Sentence Stress in Ataxic Dysarthria – A Perceptual and Acoustic Study

Running Head: Sentence Stress in Ataxia

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ABSTRACT

This study examined how speakers with ataxic dysarthria produce sentence stress and how these findings relate to other measures of speech performance. Ten speakers with ataxia and ten control speakers performed maximum performance, sentence stress, and passage reading tasks. Perceptual analyses established intelligibility levels and accuracy of stress production. Acoustic analyses included F0, intensity, and duration measures for sentence stress targets and MPTs, as well as acoustic rhythm measures for the sentence and passage reading tasks. Results showed that 60% of speakers experienced problems in signalling sentence stress irrespective of the severity of their dysarthria. Intensity and duration were most impaired, with F0 and pause insertion being used as compensatory strategies. The results highlighted the need for a detailed examination of speaker abilities in a variety of tasks in order to inform selection of the most effective treatment strategies.

INTRODUCTION

The speech problems experienced by speakers with ataxic dysarthria have been widely reported in the literature. Ataxic dysarthria is particularly characterised by rhythmic disturbances due to excess and equal stress, as well as slow rate, articulatory distortions, monopitch/loudness and poorly controlled pitch and loudness modulations (Duffy 2005, Schalling & Hartelius 2004, Schalling, Hammarberg, & Hartelius 2007).

Various attempts have been made to quantify the rhythmic disturbances in ataxic dysarthria (Henrich, Lowit, Schalling, & Mennen 2006; Liss et al., 2009). These measures largely focus on the duration of vowels and consonants. Contrastive stress tasks have also been employed to study how the modulations of pitch, loudness and duration interact to signal stress in words and sentences. These studies have identified a number of abnormalities such as reduced changes in F0, intensity and duration (Yorkston, Beukelman, Minifie and Sapir, 1984) as well as different relationships between these three dimensions (Murry,1983).

Apart from the above reports very few studies have actually been conducted to identify how speakers with ataxic dysarthria signal stress. In addition, no attempts have hitherto been made to relate findings on stress production to quantification of speaker rhythm or other speech parameters. The current study therefore aimed to revisit the production of stress in speakers with ataxic dysarthria and to relate these findings to other measures of speech performance on a more global scale.

METHOD

Participants

Ten speakers with ataxic dysarthria (AT) and ten healthy control speakers (HC) matched for age, gender and dialectal background participated in the study (see table 1 for details). Hearing and vision of all participants were normal or corrected-to-normal and they had no significant cognitive deficits. Dysarthria severity was determined from intelligibility scores derived from a passage reading task rated by five trained listeners (see below).

- *Insert Table 1 about here* -

Speech production tasks and materials

Speakers produced maximum performance tasks (MPT), including maximum phonation time and pitch and loudness glides, a reading passage (Cinderella passage, Grabe 2004) and a sentence stress task. The latter was designed to manipulate the location of sentence stress using a question-answer-paradigm[1]. Ten sentences were produced in three different versions, with stress on a different target word each time, resulting in a total of 30 productions per speaker. The target words were in initial, medial and final position, e.g. “The **lawyer** met the

[1] There is some confusion in the dysarthria literature concerning the type of stress elicited by such tasks. In this study sentence stress relates to the more natural narrow focus (e.g. Who did you meet? - I met **Tim.**) as opposed to contrastive stress (Did you meet Bob? - No, I met **Tim!**).

model in **London.**" All target words were nouns to avoid influences of syntactic processing on the results. Sentences were presented in a randomised order.

Recording Procedures

Participants were recorded in a quiet environment in their own homes or the university. Recordings were made using a portable DAT-recorder (TASCAM DA-P1) and a condenser microphone (Beyerdynamic MPC 65VSW) at a sampling rate of 44.1 kHz. Data were subsequently digitised using Kay Elemetrics Multispeech System.

Analysis

For the *perceptual analysis* five final year speech pathology students rated intelligibility for passage reading on a visual analogue scale. They also judged stress assignment in the sentence stress task, deciding whether single or multiple elements were stressed, and indicating their respective locations.

In the case of the *MPTs,* pitch and loudness glides were expressed as F0 (in Hz) and intensity range (in dB) and the duration of the sustained vowel was measured in msec. Acoustic analysis of the reading passage included the Pairwise Variability Index (nPVI, Low, Grabe, & Nolan, 2000) which quantifies rhythm as well as articulation rate (syllables/sec).

For the *sentence stress task*, the duration (in msec), peak intensity (in dB) and peak F0 (in Hz) of the primary stress vowel in the three target words were measured, as well as the number and positioning of pauses. Further variables were articulation rate, pause duration and location, and the nPVI. Pauses were defined as periods of no energy longer than 200 msec.

To quantify stress production, the percentage difference between stressed and unstressed versions of the same word across utterances was calculated for duration, F0 and intensity. In order to compare correct and incorrect productions of the sentences, F0 and intensity were investigated across stressed vs. unstressed words within the same utterance[2].

[2] This was not possible for the parameter of duration due to the inherent differences between the target vowels.

Group differences and relationships between measures were tested with non-parametric tests (Mann-Whitney-U-Test, Spearman's Rho). In addition, sentence position effects were assessed with a mixed ANOVA.

RESULTS

Maximum Performance Tasks: There was no significant difference in range for pitch or loudness glides between the ataxic and the control group (p_{F0} = .436, p_{int} =.481). However, the ataxic group showed a significantly reduced maximum phonation time (p=.022).

Sentence Stress – Rate and Pause Characteristics: Speakers with ataxia spoke at a significantly slower rate than the control group (p=.001) and produced a greater number of pauses (p=.004). There was evidence that some speakers used pauses strategically to signal stress. Six speakers (one control and five with ataxia) placed pauses around the target word in more than 50% of their utterances, mostly before but also following the target word. Of the remaining speakers nine controls and three speakers with ataxia produced no pauses, and two speakers with ataxia placed so many that no strategic use could be identified.

Sentence Stress – Perceptual Analysis: Based on the perceptual analysis of accuracy of stress placement, the ataxic group (ATA) was divided into two subgroups – high performers (ATA^H: speakers 1 to 6, 74-91% of target words correctly stressed) and low performers (ATA^L: speakers 7 to 10, 35-63% words correctly stressed). Of the incorrectly produced utterances, 23% were perceived with stress on the wrong target word and in 77% the target could not be clearly identified due to several words receiving equal stress.

Sentence Stress – Across Sentence Analysis: Figure 1 summarises the percentage difference between stressed and unstressed versions of the three target words across utterances for the control and the two ataxic groups. The positive values in the control group and ATA^H data show that in all target positions and for all speech parameters, stressed words had higher values than their unstressed counterparts. On the other hand, the negative values for the ATA^L group indicated that unstressed versions of the target words were often longer than the stressed production, highlighting particular problems with durational control. The ANOVA results largely confirm these observations, yielding significant main effects for group for duration and intensity. Bonferroni posthoc tests support the fact that the ATA^L group produced significantly smaller increases than the other two speaker groups (see Table 2). There were no significant differences in relation to F0 performance.

---Insert figure & table 2 about here---

Sentence Stress – Within Sentence Analysis: Figure 2 focuses on differences between correctly and incorrectly produced utterances in the ATA^L group. The data in Figure 2a show that for sentences with initial targets, the control speakers produced the highest F0 on the target vowel with a fast decline in F0. Although this de-accentuation was less clear for targets in final sentence position, the target vowel clearly stands out from preceding words and shows a significant fall towards the end of the utterance. The ATA^L speakers replicated this pattern in the correctly produced utterances (Figure 2b), but provided less clear signals in the incorrectly produced sentences except for utterances with initial targets (Figure 2c). A similar pattern was evident for the intensity data where the incorrect productions (Figure 2f) did not show the expected higher intensity values on the stressed words (cf. Figures 2d-e). Due to the complexity of the comparison, no multivariate statistical analysis could be performed on these data.

---Insert figure 2 about here---

Rhythm: The ATA^L group had significantly lower nPVI values in the stress sentences than the control speakers ($p=.008$) and the ATA^H group ($p=.038$), indicating that these speakers produced smaller variations in vowel length within utterances. They did not differ significantly from the other groups in the reading task (ATA^L - controls p=.304; ATA^L - ATA^H p=.476).

Relationship between speech measures: There was a significant relationship between the intelligibility and articulation rate measures for the reading passage (r=-.770, p=.009). However, with the exception of the relationship between the nPVI for reading and the stress sentences (r=.490, p=.028), none of the across task comparisons (involving reading, MPTs and stress sentences) reached significance for any of the other perceptual and acoustic measures taken.

DISCUSSION

This study investigated how speakers with ataxia produce stress at sentence level. Results showed that a considerable number of speakers (ATA^L) experienced problems in signalling stress through modulating duration, F0 and intensity. The durational impairment also affected the speakers' speech rhythm, i.e. they showed reduced levels of variation in vowel length in the sentence stress task. The results on stress production are reflective of the literature on ataxic dysarthria (Yorkston et al. 1984, Murry 1983) as well as other types of motor speech disorders (Patel & Campellone 2009). No studies have reported on the relationship between stress production and rhythm before. Although the current results suggested a link between these two measures, rhythm was not equally impaired in all speech tasks. This issue would thus warrant further investigation with larger participant numbers. Another interesting finding was the fact that the ability to signal stress was not related to the overall severity of the speaker. This was largely due to some of the more severely affected speakers successfully employing other prosodic cues. However, these could lead to unnatural speech, and the results thus highlight the need for a detailed examination of a speaker's abilities and natural compensatory mechanisms in order to identify optimal treatment strategies. The current data suggested that speakers made particular use of pitch modulations and pauses to compensate for impaired ability to use the other acoustical correlates of sentence stress. A more functional based analysis investigating the linguistic roles of speakers' tonal repertoires may help to identify additional factors relevant to achieving maximum intelligibility and naturalness. One such approach is the autosegmental-metrical (AM) framework reviewed by Ladd (2008) which has already been successfully applied to other disorders such as Parkinson's disease (Mennen, Schaeffler, Watt, & Miller, 2008). Future studies might want to make use of such approaches to gain a better understanding of how dysarthria can affect the linguistic use of prosodic components such as intonation.

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Table 1: Participant details for speakers with ataxic dysarthria.

speaker	age	gender	etiology	% intelligibility score
ATA1	46	M	CA	74
ATA2	60	F	CA	67
ATA3	28	M	FA	6
ATA4	52	F	CA	25
ATA5	28	F	FA	9
ATA6	65	F	SCA6	58
ATA7	72	M	CA	19
ATA8	51	M	CA	44
ATA9	56	M	SCA8	82
ATA10	57	F	FA	80
ATA mean (SD)	51.5 (13.6)			
Control mean (SD)	52.5 (12.8)			

CA: cerebellar ataxia of undefined type, SCA: spinocerebellar ataxia, FA: Friedreich's ataxia.

Table 2: Statistical results (ANOVA) for across sentence comparisons of duration and intensity for group and target position.

Variable	Main effect	Wilk's Lambda	F	p	Part. Eta squared	Bonferroni Post-hoc Tests p-value		
						C - ATA^H	C - ATA^L	ATA^H -ATA^L
Duration	Group		8.6	.003	.502	1.00	.002	.017
	Position	.863	1.3	.307	.137			
	Interaction	.975	0.1	.981	.012			
Intensity	Group		11.3	.001	.571	.055	.021	.001
	Position	.288	19.8	.001	.712			
	Interaction	.757	1.2	.331	.130			

Abbreviations: F = F value, p = p-value (significance level set at p<.05), C = control group, ATA^H = high performing ataxic group, ATA^L = low performing ataxic group.

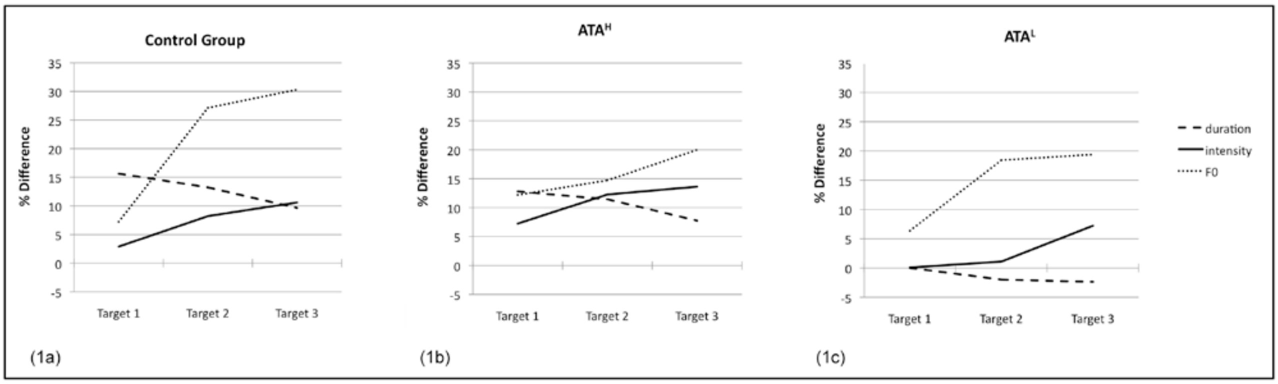

Figure 1: Percentage difference in duration, intensity and F0 between stressed and unstressed versions of target vowels across sentences for initial (Target 1), medial (Target 2) and final stress positions (Target 3).

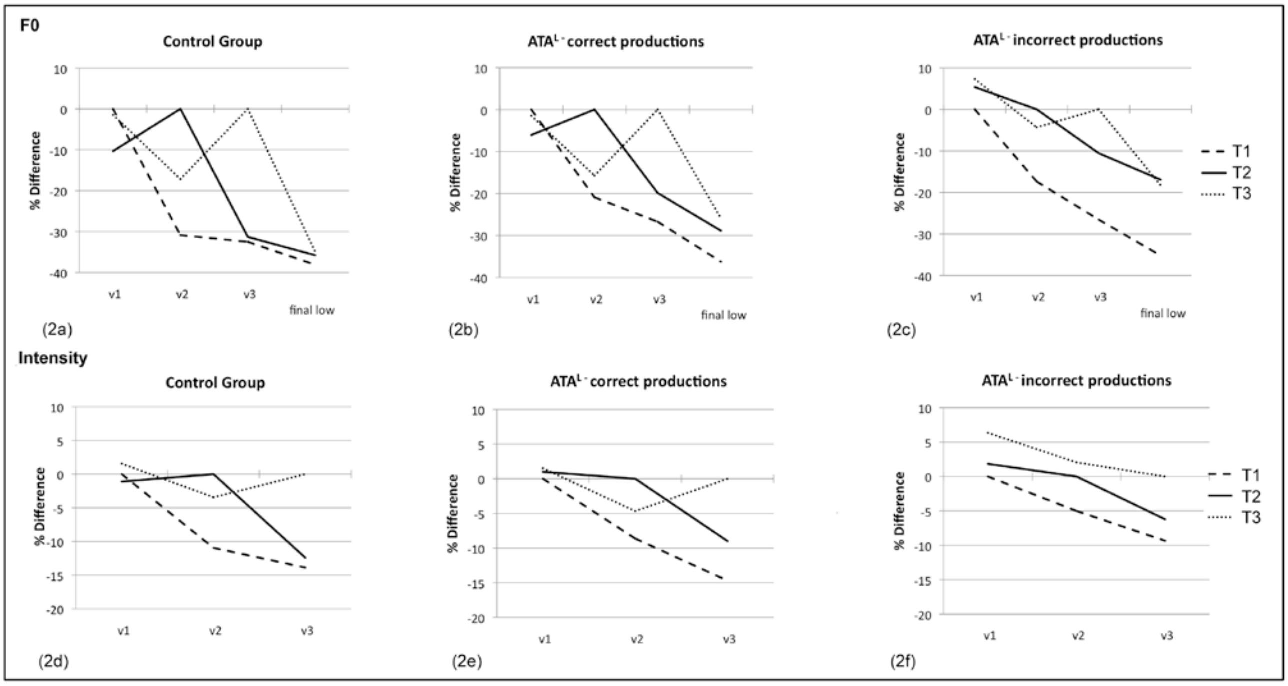

Figure 2: F0 and intensity contours for the three stress targets (T 1-3), expressed as the percentage difference between stressed and unstressed vowels across the three measurement points (initial, medial and final vowel (v 1-3)) as well as the final low in the case of F0.