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Reduced Task Adaptation in Alternating Motion Rate Tasks as an Early Marker of Bulbar Involvement in Amyotrophic Lateral Sclerosis

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Abstract

The identification of robust biomarkers to detect the onset of amyotrophic lateral sclerosis (ALS) has been an ongoing challenge. Recent evidence from multiple studies suggests that speech changes are a reliable early indicator of ALS particularly during physically demanding speaking tasks such as alternating motion rate (AMR). However, it has also been found that individuals make various behavioral adaptations to meet the maximum rate requirement in AMR. In this study, we explored the extent to which persons with early-stage ALS are capable of adapting to challenging speech-like tasks. Speech motor performance of 14 healthy controls was compared to that of 18 patients at the early stage of ALS during standard (unconstrained) and fixed-target (constrained) AMR tasks. Fixed-target tasks were designed to impose high demands on the speech motor system. Although habitual speaking rate was maintained within normal limits, findings revealed that task adaptation was reduced at the early stage of ALS. Furthermore, the difference between the number of cycles in the fixed-target task and standard task showed higher sensitivity than habitual speaking rate to detect early decline in bulbar function. The inability to adapt to the fixed-target task was a good early indicator of bulbar motor involvement due to ALS.

Index Terms: Amyotrophic lateral sclerosis, speech kinematics, alternating motion rate task, fixed-target task

1. Introduction

Amyotrophic lateral sclerosis (ALS) is a fatal neurodegenerative disease that impacts upper and lower motor neurons and causes difficulties with speech, swallowing, breathing, and mobility. Despite advances in the discovery of genetic, biochemical (blood-based), and neuroimaging-based ALS biomarkers, the diagnosis of ALS onset remains based on the presence of clinical symptoms and is, consequently, often delayed. To improve early diagnosis of ALS, researchers are now exploring speech-based markers because they are objective and relatively easy to obtain in clinical environments. Although speech markers are appealing, their effectiveness is known to be highly dependent on the speaking tasks. For example, eliciting a fast speaking rate produced less consistent articulatory patterns in talkers with ALS compared to normal controls [1]. Therefore, identifying the best diagnostic task is essential for developing a speech-based early ALS detector system.

One of the greatest challenges for detecting early speech changes is that affected talkers often use a wide variety of articulatory compensations to maintain normal speech despite underlying neurologic changes. To minimize opportunities for compensation, researchers have begun to design speech tasks that place high demands on articulatory motor performance. During the alternating motion rate (AMR) task, for example, speakers are required to produce a single syllable as fast and accurate as possible on a single breath. Although traditionally this task has been considered a maximum performance task [2], the validity of this assertion has been a subject of debate due to talkers' flexibility to bypass the speed challenge by truncating their articulatory displacements [3], [4]; shorter displacements tend to induce slower velocities, which is inconsistent with the increased physical challenge assertion.

To address this limitation, Mefferd, Green, and Pattee [1] controlled for the truncation effect instructing participants to strike a physical target placed under the jaw during the opening phase of each syllable. This task had the benefit of being more physically challenging because it induced larger and faster jaw openings, while at the same time minimizing the potential for articulatory compensation. Although their pilot study showed that the fixed-target task improved the detection of early-stage bulbar ALS, only velocity was studied. It remains to be determined if kinematic features that can index other aspects of motor performance (e.g., fatigue, fine-force control), are more sensitive to bulbar motor involvement than velocity. Therefore, with the knowledge that the fixed-target task prevents speakers from truncation of articulatory displacement during fast speeds, hypothetically, speakers with impaired motor systems may not show the same articulatory behavior as healthy controls who can adapt to the increased demands of the fixed-target task. We refer to this task-related articulatory adjustment as task adaptation.

The goals of the present study were to determine (1) if bulbar involvement can be detected based on the inability to adapt to a challenging speech-like task (i.e., fixed-target AMR task) in patients with ALS who do not exhibit overt speech symptoms in habitual speech, (2) the kinematic features that differentiate early-stage ALS patients from healthy controls in standard and fixed-target AMR tasks, and (3) articulatory kinematic features that show sensitivity to the early decline of bulbar function. The findings from this study will not only

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improve our understanding of task adaptation strategies in patients with early-stage ALS, but also will identify task-related kinematic features that can facilitate the early diagnosis, monitoring of disease progression, and new drug discovery for ALS.

2. Method

2.1. Participants

Participants consisted of 14 healthy controls (8 males and 6 females, mean age= 62.23, SD= 9.04) and 18 patients with ALS (12 males and 6 females, mean age= 55.71, SD= 10.02). All participants were native speakers of American English, passed a hearing screening in both ears, and had normal cognition. Participants with ALS had been diagnosed with ALS by a neurologist based on the El Escorial criteria [5] and were required to have no history of speech, language, hearing, or other neurological disorders. Participants with ALS varied in the site of onset (16 with spinal onset, 1 with bulbar onset, and 1 unknown). The mean total ALS Functional Rating Scale-Revised (ALSFRS-R) [6] score was 36.31 (SD= 5.47) and the mean bulbar sub-score was 11.23 (SD= 1.01). ALSFRS-R scores were not available for 5 patients. Patients with ALS were identified to be at the early stage because they exhibited a habitual speaking rate of greater than 150 words per minute (w/m) following Rong, Yunusova, and Green [7]. Speaking rate was used as a criterion to identify these patients because previous research has demonstrated that the decline of speaking rate precedes, and has a faster rate of decline, than speech intelligibility during the early stage of ALS [8], [9]. The mean speaking rate for the participants with ALS was 183.56 w/m (SD= 24.26) and for healthy controls was 188.20 w/m (SD= 18.22). The mean intelligibility scores for participants with ALS was 99.29 (SD = 1.11) and for healthy controls was 99.94 (SD= 0.24). Speaking rate and speech intelligibility were measured using the procedures described in the Speech Intelligibility Test [10] manual.

2.2. Data Collection

For the regular AMR task, participants were asked to take a deep breath and to produce the syllable /bɑ/ as quickly and accurately as possible until they ran out of breath. For the fixed-target AMR task, participants were given the same instructions but additionally, the experimenter held a blunt plastic stick under the chin of the participant. The distance between the tip of the stick and the lower jaw was determined by asking the participant to produce the syllable /bɑ/ and hold the mouth open for a few seconds. The tip of the stick was positioned so that it touched the underside of the chin during maximum jaw opening, which occurs during the vowel. Participants were instructed to hit the stick with each production. If participants failed to hit the target, they were encouraged to continue and to attempt to hit the target on the next production. Participants were given a few seconds to practice the task before recording began. Head stabilization was provided manually by the experimenter during the task.

2.3. Kinematic Recordings

Movements of the articulators during the AMR tasks were captured using a 3D electromagnetic articulograph (Wave; Northern Digital, Inc.). Following procedures described by [11], the 3D Euclidean distance between the upper and lower lip was derived during each of the AMR tasks. This was low-pass filtered at 15 Hz. These movement signals were used in the following data analyses.

2.4. Extraction of Kinematic Features

Kinematic data were analyzed using a semi-automatic MATLAB algorithm developed by Rong et al. [11]. The algorithm automatically segmented the opening and closing phases of the lip distance traces and identified cycles with large deviations from the average pattern for manual inclusion or exclusion of the deviant cycles. Based on the lip movement traces, the algorithm automatically extracted 21 variables that characterize the spatial and temporal features of lip movement during the AMR tasks. Of these 21 variables, 15 variables with potential clinical application were selected for this study. Table 1 displays the variables of interest used in this study. Spatial variables, temporal variables, spatiotemporal variables, and variables of overall motor performance are consistently color coded in blue, orange, green, and pink respectively in Table 1 and further illustrations hereafter.

Table 1: *Kinematic variables extracted from the upper and lower lip movement during AMR tasks.*

	Measures	Description
Spatial Variability	**Slp_d (mm)**	Slope of change in the distance between linear regression lines representing peaks and troughs of lip movement throughout all AMR cycles
	Sse1 (mm)	Lip opening gestural variability: Root_mean_square of residuals of the slope of regression line for peaks of lip movement
	Sse2 (mm)	Lip closing gestural variability: Root_mean_square of residuals of the slope of regression line for troughs of lip movement
	Scanning_ d1 (mm)	Mean of absolute differences of peaks (i.e. lip opening) in consecutive cycles
	Scanning_ d2 (mm)	Mean of absolute differences of troughs (i.e. lip closing) in consecutive cycles
	max_open (mm)	Maximum lip opening distance
	max_close (mm)	Maximum lip closing distance
Temporal variability	**Tsd (s)**	Standard deviation of cycle duration
	Jitter (s)	Mean of absolute differences of duration in consecutive cycles
	F (cycles/s)	Frequency of syllable repetitions
Spatiotemporal variability	**Sti**	Spatiotemporal variability index
	d_dtw	Dynamic time warping distance: index of dissimilarity between lip distance time series and a sine wave with the same frequency and average amplitude
	Max_vel (mm/s)	Maximum velocity of lip movement across all cycles
Overall performance	**Dur (s)**	Total duration of the AMR sequence
	Ncyc (cycles)	Total number of cycles in the AMR sequence

3. Results

To examine motor task adaptation of lip movements in healthy controls and patients at the early stage of ALS, kinematic measures obtained during standard and fixed-target AMR tasks were compared within each group using a pairwise t-test function in R statistical software. Figures 1 and 2 display the statistical analyses of task effect in healthy controls and patients with early-stage ALS respectively. Note that in Figures 1 and 2, the effect sizes are represented by dots at the middle of each horizontal line and each line represents the 95% confidence interval (CI) around the corresponding effect size. The red lines indicate statistically significant comparisons between kinematic measures of standard and fixed-target tasks ($p<0.05$). Horizontal lines deviated to the left indicate the directionality of change toward the fixed-target AMR task and those deviated to the right show the directionality of change toward the standard AMR task.

Var.	Task	Mean (SD)
Slp_d	S	0.010 (0.16)
	FT	0.004 (0.39)
Sse1	S	1.093 (0.47)
	FT	2.328 (1.15)
Sse2	S	0.647 (0.29)
	FT	1.092 (0.55)
Scan. d1	S	1.047 (0.48)
	FT	2.389 (1.13)
Scan. d2	S	0.579 (0.23)
	FT	1.043 (0.46)
Max open	S	11.427 (4.01)
	FT	25.160 (11.92)
Max close	S	11.272 (4.03)
	FT	24.875 (12.73)
Tsd	S	0.020 (0.01)
	FT	0.065 (0.06)
Jitter	S	0.189 (0.03)
	FT	0.328 (0.19)
F	S	5.505 (0.81)
	FT	4.071 (1.71)
Sti	S	9.301 (2.23)
	FT	11.506 (3.01)
d_dtw	S	1.651 (1.10)
	FT	15.356 (21.79)
Max_ vel	S	177.71 (60.45)
	FT	294.93 (102.8)
dur	S	20.189 (7.85)
	FT	18.868 (8.51)
Ncyc	S	105.57 (43.35)
	FT	67.286 (44.55)

ES *d* ± (95% CI)

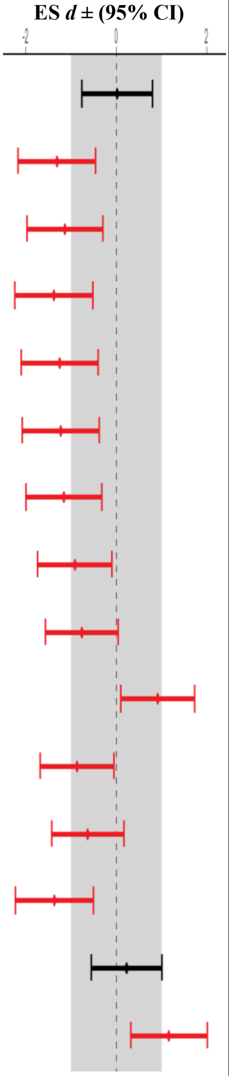

Figure 1: Kinematic features extracted from lip movement during standard (S) and fixed-target (FT) AMR tasks in the healthy control (HC) group.

Figure 1 shows that, in healthy controls, the majority of kinematic features of lip movement (spatial, temporal, spatiotemporal, and overall performance) obtained during the fixed-target AMR task are statistically significantly different from those obtained during the standard AMR task ($p< 0.05$). In addition, the direction of observed differences is mostly toward the fixed-target task (e.g., increased lip opening or max velocity in the fixed-target task as compared to the standard task). Figure 2, in contrast, demonstrates that at the early stage of ALS, only a few spatial and spatiotemporal kinematic features were statistically significantly different between the standard and fixed-target AMR tasks ($p<0.05$). The direction of the significant differences was also toward the fixed-target AMR task.

Var.	Task	Mean (SD)
Slp_d	S	-0.031 (0.24)
	FT	-0.187 (0.56)
Sse1	S	1.685 (1.18)
	FT	2.273 (1.04)
Sse2	S	0.665 (0.20)
	FT	0.723 (0.33)
Scan. d1	S	1.389 (0.62)
	FT	1.956 (0.83)
Scan. d2	S	0.599 (0.24)
	FT	0694 (0.34)
Max open	S	16.021 (6.35)
	FT	23.679 (9.65)
Max close	S	15.962 (6.60)
	FT	23.943 (9.76)
Tsd	S	0.045 (0.05)
	FT	0.046 (0.03)
Jitter	S	0.234 (0.08)
	FT	0.296 (0.18)
F	S	4.970 (1.59)
	FT	4.275 (1.89)
Sti	S	11.691 (4.22)
	FT	10.739 (3.69)
d_dtw	S	4.509 (3.93)
	FT	11.745 (12.75)
Max_ vel	S	230.80 (81.02)
	FT	291.12 (85.48)
dur	S	16.073 (5.75)
	FT	14.528 (7.08)
Ncyc	S	72.167 (34.24)
	FT	56.333 (34.71)

ES *d* ± (95% CI)

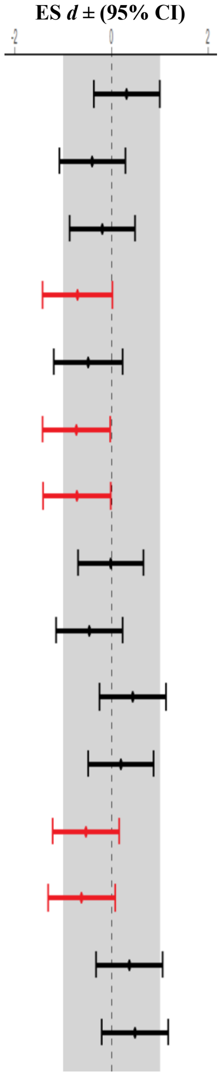

Figure 2: *Kinematic features extracted from lip movement during standard (S) and fixed-target (FT) AMR tasks in the early-stage ALS group.*

Independent samples t-tests to examine the group effect for each AMR task revealed significant differences between healthy controls and patients with ALS for Ncyc, d_max_open, d_max_close, d_dtw, and max_vel features during the standard AMR tasks as well as Sse2 and scanning_d2 features during the fixed-target AMR task ($p< 0.05$). Figure 3 displays the boxplots for kinematic features that yielded significant group differences between standard and fixed-target AMR tasks.

Finally, the difference between corresponding kinematic features in standard and fixed-target AMR tasks (e.g., Δslp_d, ΔSse1, etc.) was calculated for each participant. Subsequently, Receiver Operating Characteristic (ROC) curves were produced to determine area under the curve (AUC) along with measures of sensitivity and specificity for each variable in distinguishing between healthy controls and patients with ALS. The ROC curve of habitual speaking rate was also produced to compare its diagnostic strength to those of AMR-related kinematic features. Among all variables, ΔNyc and ΔF were observed to have AUC greater than 0.5 (chance). The AUC for variables ΔNyc and ΔF were 0.70 and 0.62 respectively. The ROC curve for habitual speaking rate demonstrated an AUC below diagonal/chance line (0.38). Figure 4 illustrates the ROC curves of ΔNyc, ΔF, and habitual speaking rate.

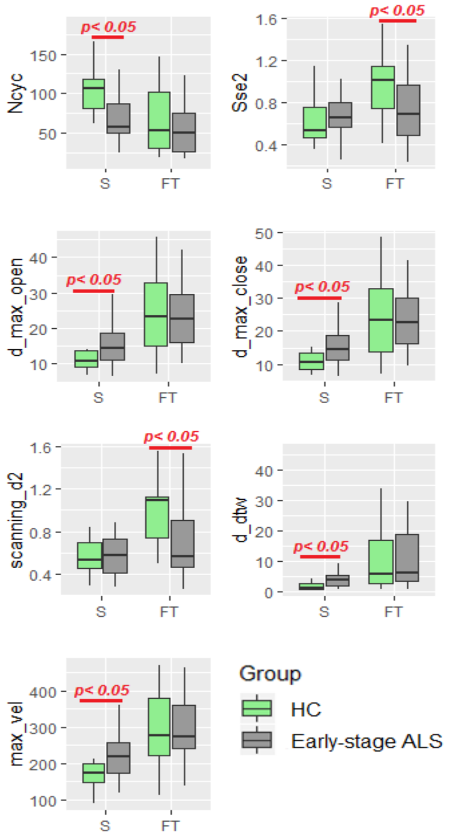

Figure 3: *Kinematic features of overall motor performance in standard and fixed-target AMR tasks.*

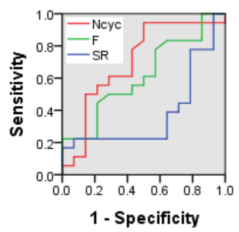

Figure 4: *ROC curves of ΔNyc, ΔF, and speaking rate (SR).*

4. Discussion

In this study, we compared the articulatory motor adaptation of healthy controls and early-stage ALS participants across two types of AMR tasks (i.e., standard and fixed-target) using kinematic features extracted from the lip movements. In addition, we identified the features that are most sensitive to early bulbar decline. It should be noted, that because of the small sample sizes, findings were interpreted based on the effect sizes to manage the problems associated with multiple comparisons and family-wise error rates. Findings of this study support our hypothesis that task adaptation is reduced in patients with early-stage ALS. Healthy controls uniformly adjusted articulatory control to accommodate each task as most lip kinematic features considerably changed from the standard to the fixed-target AMR task with effect sizes greater than 1. However, participants with early-stage ALS only exhibited task adaptation for some of the spatial and spatiotemporal kinematic features as a result of larger articulatory displacement elicited during the fixed-target task compared to the standard task. Reduced task adaptation suggests that motor strategies are limited even during the early stages of ALS and hence, patients at the early stage of ALS do not have the capability to adopt articulatory adjustments to accommodate the higher articulatory demands imposed on the neuromotor system during the fixed-target AMR task.

As displayed in Figure 3, kinematic differences between groups were primarily observed only during the standard AMR task. Relative to the healthy controls, the participants with ALS produced fewer cycles (Ncyc), but larger articulatory excursions (d_max_open and d_max_close), and higher velocities (max_vel). The observation of larger and faster movements during early-stage bulbar motor involvement is counterintuitive based on expected movement deficits associated with progressive muscle paresis, but this is consistent with prior work on bulbar motor deterioration [12], [13]. Several hypotheses have been advanced to explain this transitory gain in movement during the early stages of bulbar disease including the effects of excessive glutamate on motor function or jaw compensation for tongue weakness [14]. These paradoxical findings, however, underscore the diagnostic value of the adaptation paradigm for uniformly exposing impaired aspects of articulatory control during the early stages of the disease. These findings suggest that an adaptation paradigm that combines information from the standard and fixed-target approaches is needed for a comprehensive assessment of oromotor function for disease diagnosis.

Finally, ROC curves of task-differences (Δ) in kinematic features indicated that among all features, ΔNcyc and ΔF had higher sensitivity than habitual speaking rate to detect early decline of bulbar function. These features can be used clinically as early indicators of bulbar involvement.

5. Conclusions

Compared to healthy controls, adaptation to AMR tasks was reduced in patients with ALS at the early stage of the disease. Because the fixed-target AMR task drove more articulatory displacement than the standard AMR task, patients at the early stage of ALS were only able to adapt to the fixed-target task in spatial and spatiotemporal features, but not in temporal features. In addition, among all features, ΔNcyc and ΔF showed the highest sensitivity to detect patients with early-stage ALS. A combined approach is needed for a comprehensive assessment of oromotor function and early detection of ALS.

6. Acknowledgements

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7. References

[1] A. S. Mefferd, J. R. Green, and G. Pattee, "A novel fixed-target task to determine articulatory speed constraints in persons with amyotrophic lateral sclerosis," *Journal of Communication Disorders,* vol. 45, no. 1, pp. 35-45, 2012.

[2] R. D. Kent, J. F. Kent, and J. C. Rosenbek, "Maximum performance tests of speech production," *Journal of Speech and Hearing Disorders,* vol. 52, no. 4, pp. 367-387, 1987.

[3] D. P. Kuehn, and K. Moll, "A cinefluorographic investigation of CV and VC articulatory velocities," *Journal of Phonetics,* vol 4, pp. 303-320, 1976.

[4] A. S. Mefferd, and J. R. Green, "Articulatory-to-acoustic relations in response to speaking rate and loudness manipulations," *Journal of Speech, Language, and Hearing Research*, 2010.

[5] B. R. Brooks, R. G. Miller, M. Swash, and T. L. Munsat, "El Escorial revisited: revised criteria for the diagnosis of amyotrophic lateral sclerosis". *Amyotrophic lateral sclerosis and other motor neuron disorders*, vol. 1, no. 5, pp. 293-299, 2000.

[6] J. M. Cedarbaum, N. Stambler, E. Malta, C. Fuller, D. Hilt, B. Thurmond, A. Nakanishi, and BDNF ALS Study Group, "The ALSFRS-R: A revised functional rating scale that incorporates assessments of respiratory function", *Journal of the Neurological Sciences*, vol. 169, pp.13–21, 1999.

[7] P. Rong, Y. Yunusova, and J. R. Green, "Speech intelligibility decline in individuals with fast and slow rates of ALS progression", *Proceedings of the Sixteenth Annual Conference of the International Speech Communication Association*, 2015.

[8] P. Rong, Y. Yunusova, J. Wang, and J. R. Green, "Predicting early bulbar decline in amyotrophic lateral sclerosis: A speech subsystem approach", *Behavioural Neurology*, vol. 2015, 2015.

[9] J. R. Green, Y. Yunusova, M. S. Kuruvilla, J. Wang, G. L. Pattee, L. Synhorst, L. Zinman, and J. D. Berry, "Bulbar and speech motor assessment in ALS: Challenges and future directions", *Amyotrophic Lateral Sclerosis and Frontotemporal Degeneration*, vol. 14, no. 7-8, pp. 494-500, 2013.

[10] K. Yorkston, D. Beukelman, and M. Hakel, "Speech Intelligibility Test (SIT) for Windows [computer software]". Lincoln, Nebraska, USA: Madonna Rehabilitation Hospital, 2007.

[11] P. Rong, Y. Yunusova, B. Richburg, and J. R. Green, "Automatic extraction of abnormal lip movement features from the alternating motion rate task in amyotrophic lateral sclerosis", *International journal of speech-language pathology*, vol. 20, no. 6, pp.610-623, 2018.

[12] Y. Yunusova, J. R. Green, M. J. Lindstrom, L. J. Ball, G. L. Pattee, and L. Zinman, "Kinematics of disease progression in bulbar ALS", *Journal of communication disorders*, vol. 43, no. 1, pp. 6-20, 2010.

[13] Y. Yunusova, G. Weismer, J. R. Westbury, and M.J. Lindstrom, "Articulatory movements during vowels in speakers with dysarthria and healthy controls", *Journal of Speech, Language, and Hearing Research*, vol. 51, no. 3, pp. 596-611, 2008.

[14] R. DePaul, J. H. Abbs, M. Caligiuri, V. L. Gracco, and B. R. Brooks, "Hypoglossal, trigeminal, and facial motoneuron involvement in amyotrophic lateral sclerosis", *Neurology*, vol. 38, no. 2, pp. 281-281, 1988.