.074)	.314	+2.47*	.147 (.027)	.183	+1.33	.166 (.093)	.282	+1.25	.204 (.108)	.208	+.04	.143 (.057)	.267	+2.18*
	sergeant	.116 (.006)	.126	+1.67	.176 (.034)	.184	+.24	.201 (.119)	.302	+.85	.270 (.059)	.372	+1.73	.191 (.034)	.227	+1.06
/k/	car	.152 (.052)	.074	−1.50	.140 (.054)	.137	−.056	.152 (.032)	.296	+4.50*	.120 (.042)	.329	+4.98*	.103 (.038)	.213	+2.89*
	carpet	.153 (.050)	.086	−1.35	.107 (.009)	.160	+5.89*	.137 (.060)	.376	+3.98*	.241 (.086)	.490	+2.90*	.084 (.031)	.212	+4.13*
	carpenter	.105 (.068)	.281	+2.59*	.189 (.054)	.126	−1.17	.134 (.077)	.221	+1.13	.168 (.082)	.241	+.89	.140 (.039)	.325	+4.74*

Note: CG=control group; NR=participant with AOS and Broca's aphasia; DIFF=difference, expressed in terms of the number of standard deviations above (+) or below (–) the control group mean; +(x)=an increase in variability; −(x)=a decrease in variability; *=significantly different from the control group mean (i.e. DIFF>2 SDs).

(see Table IV). Similarly, significantly greater mean distance values were recorded for NR during the closure phase of /t/ during one and three syllable word productions and during the closure phase of /s/ during two syllable word productions (see Table IV). Significance levels could not be ascertained for duration or distance during the closure phase of /k/, or for distance during the closure phase of /t/ during two syllable word productions, as mean duration and mean distance SD values for the control group were zero (see Table IV).

Articulatory variability. The degree of variability exhibited by NR for duration and distance during the closure phases of /t/ and /s/ was not significantly different to that recorded for the control group during mono- and multisyllabic word productions (see Table IV). Significance levels could not be obtained for the degree of variability exhibited by NR for duration or distance during the closure phase of /k/ productions, or for distance during the closure phase of /t/ during two syllable word productions, as the control group's CV and standard deviation values were zero (see Table IV).

Release phase

Articulatory kinematics. No significant results were recorded for NR during the release phases of /t/, /s/, and /k/ during the monosyllabic word productions (see Table V). In contrast, significantly greater mean duration values were recorded for NR during the release phase of /t/ during two and three syllable word productions and during the release phase of /s/ during two syllable word productions (see Table V). Significantly greater mean distance values, however, were recorded during the release phase of /t/ during "a target" repetitions and during the release phase of /k/ during two and three syllable word productions (see Table V). A significantly reduced mean maximum acceleration value was recorded for NR during the release phase of /s/ during "a sarge" repetitions. In contrast, a significantly greater mean maximum acceleration value was recorded during the release phase of /k/ during "a carpet" repetitions (see Table V). With the exception of the mean maximum deceleration value recorded for NR during the release phase of /k/ during two syllable word productions, NR appeared to exhibit relatively comparable mean maximum deceleration values to the control group during the release phases of /t/, /s/, and /k/ during multisyllabic word productions (see Table V). Mean maximum velocity values were significantly greater for NR during the release phase of /k/ during two and three syllable word productions (see Table V).

Articulatory variability. Significantly more variable mean duration values were recorded for NR during the release phase of /s/ during one and two syllable word productions, and during the release phase of /k/ during two and three syllable word productions (see Table VI). Mean distance values were significantly more variable for NR during the release phases of /k/ and /t/ during one and two syllable word productions, respectively (see Table VI). Mean maximum acceleration and mean maximum deceleration values, however, appeared to be significantly more variable during the release phase of /s/ during "a sarge" repetitions and during the release phase of /k/ during two and three syllable word productions; the mean maximum deceleration value recorded during the release phase of /t/ during "a targeting" repetitions was also significantly more variable for NR compared to the control group (see Table VI). NR exhibited relatively comparable CV values to those of the control group for mean maximum velocity for each of the target sounds during

Table IV. Mean (and standard deviation) duration and distance values and mean (and standard deviation) coefficient of variance (CV) values for the control participants' (n=3) and NR during the closure phases of /t/, /s/, and /k/ in one, two, and three syllable words.

		Duration (ms)						Distance (mm)					
		CONTROL GROUP		NR		DIFF		CONTROL GROUP		NR		DIFF	
	Target	Value (SD)	CV (SD)	Value (SD)	CV	Value	CV	Value (SD)	CV (SD)	Value (SD)	CV	Value	CV
/t/	tar	10.33 (27.29)	.457 (.791)	393.00 (537.57)	1.37	+14.02*	+1.15	.28 (.74)	.460 (.797)	4.20 (5.85)	1.39	+5.31*	+1.17
	target	4.00 (11.21)	.497 (.861)	440.00 (415.30)	.944	+38.89*	+.52	.00 (.00)	.00 (.00)	6.85 (6.98)	1.02	–	–
	targeting	20.00 (31.11)	.109 (.190)	285.00 (83.67)	.294	+8.52*	+.97	.47 (.76)	.150 (.260)	3.60 (1.66)	.461	+4.12*	+1.20
/s/	sarge	79.00 (63.90)	.491 (.382)	315.00 (141.11)	.448	+3.69*	−.11	1.11 (1.24)	.648 (.329)	2.82 (1.27)	.450	+1.38	−.60
	sergeant	51.67 (66.32)	.513 (.761)	290.00 (189.97)	.655	+3.59*	+.19	.74 (1.10)	.594 (.694)	5.89 (5.52)	.937	+4.68*	+.49
/k/	car	.00 (.00)	.00 (.00)	70.00 (96.76)	1.38	–	–	.00 (.00)	.00 (.00)	.74 (.92)	1.24	–	–
	carpet	.00 (.00)	.00 (.00)	206.00 (94.57)	.459	–	–	.00 (.00)	.00 (.00)	1.73 (.67)	.387	–	–
	carpenter	.00 (.00)	.00 (.00)	152.00 (90.94)	.598	–	–	.00 (.00)	.00 (.00)	1.63 (1.25)	.767	–	–

NR=participant with AOS and Broca's aphasia; DIFF=difference, expressed in terms of the number of standard deviations above (+) or below (–) the control group mean; *=significantly different from the control group mean (i.e. DIFF>2 SDs).

Table V. Mean (and standard deviation) kinematic parameter values for the control participants' (n=3) and NR during the release phases of /t/, /s/, and /k/ in one, two, and three syllable words.

		Duration (ms)			Distance (mm)			Acceleration (m/s^2)			Deceleration (m/s^2)			Velocity (mm/s)		
	Target	CG (SD)	NR (SD)	DIFF	CG (SD)	NR (SD)	DIFF	CG (SD)	NR (SD)	DIFF	CG (SD)	NR (SD)	DIFF	CG (SD)	NR (SD)	DIFF
/t/	tar	263.00	367.00	+1.83	14.35	19.40	+1.69	8.25	6.06	−1.14	7.61	7.12	−.21	111.00	116.80	+.23
		(56.85)	(23.35)		(2.98)	(2.34)		(1.92)	(.98)		(2.37)	(2.07)		(25.67)	(23.62)	
	target	199.67	314.00	+2.35*	13.37	20.76	+3.24*	9.43	7.31	−.64	9.82	7.50	−.77	125.24	126.60	+.06
		(48.71)	(48.91)		(2.28)	(2.97)		(3.31)	(1.31)		(3.02)	(2.70)		(24.95)	(24.42)	
	targeting	192.00	296.00	+2.72*	14.02	18.03	+1.10	9.92	7.92	−.95	8.48	5.10	−1.66	130.61	107.36	−.81
		(38.26)	(42.63)		(3.64)	(2.33)		(2.11)	(.96)		(2.04)	(.95)		(28.54)	(11.21)	
/s/	sarge	183.67	200.00	+.48	10.89	10.16	+.15	14.15	7.92	−1.75	10.85	6.70	−1.01	135.93	96.48	−1.07
		(34.04)	(35.36)		(4.78)	(2.28)		(3.56)	(2.56)		(4.10)	(2.82)		(37.02)	(30.57)	
	sergeant	156.67	205.00	+2.47*	9.80	9.02	−.22	11.82	6.54	−2.34*	9.40	7.07	−.89	119.31	81.00	−1.41
		(19.61)	(31.82)		(3.63)	(1.23)		(2.26)	(1.66)		(2.61)	(.54)		(27.27)	(12.95)	
/k/	car	212.33	242.00	+.51	12.16	17.47	+1.73	9.06	13.98	+1.45	6.95	8.24	+.50	108.05	142.64	+1.43
		(58.58)	(24.90)		(3.07)	(3.37)		(3.40)	(2.30)		(2.56)	(1.41)		(24.27)	(25.58)	
	carpet	197.67	221.00	+.48	10.88	16.91	+3.00*	9.73	17.32	+3.02*	6.74	11.69	+2.29*	101.27	151.92	+2.83*
		(48.36)	(54.59)		(2.01)	(2.89)		(2.51)	(4.94)		(2.16)	(7.53)		(17.89)	(34.23)	
	carpenter	177.00	232.00	+1.35	11.63	18.46	+3.15*	10.75	15.15	+1.34	8.51	10.32	+.63	117.75	155.64	+2.25*
		(40.79)	(42.37)		(2.17)	(1.62)		(3.28)	(5.19)		(2.87)	(3.39)		(16.86)	(15.54)	

Note: CG=control group; NR=participant with AOS and Broca's aphasia; DIFF=difference, expressed in terms of the number of standard deviations above (+) or below (–) the control group mean; *=significantly different from the control group mean (i.e. DIFF>2 SDs).

Table VI. Mean (and standard deviation) coefficient of variance (CV) values for the control participants' (n=3) and NR during the release phases of /t/, /s/, and /k/ in one, two, and three syllable words.

		Duration (ms)			Distance (mm)			Acceleration (m/s^2)			Deceleration (m/s^2)			Velocity (mm/s)		
	Target	CG (SD)	NR	DIFF	CG (SD)	NR	DIFF	CG (SD)	NR	DIFF	CG (SD)	NR	DIFF	CG (SD)	N	DIFF
/t/	tar	.150 (.131)	.064	−.66	.155 (.069)	.121	−.49	.182 (.132)	.162	−.15	.327 (.078)	.291	−.46	.179 (.071)	.202	+.32
	target	.132 (.086)	.156	+.28	.113 (.008)	.143	+3.75*	.295 (.299)	.179	−.39	.294 (.235)	.360	+.28	.161 (.094)	.193	+.34
	targeting	.097 (.060)	.144	+.78	.107 (.044)	.129	+.50	.126 (.023)	.121	−.22	.160 (.005)	.186	+5.20*	.072 (.026)	.104	+1.23
/s/	sarge	.118 (.029)	.177	+2.03*	.282 (.227)	.223	−.26	.203 (.034)	.323	+3.53*	.341 (.009)	.421	+8.89*	.180 (.061)	.317	+2.25*
	sergeant	.077 (.003)	.155	+26.00*	.179 (.075)	.136	−.57	.179 (.084)	.254	+.89	.199 (.115)	.076	−1.07	.151 (.071)	.160	+.13
/k/	car	.108 (.054)	.103	−.09	.157 (.011)	.193	+3.27*	.380 (.174)	.165	−1.24	.334 (.124)	.171	−1.32	.225 (.111)	.179	−.41
	carpet	.119 (.041)	.247	+3.12*	.107 (.050)	.171	+1.28	.197 (.025)	.285	+3.52*	.232 (.072)	.644	+5.72*	.170 (.043)	.225	+1.28
	carpenter	.095 (.037)	.183	+2.38*	.086 (.058)	.088	+.03	.248 (.027)	.343	+3.52*	.163 (.065)	.329	+2.55*	.121 (.055)	.100	−.38

Note: CG=control group; NR=participant with AOS and Broca's aphasia; DIFF=difference, expressed in terms of the number of standard deviations above (+) or below (–) the control group mean; +(x)=an increase in variability; −(x)=a decrease in variability; *=significantly different from the control group mean (i.e. DIFF>2 SDs).

mono- and multisyllabic word productions, with the exception of that recorded for /s/ during monosyllabic word productions, which was significantly more variable (see Table VI).

Relative release phase duration. The mean total word durations recorded for NR and the control group are presented in Figure 2a. The magnitude of the word duration increase from the two syllable word condition to the three syllable word condition appeared to be substantially greater for NR for /t/ and /k/-initial stimuli, compared to the control group (see Figure 2a).

Relative release phase duration values are presented in Figure 2b. For /t/ and /k/, relative release phase duration values decreased from the monosyllabic word to the multisyllabic words; however, for /s/, the relative release phase duration value increased from the one syllable word condition to the two syllable word condition (see Figure 2b). Interestingly, while the release phases of /t/ and /k/ were shorter during multisyllabic word productions, the magnitude of the reduction was smaller for NR, compared to the control group, for /t/, and for /k/, there was an increase in duration from the two syllable word condition to the three syllable word condition (see Figure 2b).

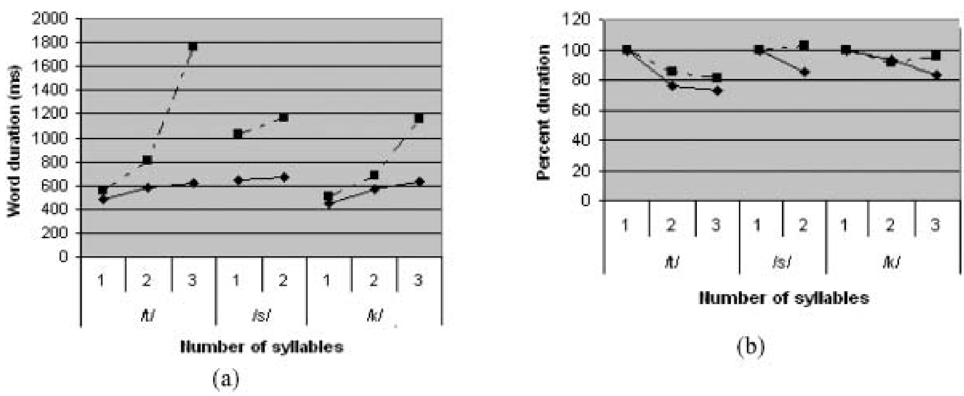

Figure 2. Mean word durations (ms) (a) and relative release phase durations, expressed as a percentage of the release phase duration values obtained for the monosyllabic words (b) for /t, s, k/ in one, two, and three syllable words. Diamonds represent control speakers, and squares represent NR.

Discussion

Having acknowledged that AOS is characterized by articulatory disturbances (McNeil et al., 1997; McNeil et al., 2004; Duffy, 2005), which are considered to be more prevalent in words of increased length (Johns & Darley, 1970; Deal & Darley, 1972; Kent & Rosenbek, 1983; Haley & Overton, 2001), the aim of the present paper was to investigate the kinematic parameters underlying target consonants in words of increasing length. It was hypothesized that NR would exhibit deviant and highly variable articulatory parameters for /t/, /s/, and /k/ during multisyllabic word productions; however, the articulatory parameters recorded during the monosyllabic word productions were expected to be relatively unimpaired.

Consistent with the former hypothesis, NR exhibited significantly deviant and highly inconsistent articulatory parameters for each of the target consonants during two and three syllable word productions. The approach and closure phases of NR's target consonant productions recorded during monosyllabic words, however, were also characterized by impaired, and highly variable, articulatory movements. The presence of articulatory variability in mono- and multisyllabic words is consistent with previous studies of AOS, which have reported variable timing parameters during mono- and multisyllabic word stimuli (Itoh et al., 1980; Square-Storer & Apeldoorn, 1991; Seddoh et al., 1996). Monosyllabic word productions, however, are typically characterized by a reduced number of articulatory errors in AOS (Johns & Darley, 1970; Deal & Darley, 1972; Kent & Rosenbek, 1983; Haley & Overton, 2001).

The duration of the approach and closure phases of NR's target consonants recorded during mono- and multisyllabic word productions appeared to be particularly prolonged. As evident from the articulatory kinematic data, NR's increased approach phase durations could be attributed to speed generation difficulties (i.e. reduced maximum acceleration), and/or to a reduction in peak velocity or maximum deceleration. These results are comparable to those obtained from previous kinematic studies of consonant production in AOS which have revealed longer closing segment durations (McNeil & Adams, 1991; Bose et al., 2001). Earlier studies, however, have reported discrepant results with respect to peak velocity. McNeil and Adams (1991) reported comparable movement velocities for the control speakers and persons with AOS, where in contrast, Itoh et al. (1980) reported reduced movement velocities for persons with AOS. The present study revealed reduced peak velocity measurements for /t/ and /k/ during mono- and/or multisyllabic word productions.

During the closure phase of target consonant productions, significantly greater duration and distance values were recorded. An increase in tongue movement at the palate could be indicative of unstable tongue-to-palate contact. Conversely, an increase in time spent at the palate could indicate a need for additional sensory feedback. This latter speculation is consistent with that of Bartle, Goozée, and Murdoch (submitted). Bartle et al. (submitted) reported silent articulatory attempts and starters in NR's kinematic data, which the authors interpreted as either an attempt to gain sufficient feedback for speech production, or as "practice" attempts to facilitate improved articulatory precision. Sensory testing was not included in the present study, however, and therefore this latter conclusion remains speculative.

Greater approach and closure phase durations can not be interpreted as phoneme prolongation during stop consonant (i.e. /t, k/) productions. Prior to the release of a stop consonant, an air-tight seal is formed with the articulators (i.e. tongue-tip pressing firmly against the alveolar ridge) during which no sound can be heard; only the release of a stop consonant is audible (Ball & Muller, 2005). In contrast, fricatives (i.e. /s/), unlike stop consonants, are characterized by an audible closure phase (Ball & Muller, 2005). As such, greater closure phase durations could be perceived as phoneme prolongation during fricative productions. NR's kinematic data is therefore consistent with what was perceived during NR's productions of /s/; NR's /s/ consonants were perceived to be mildly prolonged.

A trend of increasing difficulty in words of increasing length was evident during the release phase of target consonant productions. While the release phases of /t/, /s/, and /k/ were characterized by relatively comparable movement characteristics to those recorded for the control group during monosyllabic word productions, they were characterized by significantly greater duration or distance values during multisyllabic word productions. Increased articulatory displacements and speed generation difficulties (i.e. reduced maximum acceleration) could account for the increased durations recorded during the release phases of /t/ and /s/, respectively; however, with respect to the release phase of /k/, NR appeared to maintain a comparable duration to that of the control group by utilizing a significantly greater mean maximum acceleration, mean maximum deceleration, and/or mean maximum velocity. Given that the release phase of consonant production involves the transition from the consonant to the vowel, a prolonged release phase could account for increases in word length. Accordingly, an increase in word length was perceived during NR's "a targeting" productions. Interestingly, a normal word length was maintained during "a sarge" repetitions. The increase in word length perceived during "a carpenter" repetitions could not be attributed to a prolonged /k/ release phase duration.

Despite exhibiting more severe articulatory disturbances during the release phases of target consonants during multisyllabic word productions, NR did appear to exhibit smaller *relative* release phase durations for /t/ and /k/ during two and three syllable word productions. The release phase duration values obtained during multisyllabic word productions were expressed as a function of the release phase duration values obtained during monosyllabic word productions, not as a function of total word duration, as Haley and Overton (2001) suggested that the former method was more appropriate for participants who exhibit a substantially greater increase in word duration from monosyllabic to multisyllabic word stimuli. It was interesting to note that for /s/, NR appeared to maintain a similar release phase duration value during one and two syllable word productions. Similarly, NR appeared to utilize a different pattern of release phase reduction during /t/ and /k/-initial stimuli. According to Haley and Overton (2001), an abnormal reduction pattern can be attributed to a motoric level deficit.

Having established that the release phase of consonant production involves the transition from the consonant to the vowel, the aforementioned observations are consistent with previous reports of vowel reduction in words with an increasing number of syllables in AOS (Collins et al., 1983; Haley & Overton, 2001). In addition, studies of normal speech production have reported that consonant durations, like vowel durations, should decrease with an increase in word length (Lindblom, 1968). Therefore, by exhibiting this trend, there is sufficient evidence to suggest that NR has preserved phonologic knowledge. As such, NR's articulatory kinematic results can be interpreted with respect to motor, rather than linguistic, theories of speech production.

In terms of motor theory, AOS has been delineated a motor programming impairment (Darley et al., 1975; Clark & Robin, 1998), as well as a motor planning impairment (van der Merwe, 1997). Darley and his colleagues (1975) attributed AOS to a breakdown at the level of the motor speech programmer (MSP) in their three-stage model of speech production. Speech motor programming involves attending to the general motor program (GMP), which defines the relative timing and/or force of an action, as well as its' parameters, which defines the absolute duration and force of movement (Schmidt, 1982a, b; Clark & Robin, 1998). Given that NR had a tendency to reduce relative release phase durations in words with an increasing number of syllables (i.e. maintain relative timing of movement), it could be speculated that NR had difficulty attending to the parameterization processes involved in motor programming. Such difficulty could account for NR's longer absolute segment durations and subsequent decrease in speech rate. This result is consistent with that of Clark and Robin (1998), who concluded that persons with apraxia could only attend to one of the motor programming processes (i.e. GMP or parameterization).

According to van der Merwe's (1997) model of sensorimotor control for speech, a slow rate of speech that is due to a motor programming impairment is considered to be the result of a primary disorder in speech rate. If it is the result of a motor planning impairment, however, the reduction in speech rate is considered a compensatory change (van der Merwe, 1997). Given that van der Merwe (1997) attributed AOS to a disturbance in motor planning, it could be speculated that NR decreased her rate of speech, by increasing her segment durations, to assist in the planning of consecutive speech movements. As such, NR's articulatory disturbances could have been the result of an underlying motor planning impairment.

Conclusion

Deviant articulatory parameters and articulatory variability was recorded for each of the target consonants during multisyllabic word productions. The approach and closure phases of the target consonant productions, however, were also deemed deviant during monosyllabic word productions. In general, the approach and closure phases of /t/, /s/, and /k/ in mono- and multisyllabic word productions were primarily characterized by increases in duration, caused by reductions in maximum acceleration, maximum deceleration, and/or maximum velocity.

The effect of word length was most evident during the release phase of target consonant productions. Duration values were significantly greater during the release phases of /t/ and /s/ during multisyllabic word stimuli, whereas distance values were significantly greater during the release phase of /k/ during two and three syllable word repetitions. No significant disturbances were exhibited by NR during the release phase of target consonant productions during monosyllabic word repetitions. Articulatory overshooting and speed generation difficulties could account for the longer release phase durations. Increases in maximum acceleration, maximum deceleration, and/or maximum velocity appeared to counteract the increase in distance recorded during the release phase of /k/ in order to preserve a comparable duration to that of the control group.

Regardless of exhibiting more severe articulatory disturbances during the release phase of target consonant productions, there was evidence to suggest that NR had retained a certain degree of phonologic knowledge. Therefore, the results obtained from the present study were in support of a motoric account of apraxia of speech, and as such, could be interpreted with respect to a motor programming or a motor planning impairment. Through the collection of physiological data from a larger number of participants, it is expected that the current understanding of AOS and how it relates to theories of speech motor control will strengthen.

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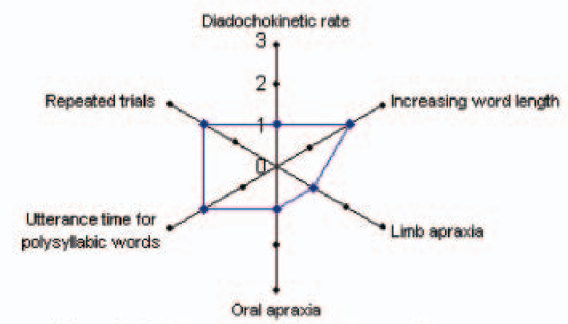
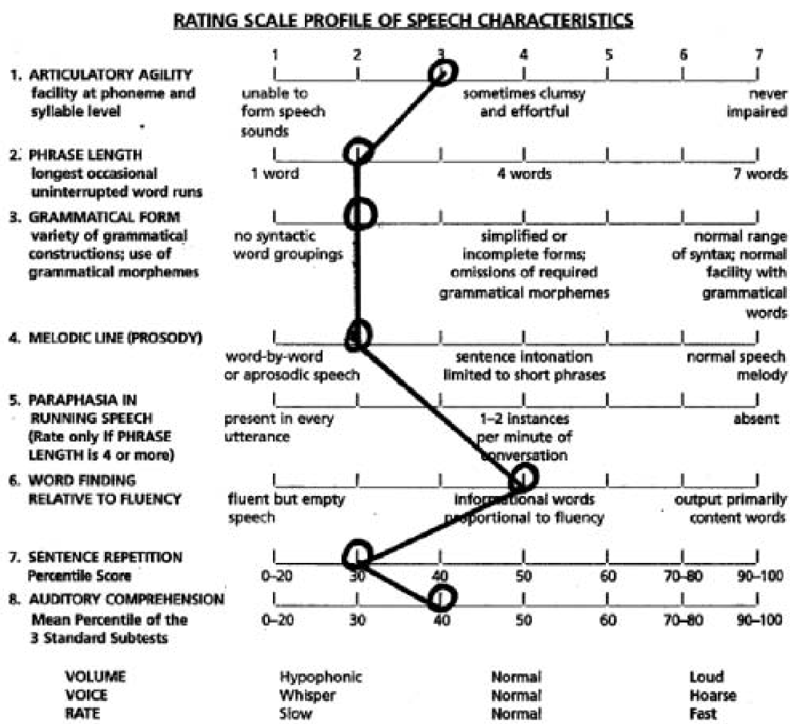
Appendix A



NR's Apraxia Battery for Adults-Second Edition (ABA-2) assessment profile. The stems represent the six subtests of the ABA-2. 0 = normal function; 1 = mild impairment; 2 = moderate impairment; 3 = severe impairment.

Appendix B



NR's Boston Diagnostic Aphasia Examination (BDAE) assessment profile.