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EFFECTIVENESS OF SPEECH RATE-CONVERSION SOFTWARE FOR PATIENTS WITH DYSARTHRIA

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ABSTRACT

The effectiveness of using speech rate-conversion software by artificially decreasing sound waveforms without changing the pitch was studied in 62 individuals with dysarthria. Besides having patients read a standard common passage entitled “The North Wind and the Sun” aloud, they had casual conversations on a different occasion. Both reading and conversations were recorded on a digital audiocassette recorder in a sound-treated studio. Using speech rate-conversion software, the two types of speech samples (reading and speaking) were played back under 5 rate-delay conditions (100, 150, 200, 250, and 300% slower than the original recording) for evaluation of intelligibility and naturalness by 3 speech and language pathologists. With regard to both intelligibility and naturalness, a significant difference was observed among the 5 rate-delay conditions regardless of the type and severity of dysarthria. A 200% delay in rate delivered the greatest improvement in intelligibility; conversely, any rate-delay less or more than 200% resulted in slight deterioration. In addition, a 150% rate-delay in speech yielded the greatest improvement in naturalness, while any delay less or more than 150% resulted in a significant deteriorating tendency. These findings suggest that reducing verbal speed within the range of 150 – 200% may be useful in the clinical management of dysarthria.

Keywords: dysarthria, speech rate-conversion software, intelligibility, naturalness

Introduction

It is widely known that slowing the rate of speech can improve intelligibility in individuals with dysarthria (Yorkston, Beukelman, Strand, and Bell, 1999; Duffy, 2005; Nishio, 2007). In the clinical setting, different rate-control techniques such as alphabet board supplementation (Beukelman and Yorkston, 1977; Hunter, Pring, and Martine, 1991;

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Beliveau, Hodge, and Hagler, 1995; Dowden, 1997; Hustad and Beukelman, 2001, 2002; Hustad and Garcia, 2002; Beukelman, Fager, Ullman, Hanson, and Logemann, 2002; Nishio and Niimi, 2005), pacing board (Helm, 1979; Pilon, Mcintosh, and Thaut, 1998; Nishio, Tanaka, Abe, Shimano, and Yamaji, 2007), rhythmic cueing (Yorkston and Beukelman, 1981; Yorkston, Hammen, Beukelman, and Traynor, 1990), delayed auditory feedback (DAF) (Hanson and Metter, 1980; Downie, Low, and Lindsay, 1981; Hanson, Gerratt, and Ward, 1983; Dobbs, Bowes, Henley, Charlett, O'Neill, Dickins, Nicholson, and Dobbs, 1993; Dagenais, Southwood, and Lee, 1998) and visual feedback (Berry and Goshorn, 1983) have been used to slow the speech of individuals with dysarthria to improve intelligibility and/or naturalness in speech.

On the other hand, artificially converting and editing speech by acoustic techniques, where the speech rate is modified using speech rate-conversion software (Nakamura, Seiyama, Ikezawa, Takagi, and Miyasaki, 1994; Watanabe, 1996), has recently been developed. Much attention has been focused on the useful time-domain harmonic scaling (TDHS) method (Malar, 1979), where the speech rate is modified by extending the sound waveform against time without altering the pitch. As such, multiple modified and improved versions of the TDHS method have been developed to date.

The innovated software programs and related devices, which were originally developed for the enhancement of linguistic education/training, have also been extensively employed in the elderly with hearing impairment to improve their speech perception ability. Although unreported to date, these software and devices may be useful in the prosthetic management of dysarthria in clinical treatment on the whole. Of cases worthy of using these innovations are patients who find difficulty in speech training; these recently innovated software and devices may in fact serve as useful alternatives along with voice amplifiers and relevant devices.

In this study, we elucidated the effects of speech rate-conversion software on speech intelligibility and naturalness of Japanese patients with dysarthria. The following issues were addressed accordingly:

1. The relationships of speech rate-delay and intelligibility and naturalness in individuals with dysarthria were investigated, and optimal speech rate-delay conditions for the respective speech features were established.
2. The efficacy of speech rate-conversion software in relation with the type of dysarthria was elucidated.
3. The effect of dysarthria severity on the efficacy of speech rate-conversion software was also investigated.

Methods

Subjects

A total of 62 individuals with dysarthria (male: 42; female: 20; mean age: 60.0 years; SD=14.4) participated in the investigation. The mean ages of males and females were 62.5 (SD=12.0) and 54.8 (SD=17.8) years, respectively. In tandem with the objectives of the present study, the distributions of dysarthria were categorized according to the etiological factors (Table 1) and dysarthria types (Table 2) . Based on an extensively employed and commonly accepted standard classification system in the field of speech pathology (Darley, Aronson, and Brown, 1975), dysarthria was categorized accordingly (Table 2). A defect in the unilateral upper motor neurons (UUMN), which is often quoted in current studies, was also included as a type of dysarthria (Table 2). Patients were categorically enrolled in the investigation according to the following criteria:

1. Adult-onset dysarthria,
2. Dysarthria without other speech or language disorders,
3. Dysarthria without history of either speech disorder prior to disease onset,
4. Dysarthria without tracheostomy.

Table 1. Distribution of Etiologies

Etiological factors	Cases (n)
Cerebrovascular disease	23
Spinocerebellar degeneration Amyotrophic lateral sclerosis Parkinson's disease	12 9 9
Neuropathy	2
Encephalitis Others (one for each etiology) Myasthenia gravis, Dystonia, Myoclonus, Shy-Drager Syndrome, Brain injury	2
Total	62

Recording Procedures

Table 2. Distribution according to dysarthria types

Dysarthria type	Cases (n)
Flaccid	7
Spastic	11
Ataxic	19
Hypokinetic	9
Hyperkinetic	3
Mixed	9
UUMN*	4
Total	62

*: UUMN=unilateral upper motor neuron.

The speech samples employed to measure speech intelligibility and naturalness included reading of a standard passage aloud entitled “The North Wind and the Sun” in Japanese (reading), and casual question-response conversations on seven items with a speech pathologist (speaking). Patients were each asked to read a passage once at his/her own pace with habitual and comfortable pitch, volume/loudness, and rate. All speech samples were recorded on a digital audio-cassette recorder（Sony TCD-D10）with a sampling rate of 44.1 kHz in a sound-treated studio. The vocal input receptacle of a microphone (Shure, SM48) was placed and positioned directly opposite (180º) to the mouth of patients with a constant mouth-to-microphone distance of 15 cm.

Speech Intelligibility and Speech Naturalness

The speech samples (reading and speaking) were reproduced with their speech rate delayed using time-warping (i.e. speech rate-conversion software) equipped with optional auditory feedback tools of the Computerized Speech Lab (CSL-Model: 4400, KayPentax). The present device was capable of reproducing and delaying speech rate input by 300% via either conduction through the connecting cord or through the microphone per se. During playback, the articulation time (i.e. time-intervals where speech segments are reproduced) and pause-time (i.e. silent periods in the speech waveforms) were identified, and were extended accordingly under different rate-delay conditions.

Using above-mentioned speech rate-conversion software, the two speech samples (reading and speaking) were all played back under 5 rate-delay conditions (100, 150, 200, 250 and 300%), and the intelligibility and naturalness were evaluated by three ‘blind’ listeners based on a 9-grade rating scale (Table 3). At 100% speech rate-delay, the speech speed was reduced by 1 fold or in other words the speech rate remained unchanged. At 150 and 300%, the rates were respectively reduced by 1.5 and 3 fold, and so on.

Table 3. Rating scale for speech intelligibility

Scores	Comprehensive levels of speech
1	Speech is fairly understandable
1.5	Between levels 1 and 2
2	Speech is understandable in large part, but with some difficulty
2.5	Between levels 2 and 3
3	Speech is understandable if the listener knows the content spoken
3.5	Between levels 3 and 4
4	Speech is understandable in small part
4.5	Between levels 4 and 5
5	Speech is not understandable at all

The listeners were asked to rate the patient's speech intelligibility perceptually using the 9-grade rating scale, where the speech intelligibility level was scored according to severity in understanding the speech content. A highest score of 5 was given to speech not understandable at all, a lowest score of 1 was given to speech fairly understandable, and so on (Table 3). This rating system was developed by Taguchi (1966), revised by Itoh (1992), and has been extensively applied in speech and linguistic studies in Japan since 1992. Furthermore, the reliability of this 9-grade rating scale has previously been confirmed by Nishio and Niimi (2001).

Speech performance with regard to naturalness was perceptually rated with a 5-point severity-rating scale as follows: extremely natural (1; without any unnatural elements); fairly natural (2; with slight unnatural elements); natural (3; natural with negligible unnatural elements); unnatural (4; with certain unnatural elements); and extremely unnatural (5; without any natural element). This severity scale developed by Nishio has its reliability confirmed in 2004.

Scoring by the Listeners

Three speech and language pathologists assessed the listening aspect and rated both the intelligibility levels and naturalness consistently for each speech sample (played back under 5 rate-delay conditions in speech) A mean score was computed for each speech sample by averaging the rating scores of the three listeners.

Severity Level

The intelligibility scores on severity of dysarthria of patients were homogenously graded into 3 groups with 3 different intelligibility levels: mild (<2.3), moderate (<3.7) and severe (>3.7), where the higher the speech intelligibility scores, the more severe was the pathological state. In our findings, 36 (male: 20; female: 16; mean age: 59.0 years, SD=16.4), 17 (male: 15; female: 2; mean age: 61.6 years, SD=11.0) and 9 (male: 7; female: 2; mean age: 61.4 with SD=12.4) patients were distributed in the mild, moderate and severe dysarthria groups, respectively. Significant differences in age between any of 2 of the 3 groups were not established with one-way analysis variance assay.

Method Reliability

With regard to the evaluated intelligibility levels and naturalness by the 3 listeners, the 5 rate-delay conditions (100, 150, 200, 250 and 300% delay in speech speed) provided Kendall's coefficient of concordance and yielded extremely high levels of W=0.95 with significant differences ($p<0.001$) in intelligibility and naturalness.

Results

Speech Intelligibility

The relationships between speech intelligibility and 5 different rate-delay conditions in 62 cases of dysarthria (Figure 1) indicated the peak improvement in speech intelligibility was achieved at 200% rate-delay in speech. Delay rates less than or more than 200% portrayed a reversed tendency, where speech intelligibility would be reduced accordingly. Significant improvements ($p<0.001$) in speech intelligibility were established with the 5 different rate-delay conditions when verified with the Kruskal-Wallis test.

From data on the speech intelligibility levels of the different types of dysarthria evaluated under 5 different rate-delay conditions (Figure 2), the levels registered the highest improvement at 200% delay in speech rate in 6 of 7 listed types of dysarthria (exception: UUMN). Delay rates less than or more than 200% indicated a reversed tendency; i.e. improvements of the speech intelligibility were reduced. When verified with the Friedman's two-way analysis of variance, significant differences ($p<0.001$) were established. Although ataxic dysarthria was the only type that showed significant improvement ($p<0.05$) in speech intelligibility, other types did not indicate any significant difference when compared with the 5 rate-delay conditions using the Kruskal-Wallis test.

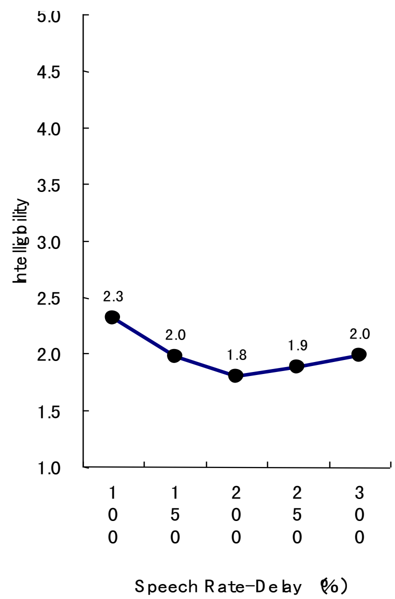

Figure 1. Intelligibility scores at the respective rate-delay conditions in 62 patients with dysarthria showed highest improvement in speech intelligibility levels at 200% rate-delay in speech. Rate-delays of less or more than 200% produced reversed tendencies in intelligibility levels.

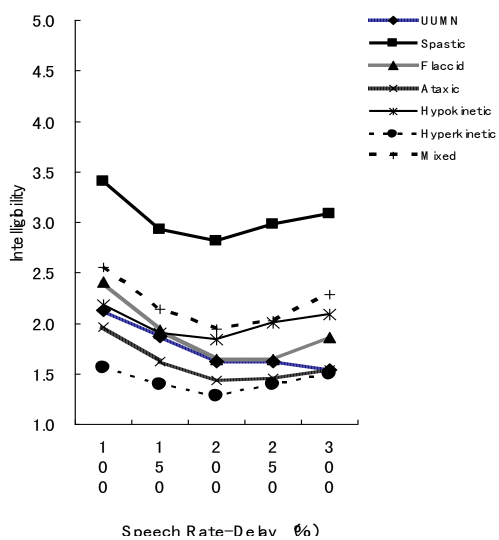

Figure 2. Intelligibility scores of the different types of dysarthria under various speech rate-delay conditions. Except for the unilateral upper motor neuron (UUMN) type, all other types (spastic, flaccid, ataxic, hypokinetic, hyperkinetic and mixed) indicated highest improvement in intelligibility levels at 200% rate-delay in speech. Rate-delays of less or more than 200% for all types (except UUMN) registered reversed effects in intelligibility levels, indicating that speech comprehension was best attained at 200% rate-delay in speech of dysarthria patients.

In a fashion similar to dysarthria types (Figure 2), the relationships between the severity groups and the rate-delay conditions (Figure 3) portrayed a similar tendency in intelligibility levels with rate-delay condition; viz., the highest improvements of intelligibility levels were established in all (mild, moderate and severe) groups at 200% delay in speech rate/speed. In a manner similar to intelligibility levels and rate-delay conditions of the different dysarthria types (Figure 2), significant difference ($p<0.01$) was established when verified with the Friedman's two-way analysis of variance. In group comparisons under the 5 rate-delay conditions using the Krustal-Wallis test; although a significant difference ($p<0.001$) in intelligibility scores was established between the mild and moderate groups, significant difference was not verified with the severe group.

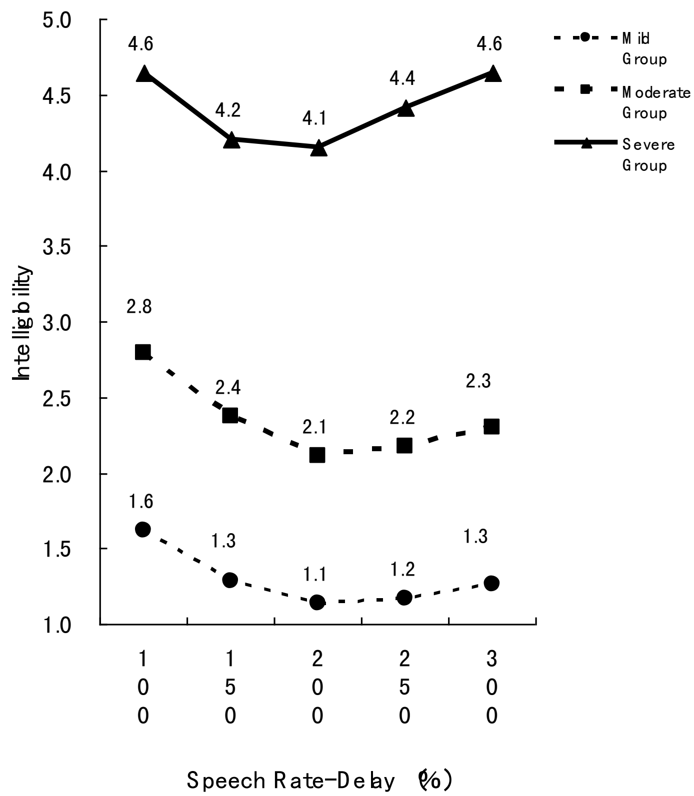

Figure 3. The relationships between the 3 severity (mild, moderate and severe) groups and the rate-delay conditions portrayed the highest improvement in intelligibility level at 200% rate-delay in speech for all groups.

Speech Naturalness

On comparing the 5 rate-delay conditions in 62 cases with dysarthria, the naturalness levels achieved highest improvements at 150% rate-delay in speech, while naturalness portrayed a distinct decreasing tendency under a rate-delay of less or more than 150%. Comparisons with the Kruskal-Wallis test indicated significant differences ($p<0.001$) in speech naturalness under the 5 rate-delay conditions (Figure 4).

In correlating the dysarthria types with speech naturalness under the 5 different rate-delay conditions, all types established improvements in speech naturalness levels at 150% rate-delay in speech （Figure 5). The naturalness levels of all dysarthria types indicated a markedly reversed (i.e. decreased) tendency when the rate-delay was less or more than 150%. On comparison with the Friedman's two-way analysis variance, significant differences ($p<0.001$) were noted. Although the ataxic ($p<0.001$), hypokinetic ($P<0.05$), mixed ($p<0.05$) and UUMN ($p<0.05$) types established significant differences, the flaccid, spastic and hyperkinetic types indicated insignificant tendencies when the respective types were each compared under the 5 rate-delay conditions using the Kruskal-Wallis test.

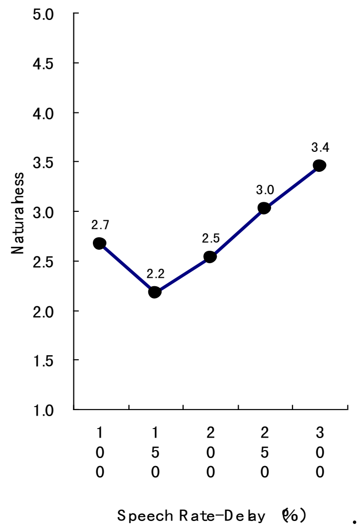

Figure 4. On comparing the 5 rate-delay conditions in 62 cases with dysarthria, the naturalness levels established the highest improvement at 150% rate-delay in speech, while naturalness portrayed a distinct decreasing tendency under rate-delays of less or more than 150%.

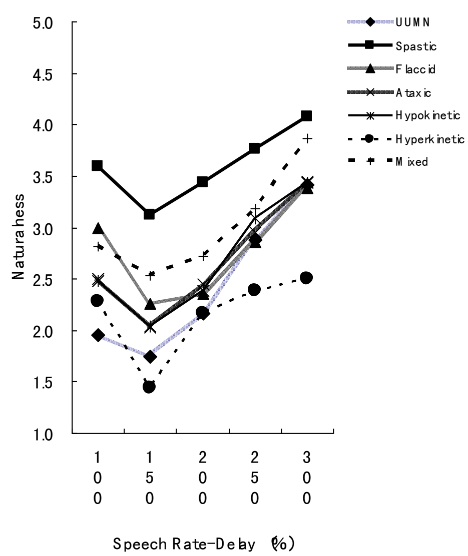

Figure 5. All types of dysarthria established the highest improvement in speech naturalness levels at 150% rate-delay conditions; however the naturalness levels indicated a markedly reversed (i.e. decreased) tendency when the rate-delay was less or more than 150%.

On correlating naturalness with the severity groups under the 5 rate-delay conditions in speech, peak improvements of naturalness were established at 150% rate-delay condition while any rate-delay lower or higher than 150% would markedly reduced the naturalness levels (Figure 6). When verified by the two-way analysis variance test, significant differences ($p<0.01$) were noted. Although the mild and severe groups indicated significant differences ($p<0.001$) under the 5 rate-delay conditions, comparisons with the severe group did not show any significant difference when verified with the Kruskal-Willis test (Figure 6).

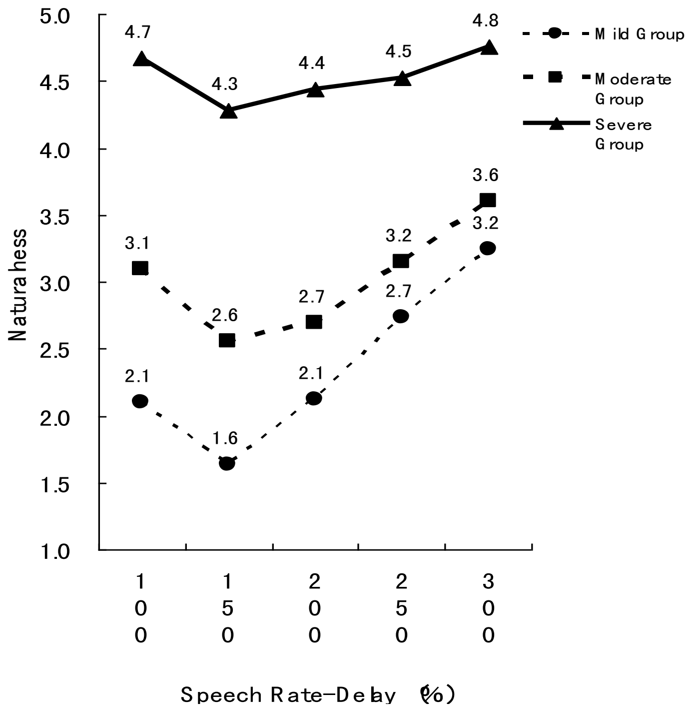

Figure 6. On correlating naturalness with the severity groups under the 5 rate-delay conditions in speech; peak improvement in naturalness was establsihed at 150% rate-delay in speech, while any delay lower or higher than 150% would markedly reduced the naturalness levels.

Discussion

From the present results, speech intelligibility and naturalness reflected the highest comprehensive levels at 200% and 150% rate-delay conditions in speech, respectively. As such, in cases where speech rate-conversion software was employed in the clinical treatment of dysarthria, the most effective management would be established within the range of 150 - 200% rate-delay conditions in speech. Intelligibility levels would instead be exacerbated if the rate-delay were either less or more than 200%, disproving the simple proportional relationship that intelligibility levels would improve with increases in the rate-delay condition (i.e. lower speech rate) when applying present speech rate-conversion software. .

Improvement in speech intelligibility increased with speech rate-delay in the present investigation may be attributed to: 1) elevation of speech perception ability related with segmental information via an increase in the articulation time; and 2) a delayed speech rate facilitated comprehension on the listener side by providing more time for processing acoustic signals. Furthermore, the rationales for the decrease in speech intelligibility with rate-delay of more than 200% include: 1) prevalence of noise incorporating intermittent consonants such as plosive, affricate and fricative sounds; 2) perception on the listener side of elevated noise components (produced by abnormal articulatory movement due to time-delay; 3) probable degradation of segmental information structuring the connected speech.

These findings advocate that not only the adjuvant effect of using speech rate-conversion software in clinical treatment of dysarthria (incorporation with various currently employed techniques used in the speech training) was constructive, but the use of said software to merely delay the speech rate may also indirectly elevate the value-added communication ability in some dysarthric speakers who find medical (internal medicine) problems with certain devices routinely used for speech-training

Hitherto, naturalness displays a decreasing tendency with delay in speech rate (Yorkston, Beukelman, Strand, and Bell, 1999; Nishio, 2007). In the present article, a 150% rate-delay in speech improved naturalness compared with either 100% or >150% rate-delays, regardless of the type and severity of dysarthria. The rationales for the improvement in naturalness with 150% rate-delay in speech may include: 1) a reduction of hoarseness (especially rough hoarseness) with rate-delay in speech; 2) an elevated speech-perception ability of segmental information on the listener side due to probable attenuation in articulatory distortion. The distinct exacerbations in naturalness with increases in rate-delays exceeding 150% may be attributable to: 1) perceptional extension of abnormality in prosody with delay in the speech rate; 2) degradation of suprasegmental information and/or prosodic features such as rhythm, stress and intonation accompanying delay in the speech rate; and 3) factors related to voice-synthesizing components in speech.

The results of using speech rate-conversion software in the present study are probably different from those clinical outcomes obtained in behavioral management approaches of speech rate control. In behavioral management of speech rate control; when the speech rate of patients with dysarthria is deliberately delayed, the following events occur: 1) coordination is enhanced through interactions of various speech components; and 2) actualization with emphasis on speech intelligibility through interactions of various speech subsystems attributable to delay in articulatory movement (Yorkston, Beukelman, Strand, and Bell, 1999; Nishio, 2007).

In summary, speech intelligibility and/or speech perception ability on the listener side can be potentially improved when the speech rate of patients with dysarthria is subjected to conditioning training with complementary use of speech rate-conversion software.

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