ICA 2013 Montreal
Montreal, Canada
2 - 7 June 2013

Speech Communication
Session 4aSCb: Voice and F0 Across Tasks (Poster Session)

4aSCb5. Biomechanical models of damage and healing processes for voice health
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In voice-loading occupations employees are required to use their voice for continuous and large periods of time, which might lead to voice problems. In this work anomalous vocal-fold vibrations due to long-time high voice-load are investigated. Laryngeal endoscopic high-speed images within the vocal-fold plane are available. This data is used to improve existing continuum biomechanical models of the vocal-folds by analyzing the injury processes. The project is expected to result in methods that objectively demonstrate the impact of high voice-load on voice. A detailed description of the currently developing work will be presented, including a rigorous analysis of the hypothesized injury processes of the vocal folds.

Published by the Acoustical Society of America through the American Institute of Physics
INTRODUCTION

Voice-loading occupations are defined as occupations that require the constant use of the voice, such as teachers. A previous investigation performed in Swedish schools showed that 13% of the teachers suffer from voice problems [1]. Although signs of voice problems as throat cleaning and hoarseness occur, sometimes no observable changes in the larynx's physiology are apparent by high-speed camera examination. In contrast to organic voice problems, vocal folds with functional voice problems are not always morphologically altered, making it difficult to objectively prove abnormal voice health. Consequently, clinical research gives very little insight on the processes of injury, healing and recovery.

The present work is expected to contribute to the physiological understanding of voice dysfunction due to high voice loads by working on the inverse problem of determining model parameters from high-speed laryngeal imaging and electromyography (EMG) measurements during phonation.

OUTLINE OF EXISTING MODELS

Vocal folds consist on a multi-layered structure of tissues of different elasticity and viscosity. In the deepest part of the structure, a stiff tissue is located, which corresponds to the muscle. The basic principle for the voice production is that vocal folds vibrate as a result of the interaction between airflow and tissue movement [2]; under normal conditions, the vocal folds are a self-oscillating system.

A simple two-dimensional (vertical plane) early model of the vocal folds vibration was described as a two-mass-spring-damper system in [3]. This study showed the importance of the model parameters that can modify the self-sustained behavior of the system, e.g. mass, stiffness, prephonatory area or subglottal pressure. The last mentioned parameter was investigated in [4], where the concept of oscillation threshold pressure was introduced. This concept refers to the pressure required to initiate vocal fold vibration and depends on viscoelastic properties of the tissue. Subsequently, in [5] the popular body-cover concept was used to develop a lumped-mass model that captured the layered structure by introducing the muscle as a mass. In the same study, simple aerodynamic forces acting on the tissue were derived, which have been used in later two-mass [6] or multi-mass [7] models. Multi-mass models provide an accurate resolution of the vibration patterns, and they can be extended in the transversal and sagittal planes [8]. However, the rough cover division into block mass elements makes it difficult to analyze in detail the phenomena that take place at the surface, such as the mechanics at collision, relevant for investigating voice disorders. Hence, in [9] a continuous geometry between mass points was introduced, together with a new aerodynamic force distribution used in further voice investigations; see, e.g., [10].

Despite the effort of developing highly detailed mass-spring-damper systems, continuum models of the vocal folds have been investigated [11]. These models consider more realistic geometries and a more accurate layered structure of the vocal folds, as well as complex vibrational patterns, which contribute to a better understanding of the underlaying factors in voice disorders.

HYPOTHESES FOR THE DAMAGE PROCESSES OF VOCAL FOLDS

Some damages occur as a consequence of repeated collisions between the vocal folds. In [12] it was hypothesized that the safety accumulated distance traveled by the vocal folds before damage can be linked to industry standards for hand-transmitted vibration in power tool use. In this sense, the safety limit for the vocal fold vibration is reached after about 17 minutes of constant voice use. It was concluded that the repetitive collisions of the vocal folds might be likely a cause damage. In [13] the spatial distribution of impact pressure was investigated, showing a strong relation with lung pressure and glottal width. Their simulations revealed that low lung pressure and wide glottal widths reduce impact pressure; by speech training, the development of vocal nodules caused by prolonged voice use can be prevented.

Heat production in tissue due to dissipated mechanical vibration energy can be a cause of damage [12]. However, the total amount of dissipation is small and therefore this factor is of less importance. Furthermore, several studies have shown that dehydration of the vocal folds affects vocal fold vibration and
voice quality, and humidity affects the elastic properties of the tissues [14].

It is likely that in prolonged overload voicing injury occurs as a combination of several processes mentioned above, in particular the collision during phonation that might result in mechanical fatigue.

**MEASUREMENTS**

In most of damage mechanisms, it is important to know which of the tissue layers is primarily affected and how the properties change in time. The degradation of the tissue that affects vocal folds vibration can be sometimes identified by endoscopy, like a high-speed camera. In [15] visualization methods for voice research were provided, emphasizing the need of further development of clinical standards, objective imaging and complementary measurement techniques; experimental data is believed to be crucial for a prolific research on voice's theory.

With the aim to show evidences of a transition point between a normally functioning voice and a voice with a functional overload, data will be obtained from test subjects without voice problems. The subjects will be asked to follow a test for vocal loading. The test will take into account voice intensity (sound pressure level) and fundamental frequency, by repeating a reference sound presented at a constant sound pressure level. It is known that when experiencing vocal fatigue, the lung pressure is increased and the stiffness of the vocal fold structure is changed in order to keep constant voice intensity; therefore, the model parameters change in time. Hence, EMG data together with high-speed laryngeal recordings will be collected during a certain voicing time. This data will be used to describe physiological and anatomical changes in the transition from normal to overloaded voice.

**CONCLUSIONS**

In the present study, the modeling will be implemented as simple multi-mass system with linear forces and discontinuous geometry. In order to capture the complexity of the geometry and the tissue structure, the model will be further extended to a continuum model that includes non-linearities at collision, vocal tract coupling, time variation in the excitation (lung pressure) and material parameters. The measurement data will be used to validate the model and to characterize overloaded voice and its effects.

**REFERENCES**


