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Dysarthric speech: A comparison of computerized speech recognition and listener intelligibility

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Abstract—The purpose of this study was to identify and compare the recognition of dysarthric speech by a computerized voice recognition (VR) system and non-hearing-impaired adult listeners. Intelligibility "functions" were obtained for six dysarthric speakers who varied in severity and six age- and gender-matched controls. Speakers produced 70-item word lists over 5 sessions. VR using the IBM VoiceType and perceptual judgment scores were obtained and functions plotted by session. Data indicate that computerized recognition of both dysarthric and nonimpaired speech was characterized by initially steep increases in correct recognition with more gradual increases noted during the second through fifth sessions. Perceptual recognition by non-hearing-impaired adults indicates generally stable intelligibility scores over time. Severity of dysarthria did appear to influence recognition of target stimuli. Implications of these data to the application of computerized VR technology are presented.

Key words: *dysarthria, motor speech disorders, speech disorders, speech intelligibility, speech recognition.*

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INTRODUCTION

The dysarthrias comprise a group of motor speech disorders that result from damage to the central and/or peripheral nervous system. Dysarthria is associated with various etiologies, including cerebrovascular accident (CVA), cerebral palsy, degenerative neurological diseases (e.g., Parkinson's disease or amyotrophic lateral sclerosis), and traumatic brain injury (TBI). Dysarthria may range in severity from minimal impairment to that which renders speech virtually unintelligible. Excessive nasalization, disordered speech prosody, imprecise articulation, and variable speech rate are often associated with damage to neuromuscular systems regulating speech (1). Aberrations in speech physiology may result in distortion of the acoustic signal and reduced speech intelligibility. Reduced speech intelligibility affects all aspects of life, and individuals with intelligibility deficits experience difficulties with social interaction, academic performance, and vocational placement (2).

Recent changes in voice recognition (VR) technology, including speaker-adaptable systems, have resulted in the development of systems that enable people with communication disorders to access computers. VR is one way to remove some of the complex barriers to participation by persons with disabilities, particularly those with severe speech impairments (3,4). Speech recognition (SR) is a practical computer access mode for people with motor limitations or disabilities without speech involvement (5).

Unfortunately, many people with disabilities affecting the upper limbs also have dysarthria. While SR systems have been used successfully with dysarthric speakers to write, to control their environment, and to clarify speech, recognition performance appears to deteriorate rapidly for vocabulary sizes that exceed 30 words (6,7).

Many SR systems do not require intelligible speech input, but rather, simply match a voice pattern with one previously recorded (i.e., a speaker-dependent system). Ultimate versatility of VR, however, would involve speaker-adaptable recognition of unlimited connected speech in a natural spoken environment (6). The general goal of speaker adaptation allows the system to learn acoustic characteristics of individual speakers (8). For speaker-dependent systems, consistency of sound production is paramount to successful recognition (7). The ability of speaker-adaptable systems to learn and adapt to the speaker, however, may compensate for inconsistencies in speech production. Speech intelligibility may be as important as the consistency of production in achieving good recognition scores.

Carlson and Bernstein (9) demonstrated that speakers with dysarthria are less well recognized by VR systems than speech of people with hearing impairments. They noted that recognition accuracy varied widely across dysarthric speakers. Coleman and Myers (3) reported that VR systems performed less well for dysarthric speakers than nonimpaired speakers, but did not investigate the cause of recognition errors. Recent work by Huckle, Doyle, and Haaf (10) demonstrated that VR systems do appear to be differentially sensitive to acoustic features inherent in the signal. These investigators emphasized the need for research to determine the cause of low recognition scores, and, perhaps more importantly, to identify acquisition/recognition functions over time and provide direction for client training to improve recognition accuracy.

The acoustic level of the speech process is possibly the most critical for assessment and remediation of dysarthria because it provides essential information about speech production and its effects on the listener (or VR system). Acoustic analyses have provided reliable data on dysarthrias associated with several diseases and also may permit quantification of subtle changes in speech behavior over time (11–14). Research indicates that certain speech parameters, such as voicing contrasts, nasalization, and vowel height, may be critical in degrading speech intelligibility (15,16). Research is needed to determine whether these parameters are also associated with low recognition scores and whether speech training on these specific parameters can improve recognition accuracy for dysarthric speakers.

Several investigators have suggested that dysarthric speakers may improve their speech intelligibility and precision of articulation through interaction and training with a VR system. To date, however, there have been only limited efforts relating listener judgments of intelligibility of speech over time to acquisition functions of a computer recognition system. The IBM VoiceType® (IBM Canada, Markham, ON) is a speaker-adaptable SR system that utilizes a 7,000 word vocabulary and a backup dictionary of approximately 80,000 words that assists in word prediction. The system is designed so that productions are matched against user-independent word templates stored in memory and adapts to individual speech characteristics by adding the individual's own word templates to its user-provided vocabulary. Thus, a major component of this speaker adaptation causes the VR device to "learn" particular acoustical characteristics of the speaker.

Despite the power of the VR systems to recognize speech, little is known about acquisition functions associated with VR using speaker-adaptable systems, specifically the VoiceType, when input is provided by dysarthric speakers. The comparative functions of the listener's perceptual recognition and that of a VR system is also unknown. Thus, the purpose of this investigation was to compare SR using the VoiceType to intelligibility of human listeners.

METHODS

Speakers

Six speakers (three males and three females), who ranged in age from 15 to 55 years, served as subjects for this investigation. The level of severity of intelligibility impairment for each subject was determined by a speech-language pathologist using CAIDS, the Computerized Assessment of Intelligibility of Dysarthric Speech (17). Scores obtained from this evaluation are presented in **Table 1.** Two speakers exhibited mild deficits (>70 ≤90 percent intelligible), two were moderately impaired (>40 ≤70 percent), and two were severely impaired (>10 ≤40 percent). Six age- and gender-matched nonimpaired speakers served as controls. A summary of each experimental subject including etiology, time postonset, type of dysarthria, and a brief description of speech impairment(s) is provided in **Table 2.**

Table 1.
Individual speaker intelligibility scores (in % age) for word and sentence materials obtained from the CAIDS.

Severity Level		Word	Sentences
Mild	Female 1	76	99.5
	Male 1	80	94.1
Moderate	Female 2	40	80.5
	Male 2	42	88.2
Severe	Female 3	38	90
	Male 3	28	55

Speech Stimuli Instrumentation and Procedure

All experimental and control subjects produced randomized 70-item word lists over 5 separate sessions (11). Spoken stimuli were routed to two recording devices during the experiment: 1) a VR system (IBM VoiceType, Version 1.0) via a microphone headset (Shure Prologue 24L) placed within 1.3 cm of the left corner of the subject's mouth and 2) a digital audio tape (DAT) recorder (Sony Model DTC-750) using a second microphone (Shure 24L) positioned at a constant microphone-to-mouth distance of 7.6 cm. The microphone for the DAT recorder was routed through a preamplifier (Rane MS1: Rane Corporation, Mukilteo, WA). If incorrect VoiceType recognition of a stimulus token occurred, input was corrected online by one of the experimenters by typing the intended target into the system or by having the subject use spell mode. Regardless of the clarity of the speech target, if an error in VoiceType recognition occurred, the correct token was supplied so that an acoustic template was generated for recognition of stimuli to be input in later trials. These stimuli were then used for the generation of master experimental stimuli tapes used during the perceptual phase of the investigation.

Perceptual Assessment

A perceptual phase of the study was included primarily to determine similarities and/or differences in the recognition of dysarthric speech by computer and by human listeners. It also was anticipated that use of these two types of stimulus recognition would serve to define any decrements in ongoing speech intelligibility due to fatigue or other factors.

Table 2.
Description of Subjects: Etiology, Dysarthria Type, Characteristics, and CAIDS rate/words per minute (wpm).

Subjects/Severity	Etiology	Time Post Onset	Type of Dysarthria	CAIDS rate/wpm
Mild				
Female 1	CHI	4 years	Primarily ataxic with flaccid component— weakness of CNs VII, IX, XII, reduced rate, mild vocal tremor, monotone, imprecise articulation	128.9
Male 1	CP	n/a	spastic — imprecise articulation, rate disturbance, decreased volume on final consonants, vocal fry	102
Moderate				
Female 1	CP	n/a	ataxic — explosive loudness, poor breath control, decreased rate, blend reduction, stopping, w/r substitution	33.8
Male 1	CHI	4 yrs	flaccid — decreased rate, pitch inconsistency, reduced pitch variation, hypernasal, imprecise articulation	81.3
Severe				
Female 1	CHI	20 yrs	spastic — decreased rate, monotone, strained voice, w/r substitution, hypernasal	59.5
Male 1	CP (ataxic)	n/a	ataxic — monotone, imprecise articulation, inconsistency in voicing of consonants, j/l substitution, distorted sibilants & affricates, inconsistent sound errors, insertion of neutral vowel between consonant blends, decreased accuracy/intelligibility with increase in length/complex of utterance	116.1

Note: CHI = Closed head injury; CP = Cerebral palsy.

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Preparation of Experimental Stimuli for Perceptual Phase of Investigation

Stimuli for the perceptual phase of the investigation were prepared by randomizing the original stimuli produced by each of the 12 speakers (6 dysarthria and 6 control) across the 5 recording sessions. For each speaker in each session a total of 70 stimuli were produced. Original DAT recordings were duplicated in random order using a second DAT recorder/player and were then submitted to perceptual evaluation[1].

Listeners

Ten young adults without hearing impairment served as listeners for the perceptual phase of the study. Listeners ranged in age from 22 to 27 years (mean=25±4 years); all were first-year students in communication sciences and disorders. Although all had some knowledge of disordered speech, none had formal coursework or clinical experience with dysarthric speakers. All listeners reported a negative history of hearing difficulties and all passed a pure-tone audiometric screening at 20 dBHL for the octave frequencies 500, 1,000, and 2,000 Hz.

Listening Procedure

Listeners heard all stimuli during a single session. A total of 420 stimuli were produced by both dysarthric and control speakers (70 stimuli × 6 speakers per group) in each session. Additionally, 20 percent of the original stimuli from each session (n = 84 stimuli × 5 sessions) were randomly selected and reproduced for reliability purposes; this resulted in a total of 2,520 stimuli (420 stimuli × 5 sessions + 420 reliability samples). Stimuli were presented through headphones at a loudness level judged as comfortable by each listener. All listeners identified stimuli using a modified closed-set response paradigm in which the target stimulus appeared with three foils; however, the listener also was allowed to "write in" a word if she or he did not find a suitable choice from the four choices provided. Stimulus foils were obtained from materials developed by Kent and colleagues (11). For example, if the target stimulus was "bad," foils offered were "bed," "bat," and "pad," as well as the write-in option. Thus, listeners generated 42,000 perceptual responses (70 stimuli × 12 speakers ×5 sessions × 10 listeners).

[1]The one exception was the word "leak" from the Kent et al. stimuli, which appeared twice on the word list used. To ensure that all words were input only once to VoiceType, the second production of "leak" in each session was only input to the DAT. This resulted in the original recording of 70 stimuli, with 69 items input to VoiceType for each session.

Data Analysis

VoiceType recognitions of stimuli for each speaker in each recording session were obtained and percent correct scores were calculated. A similar recognition score was obtained for each control subject, but these data were then used to calculate mean scores by gender. Identical procedures were used to calculate intelligibility based on perceptual responses obtained from the 10 listeners. Both VoiceType and listener-based intelligibility data were segmented by session and VoiceType recognition, and perceptual intelligibility functions were plotted over the five sessions.

RESULTS

VoiceType Recognition

Unique functions for VoiceType recognition and the listeners' perceptual identification of stimuli were noted between control and dysarthric speakers over the five sessions. For control speakers (n=6), VoiceType scores ranged from 4 to 19 percent for Session 1, but the range increased from 54 to 73 percent in Session 2 and exceeded 68 percent by Session 3. For dysarthric speakers, performance generally varied by severity. VoiceType recognition scores for the six dysarthric speakers were <9 percent in Session 1; in fact, two dysarthric speakers exhibited 0 percent recognition in this initial session. Recognition increased for all subjects in Session 2 (range = 16 to 62 percent). By Session 5, scores increased to 35 percent for one of the severely impaired speakers (male) to a high of 80 percent for one of the mildly impaired speakers (female). Scores for each speaker by session are presented in **Table 3.** Control speakers demonstrated a slightly steeper and more consistent function than dysarthric speakers, who did demonstrate some variability across the five sessions regardless of severity level. Although the severely dysarthric male subject did exhibit the poorest recognition function over the five sessions, the other dysarthric speakers' recognition scores were similar, particularly at and beyond Session 3. It was noted that male dysarthrics generally performed more poorly relative to their female counterparts; as expected, control subjects were recognized with greater accuracy than age- and gender-matched dysarthric subjects. These data are presented graphically in **Figure 1.**

Table 3.

Overall VoiceType percent scores for recognition and perceptual intelligibility by listeners (n = 10) for six dysarthric speakers and six age- and gender-matched control speakers. Data presented are segmented by evaluation session and by severity level.

Session		1	2	3	4	5
VoiceType Recognition		Control Speakers*				
		8	65	71	78	79
		Dysarthric Speakers				
Mild	**Male**	9	48	38	48	54
	Female	4	62	64	74	80
Moderate	**Male**	7	48	46	54	54
	Female	0	39	41	62	52
Severe	**Male**	0	16	19	19	35
	Female	3	54	74	67	77
Perceptual Recognition		Control Speakers*				
		100	100	100	100	100
		Dysarthric Speakers				
Mild	**Male**	96	95	95	95	95
	Female	95	95	93	96	96
Moderate	**Male**	82	86	91	90	88
	Female	86	85	86	84	87
Severe	**Male**	95	95	94	89	93
	Female	79	82	79	77	81

*Mean values denoted.

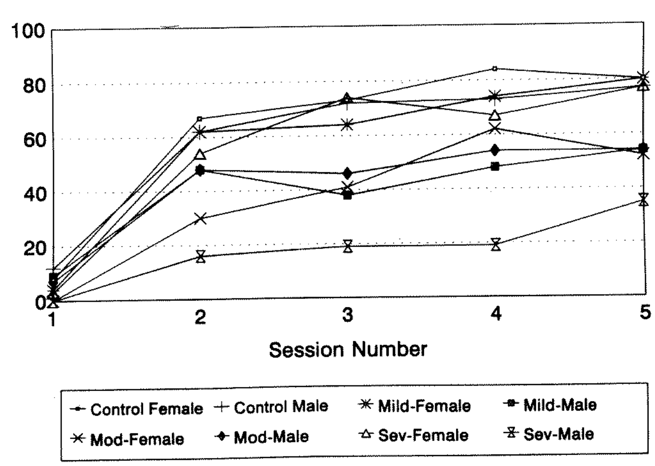

Figure 1.
VoiceType recognition accuracy (in percentage) across 5 sessions: control speakers and mild, moderate, and severe dysarthric speakers.

Listener Recognition

As expected, listener recognition of stimuli produced by control speakers was at 100 percent across all five sessions. Mean listener intelligibility scores for mildly dysarthric speakers was consistently observed to be at 94–96 percent, for moderately dysarthric speakers intelligibility ranged from 90–94 percent, and for severely dysarthric speakers from 78–85 percent. These data are presented graphically in **Figure 2.** In contrast to the findings for VoiceType recognition functions, no overlap between speaker severity level classifications was observed across the five sessions; each speaker group (control, mild, moderate, and severe dysarthric speakers) exhibited consistent and perceptually distinct intelligibility across the five sessions.

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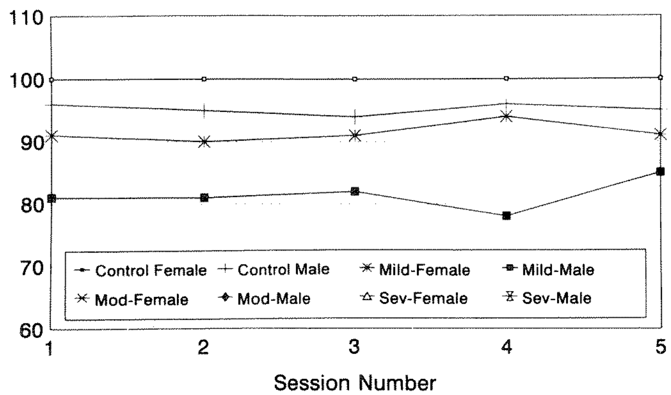

Figure 2.
Mean perceptual recognition accuracy (in percentage) across 5 sessions: control speakers and mild, moderate, and severe dysarthric speakers.

DISCUSSION

Generally, commercial distributors of VR systems have suggested that a maximum of five sessions is adequate to establish a recognition template that will serve as the basis for comparison of speech input. However, data to confirm this suggestion have been unavailable. Based on the present findings, data do not fully support this time-frame or learning curve. Although the greatest increase in VoiceType recognition existed between Sessions 1 and 2, improvement continued into Sessions 4 and 5 for both control and dysarthric speakers (regardless of severity). In fact, the present data suggest that rather substantial increases in recognition accuracy may be seen with more training sessions. This change may, however, be less apparent in speakers with more severely impaired speech, or, perhaps more importantly, inconsistent production. Given that no clear asymptote in the function was noted, VoiceType scores may have continued to improve in later training sessions. Our data are in agreement with Ferrier, Jarrell, Carpenter, and Shane (18), who found parallel and nonsignificant differences in learning curves for a nonimpaired speaker and a mildly dysarthric speaker. Although the present data cannot be generalized to dysarthric speakers as a group, our data suggest a clear need to evaluate clinical applications of VR performance for at least five sessions for template formation.

In order to optimize clinical applications and utility of computerized technology for those who exhibit speech disorders, a clear need exists to determine maximum performance capabilities using VR. Nevertheless, careful consideration of the interaction between speech intelligibility and consistency is essential when considering use of VR systems (19). Specifically, reduced intelligibility due to consistent motoric breakdown during speech would likely result in less variable recognition by computer, when compared to a speaker with inconsistent speech production capabilities. Based on the present data, the VoiceType system may offer potential user access for dysarthric speakers, particularly those with severe impairments in intelligibility. If a dysarthric speaker's production is consistently disrupted regardless of severity, Voice Type recognition should continue to improve with training. It is essential, however, that clinicians seek to identify the optimal number of training trials needed to establish the best recognition possible (10). Though it is clear that recognition accuracy will improve with use, core vocabulary must be trained to enhance the voice-to-text capability of VoiceType.

In regard to the perceptual data gathered from listeners in the present investigation, several findings deserve discussion. First, in contrast to the VoiceType recognition, perceptual scores did not overlap for control or dysarthric groups. That is, each speaker class maintained a unique recognition function, and mean scores across the five sessions did decrease with severity (see **Figure 2**). Based on this finding, it appears that listeners were able to clearly distinguish and differentiate among the subjects evaluated. When this finding is viewed along with those from VoiceType recognition phase of the investigation, a second issue is raised. Specifically, listener data indicate that perceptual scores were quite good for the three pairs of dysarthric speakers. This discrepancy in expected performance was most notable for those speakers who were identified as being severely dysarthric. One would assume that this classification would have resulted in greater reductions in intelligibility of stimuli evaluated. These data are not consistent with the CAIDS word scores used for subject classification, and the reason for this difference is not clear. However, despite the categorization of severity level using the CAIDS for their inclusion in the study, listener recognition was quite good, even for the severe dysarthrics (**Figure 2**). Listener scores were better for control, mild, moderate, and severe dysarthric speakers, when compared to the best VoiceType recognition score across the five sessions. We are currently investigating the nature of this inconsistency through use of acoustic analyses of target stimuli and their differentiation from foils. As such, unique speaker capabilities (e.g., neuromuscular integrity affecting laryngeal, velopharyngeal, and oral systems) may have contributed to increased or decreased individual scores than that anticipated based solely on clinical assessment of speaker intelligibility using an open response format. Similar concerns have been addressed previously by Schmitt and Tobias (7,9); concerns pertaining to the potential influence of consistency and context on recognition have also been raised[2].

The above-noted concern regarding the discrepancy between perceptual recognition of the speakers' stimuli and that identified from clinical assessment using the CAIDS does raise several concerns, which have a direct bearing on clinical practice with dysarthric speakers. Namely, a difference was found to exist between the clinical classification of speaker severity and those that might be assumed based on recognition by listeners (see **Figure 2**) As stated by Kent et al., the measurement and quantification of speech intelligibility ". . . is not an absolute quantity but rather a relative quantity . . . (11, p 482)." Consequently, it is subject to variability that emanates from a variety of sources both internal and external to the speaker. Ideally, one would hope that, regardless of stimuli construction, a more favorable correspondence across these two tasks would have emerged. Although this concern is not as significant an issue for the speakers with mild impairment, and very possibly those speakers who exhibited moderately reduced speech intelligibility, the performance by severe dysarthrics is indeed unexpected. One would certainly assume that a single word intelligibility task would culminate in more dramatic reductions in overall intelligibility with scores below 50 percent anticipated as a very real possibility. Again, the cause for this level of disparity between clinical classification using the CAIDS and the overall judgments obtained from a group of nonimpaired listeners is unknown. Therefore, continued efforts to establish reliable and valid methods of evaluating speech intelligibility are essential (11).

In conclusion, this investigation gathered initial comparative data on the recognition of single word stimuli produced by dysarthric speakers who differed in level of severity and by age- and gender-matched control speakers. The specific goal of the study sought to identify and quantify the similarity or difference between stimulus identification by a computerized VR system (IBM VoiceType) when compared to that of nonhearing-impaired adult listeners. The findings of this study indicate that VR is characterized by initially steep increases in correct recognition with more gradual increases noted during the second through fifth input sessions. In contrast, perceptual recognition by nonhearing-impaired adults indicate generally stable intelligibility scores over five sessions. Finally, level of severity exhibited by dysarthric speakers did appear to influence recognition of target stimuli.

[2]Thomas-Stonell N, Kotler AL, Leeper HA, Doyle PC. Computerized voice recognition: the influence of consistency and context on recognition accuracy. Unpublished data.

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