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The Role of the Lombard Reflex in Parkinson's Disease

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***Abstract*—Parkinson's disease (PD) is a severe disease with many symptoms, including speech disorders. Although many methods exist to treat some of PD's symptoms, therapies for speech impairment are not effective and satisfactory, resulting in an open area of research. The current project aims at taking advantage of the Lombard reflex to improve the speech loudness of PD patients. As a first step, the experience of the Lombard reflex by Japanese PD people was confirmed, and the perception of PD patients' speech was evaluated by several subjects. In a following step, methods based on masking sound will be used for intensive training and for self-training of PD patients. However, after intensive training, PD patients may be able to talk louder even without masking noise. In addition, the design and the development of a device based on masking sound that can be used by PD patients while using phone is under consideration.**

I. Introduction

To date, several studies reported that PD is the second most common neurodegenerative disease in developed countries [1]. It affects 1–2% of people over the age of 60 years, but the symptoms can develop before the age of 40 years [2]. Among PD patients, 70% develop speech impairments, such as dysarthria [3]. A main symptom of dysarthria is monotony of pitch and loudness. Dysarthria worsens in the late stage of the disease and can cause loss of communication and social isolation. Although other disease symptoms (i.e., akinesia,rigidity, tremor) can be treated using dopamine therapy, dysarthria worsens for most patients.

This study investigates the effect of the Lombard reflex on PD patients. People without PD attempt to increase the intelligibility of their speech when speech is produced in a noisy environment. During this process, several speech characteristics change, including increased loudness. This phenomenon is known as the Lombard reflex.

In automatic speech recognition in noisy environments, the Lombard reflex has a negative effect on accuracy because it causes mismatches between training and testing conditions. However, the current project attempts to take advantage of the Lombard reflex to improve speech intelligibility and clarity of PD people. During the first stage of the project, the main question was to determine whether Japanese PD patients could experience the Lombard reflex. The final goal is to develop a new rehabilitation technique applicable in speech therapy of PD patients and a device for use by PD patients while talking on the phone to increase the loudness of their speech.

A study published in 1992 showed that the speech intensity of people with PD increased when using a masking noise [4]. However, no report exists on the results of a follow-up evaluation. In another study, similar experiments were conducted, but the results were different [5]. Very limited studies that describe the relationship between the Lombard effect and PD, scarce information about this topic, and the lack of agreement between the few papers on the topic provide a great opportunity for further and deeper investigation of this problem. Moreover, to the best of our knowledge, no similar study investigating the effect of the Lombard effect on Japanese PD patients has been introduced to date.

II. Dysarthria in PD

Parkinsonian dysartria, or hypokenetic dysarthria, is a speech production disorder resulting from PD. The main characteristics of dysarthria are monotonous and reduced pitch and loudness, variable rate, short rushes of speech, imprecise consonants, and a breathy and harsh speech. Each of the speech production subsystems, respiration, phonation, articulation, resonance, and prosody, may

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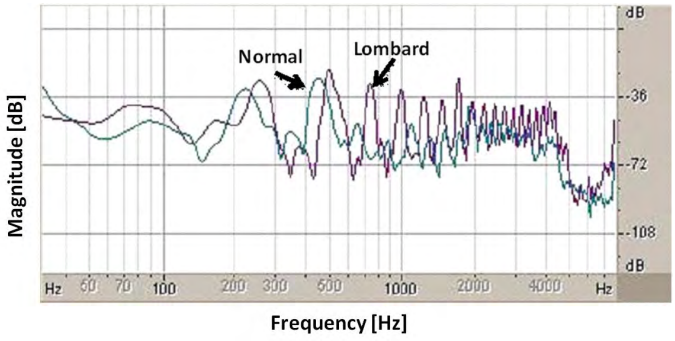

Fig. 1. Power spectrum of a normal clean and a Lombard utterance.

be affected in dysarthria [6]. Some characteristics of PD people include impairment in the ability to sustain prolonged vowel phonation, variations in speaking rate, reduced speech loudness, perception that they are hypernasal, and affected prosody of speech.

Several methods have been introduced for the treatment of dysarthria. Treatment methods include speech therapy, pharmacologic treatments, and surgery. The three main speech therapy methods include the use of devices, treatment focused on speech prosody, and the Lee Silverman Voice Treatment (LSVT). Today, many PD patients receive speech therapy treatment from speech therapists. During these treatments, patients are asked to sing or speak louder. Intensive speech therapy treatments show improvements in speech loudness and in other aspects of speech, but the effect of most PD treatments on dysarthria remains unsatisfactory. LSVT seems to be one of the most effective therapies.

III. Lombard reflex

When speech is produced in noisy environments, the speech production process is modified, leading to Lombard reflex [7]. Specifically, given reduced auditory feedback, the talker attempts to increase the intelligibility of his/her speech. During this process, several characteristics of speech change. In particular, the intensity of speech increases, fundamental frequency (F0) and formants shift, the durations of vowels increase, and the spectral tilt changes. Because of these modifications, the performance of a speech recognizer decreases not only because of noise contamination but also because of the Lombard reflex [8], [9], [10].

One way to investigate the effect of the Lombard reflex is to analyse clean speech uttered when the speaker is listening to noise through headphones or earphones (i.e., Lombard speech). Even though Lombard speech does not contain any noise components, modifications in speech characteristics can be realized.

Figure 1 shows the power spectrum of a normal clean word and a Lombard word recorded when listening to office noise through headphones at 75 dB(A). The example clearly illustrates the modifications leading to the Lombard reflex: power is increased, formants are shifted, and spectral tilt is changed.

IV. Methods

A. Data recording

Three PD patients (i.e., a male and two female), who agreed and accepted the experimental conditions, participated in the experiments. Their ages were 76–82 years old, and all three participants used a wheelchair. However, they were able to read and speak, although their speech loudness was of low volume. The participants were patients of the Kyoto Prefectural University of Medicine, Japan, and stayed in the hospital to receive pharmacological treatment. During their stays in the hospital, they also received speech therapy treatment from a professional speech therapist. The patients were instructed by the speech therapist to speak with increased speech loudness or to sing their favourite song. The speech therapy treatment also included training of facial/lip muscles.

The recording took place in the office of the speech therapist. Some background noise of 35 dB(A) SPL also existed. Two close-talking microphones, a distant-talking microphone, and a microphone array were used to capture the patients' speech. A portable computer with special recording software installed and a 16-channel sound card was used. Another portable computer for showing the words that had to be read was used.

Several kinds of noise were considered for masking. Considering the condition of the patients and their ages, using music for the masking sound was finally decided. The music was selected to be comfortable and enjoyable for the patients. After the experiments, all patients expressed their satisfaction regarding the selected music.

Before the experiments, the speech therapist explained the experimental procedure to the participants. Their positions on the wheelchair were also adjusted to ensure that they sat as comfortably as possible.

Each participant sat in front of the laptop at a distance of 50 cm and was instructed to read the utterances shown on the screen. In the first session, the experiment did not include masking noise. In the second session, the participant read the utterances while listening to the selected music played back through headphones at an average sound level of 70 dB(A).

During the experiments, the speech therapist was also present and continuously monitored the patients' condition by asking them questions or by watching their

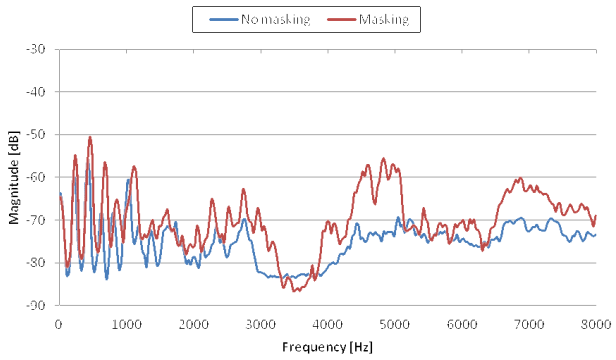

Fig. 2. Average power spectrum of the five Japanese vowels in the case of the 1st PD patient.

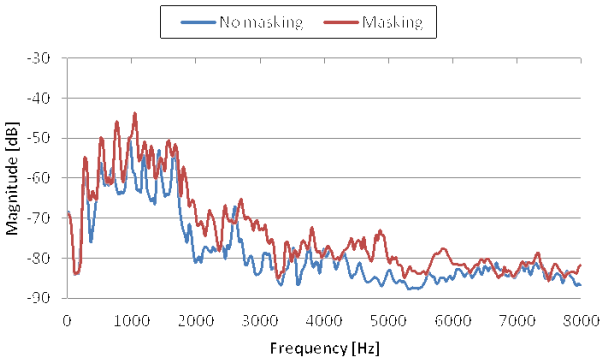

Fig. 4. Average power spectrum of the five Japanese vowels in the case of the 3rd PD patient.

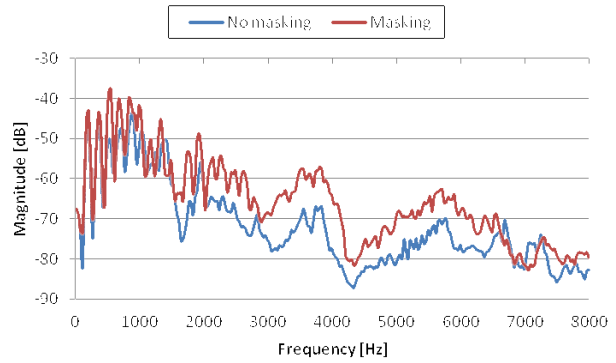

Fig. 3. Average power spectrum of the five Japanese vowels in the case of the 2nd PD patient.

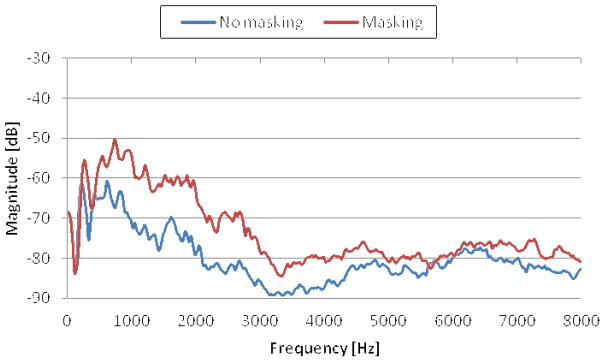

Fig. 5. Average power spectrum of Japanese sentences in the case of the 3rd PD patient.

reaction. In one case, a family member of the participant was also present.

B. Subjective evaluation of speech produced by PD patients

Speech produced by PD patients was evaluated by four subjects. The aim of this experiment was to investigate whether the speech changes occurred while listening to masking sound can be perceived by other listeners. It may happen, however, that some speech characteristics change under Lombard conditions, but these characteristics can not be observed by listeners. In such a case, the Lombard reflex might not be an effective way to deal with the speech disorders of PD patients.

The four subjects had to listen a vowel produced under clean environment and its pair-vowel which produced while patients listening to masking sound. The task of the subjects was to select the vowel instance which better matches a specific characteristic. In particular, the subjects selected the vowel according to loudness, duration, and naturalness. In total, twenty vowel-pairs were played back through a headset. The age of the subjects was 25-36 years old and all were normal-hearing.

V. Results

A. Analysis of speech produced by PD patients

This section introduces the analysis results. Three characteristics that indicate experiencing the Lombard reflex are investigated. In particular, the changes that occurred when there was masking sound in comparison with the case when masking sound was absent are examined.

Figure 2, Figure 3, and Figure 4 show the average power spectrum of the five Japanese vowels when the three patients were listening to masking sound compared with the case when masking sound was absent. As is shown, when masking sound was present, in all cases the power was increased in the middle frequency range (around 1–6 kHz), indicating higher vocal effort and higher vocal fold tension, which reflects well the Lombard reflex. Figure 5 shows the average power spectrum

TABLE I
RESULTS OF SUBJECTIVE EVALUATION OF SPEECH OF PD PATIENTS

Subject	Speech characteristic		
	Loudness	Duration	Naturalness
M01	95	100	15
M02	95	85	60
F01	100	90	45
F02	100	100	20
Average [%]	97.5	93.75	35
SDev	2.89	7.5	21.21

when using sentences in the case of the third patient. As is shown, the power was also increased in this case.

The analysis of pitch showed that when the patients were listening to masking sound, F0 was increased. The mean F0 value for the five vowels was 213 Hz and the standard deviation was 12.6. When masking sound was absent, the mean F0 value was 196.5 Hz and the standard deviation was 5.8. Therefore, higher F0 and also variability were observed when masking sound was used. The difference was tested using a paired t-test [11]. The two-tailed P value was 0.0132. By conventional criteria, this difference is considered to be statistically significant.

When Lombard reflex is experienced by a talker, vowel durations also increase. For this reason, the vowel durations when listening to masking sound were compared with the vowel durations when speech was produced without masking sound. When masking sound was used, the mean duration of the five vowels was 0.4956 seconds. In the case of no masking sound, the mean duration was 0.3169 seconds. The two-tailed P value was 0.0143. By conventional criteria, this difference is considered to be statistically significant.

B. Subjective tests for speech of PD patients

Table I shows the results of the subjective tests. As is shown, the four subjects perceived the vowels produced under Lombard conditions louder in a rate of 97.5%. Also, the subjects perceived the duration of Lombard vowels longer in a rate of 93.75%. Regarding the speech naturalness, only 35% of the Lombard vowels were selected to be more natural compared to non-Lombard vowels. After discussing the results with the four subjects, the possible reason of this might be the longer duration of the vowels.

In the case of PD patients, however, the most important and critical characteristic for communication is speech loudness. A trade-off between naturalness and loudness in PD patients should be allowed and accepted. The results reported in this section show that speech changes occurred while listening to masking sound can be also clearly perceived by other listeners. This is a promising result which confirms the hypothesis that the Lombard reflex can be used to improve verbal communication of PD people.

VI. CONCLUSIONS AND FUTURE WORK

This study focuses on the Lombard reflex in the case of PD patients. The results obtained show that Japanese PD patients experience the Lombard reflex when listening to masking sound while talking. As a result, the speech's power, pitch, and vowel duration increased. Based on these observations, the current project will focus on developing new speech rehabilitation methods for PD people. Experiments using more participants and further analysis are currently in progress.

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