Clinical Application of a Computational Voice Simulator

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ABSTRACT

The National Center for Voice and Speech (NCVS) voice simulator uses input vocal fold tissue geometries and mechanical properties to produce a virtual voice of a defined pitch and sound pressure level. Translating the voice simulator for clinical use allows us to test various factors regarding voice production, such as gender differences in vocal fold tissue properties. Using the MATLAB programming platform, a Graphical user interface (GUI) was implemented to analyze the effects of differing vocal fold anatomy on voice production between males and females. Using tissue property measurements from a literature search, two groups of optimization simulations were carried out: one using typical female geometries and pitch targets and the other utilizing typical male geometries and the pitch targets. Results were assessed using 2D plots to show dependence of pitch on vocal fold properties and cluster analysis to show mechanical differences between male and female vocal fold layers. 2D plots demonstrated a strong linear dependence of the voice frequency on the longitudinal shear modulus of the vocal ligament in both males and females. Cluster analysis showed that given average speaking pitches of males and females as an initial target, simulations calculated distinctly different geometric parameters for each gender. These simulations demonstrate a relationship between gender differences in voice output and the vocal fold anatomy that underlies it. Further utilization of the GUI-driven voice simulator will allow us to systematically explore each tissue parameter to better understand how vocal fold tissue geometries and mechanical properties affect the human voice.

INTRODUCTION

The human voice is produced by self-sustained oscillations the vocal folds driven by airflow. The oscillations are determined by the geometries and biomechanical properties of the tissue that make up the vocal folds, as well as their interactions with the air stream. Over the past three decades, the physical principles that govern vocal fold oscillations have been developed to the point where these oscillations can be simulated computationally. Given input vocal fold tissue geometries and properties, a simulator can produce a target output voice of a specific pitch and sound pressure level. The simulator allows us to test various hypotheses of voice production, such as how gender differences in vocal fold anatomy can lead to different voice outputs. Such a simulator also gives us a tool to systematically investigate the effects of changes to vocal fold geometry or tissue properties on the voice, the results of which can then guide surgical intervention. These types of investigations are difficult to carry out in human subjects because of our inability to methodically alter normal anatomy and because of large inter-subject variation. Modifying the voice simulator for clinical use, specifically in the setting of surgical planning, will advance the surgical treatment of these difficult problems for which current methods remain unsatisfactory. The purpose of this study was to create a user-friendly graphical interphase for the NCVS voice simulator, and to use it to determine gender differences in vocal fold tissue properties.

MATERIALS AND METHODS

Graphical user interface (GUI): A GUI was designed and programmed in MATLAB, a widely used platform for scientific and engineering computing. The GUI was designed with windows that allow control of vocal fold tissue geometries and mechanical properties (Figure 2), ranges of inputs for "brute force" simulations in which a range of properties are investigated (Figure 2), and optimization parameters that allow "smart" simulations with target pitch and sound pressure levels (Figure 3) . Geometric and tissue properties: The simulator is controlled through mechanical and morphological inputs. A literature search was performed to compile results of actual tissue property measurements from various labs to determine values to use in the simulator. Specific to our study, values were found for the vocal fold superficial layer, the vocal ligament, and vocalis muscle layer, along with other geometric parameters such as length *L*, thickness *T*, and depth *D*[1]. Further, each of the layers had specific viscoelastic properties: transverse shear moduli (*μ*), longitudinal shear moduli (*μ'*), and viscosity[2,3,5]. Gender differences in tissue properties: Two groups of simulations were carried out, one using typical female geometries with the average female speaking voice frequency (F0) of 200 Hz as the desired target, the other using typical male geometries and 100 Hz as the desired target (Figure 1). Assessment of outcome: Each group of simulations comprised of several thousand simulations producing several thousand "solutions", with each solution equivalent to a specific combination of frequency, sound pressure level, and corresponding tissue properties that generated those specific voice qualities. Clusters of solutions were then identified with cluster analysis.

Geometric, Viscoelastic, and Optimization Parameters

	MALE SIMULATION	FEMALE SIMULATION
L (cm)	1.6	1
T (cm)	0.8	0.5
D-layer1 (cm)	0.09	0.05625
D-layer2 (cm)	0.18	0.1125
D-layer3 (cm)	0.45	0.28125
Columns/layer	2-4-10	2-4-10
x01	0.03	0.03
x02	0.03	0.03
xBulge	0	0
NP	0	0
NP	0	0
NP	0	0
µ'1 (dyn/cm2)	500-40000	500-40000
µ'2 (dyn/cm2)	500-50000	500-50000
µ'3 (dyn/cm2)	500-100000	500-100000
µ1 (dyn/cm2)	500-30000	500-30000
µ2 (dyn/cm2)	500-100000	500-100000
µ3 (dyn/cm2)	100-10000	100-10000
h1 (poise)	2	2
h2 (poise)	2	2
h3 (poise)	2	2
PL (cmH2O) [1 kPa = 10.2 cmH2O] [Simulator assumes cmH2O, i.e. CGS units]	2-10	2-10
Objective Function 1	F0 (target 100 Hz, range 90-110)	F0 (target 200 Hz, range 190-210)
Objective Function 2	SPL (target 70 dB, range 60-80)	SPL (target 70 dB, range 60-80)
Objective Function 3	N/A	N/A
# offspring/ generation	20	20
# generations	200	200
# simulations	4000	4000
# decision variables	7	7

Figure 1. Male and Female Input Vocal Fold Parameters

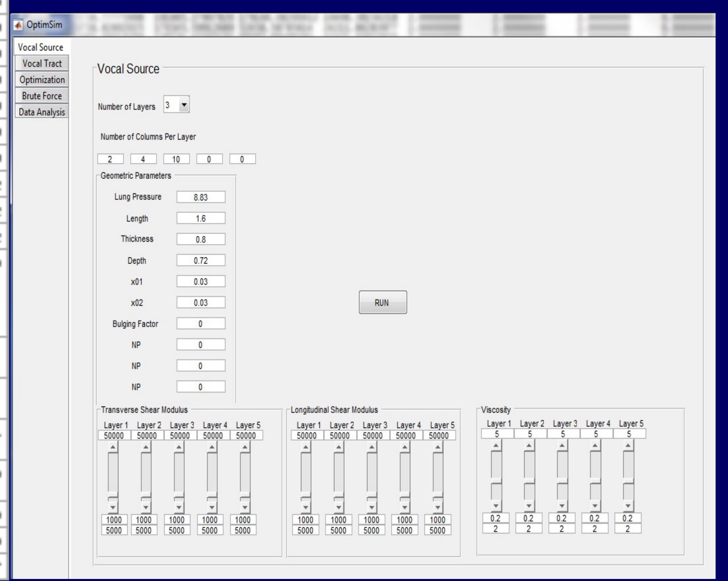

Figure 2. The Vocal Source tab allows user control of vocal fold tissue parameters

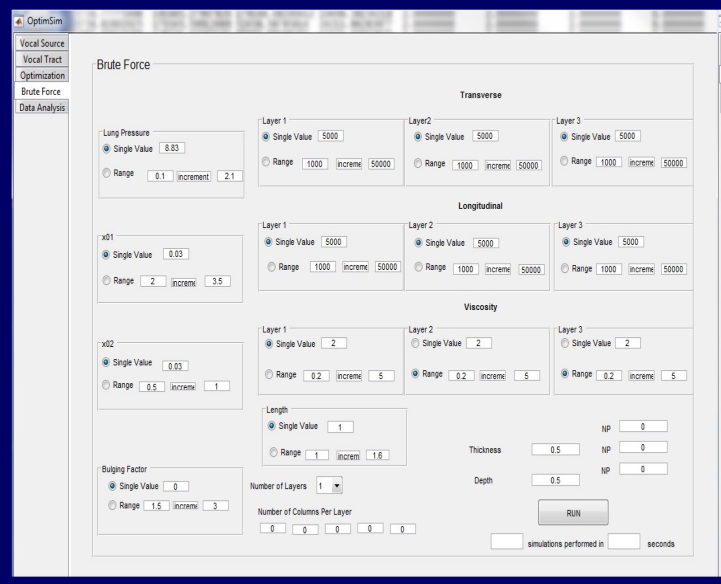

Figure 3. The Brute Force Tab allows the user to input a range of values for each vocal fold tissue property.

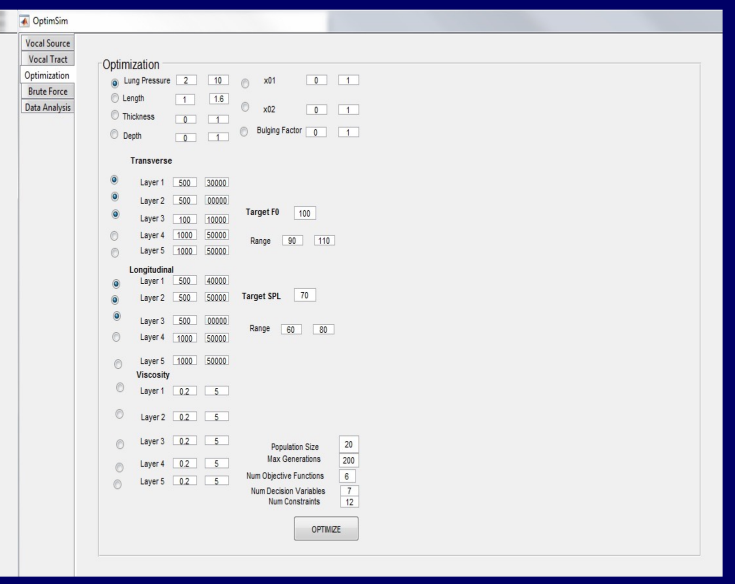

Figure 4. Optimizer Tab. For a target pitch and SPL, the optimizer tab calculates vocal fold parameters.

RESULTS

A GUI was successfully implemented. A single simulation required about 29 seconds to complete. A group of 1000 simulations, which was typical, took about 8 hours to complete. The solutions were visualized in 3D plots showing the relationships between pairs of variables. There was a strong linear dependence of the voice frequency on the longitudinal shear modulus of the vocal ligament (*μ'2*), which is consistent with the general understanding of vocal physiology (Figure 5). There was no clear dependence of the frequency on the other tissue properties, such as the transverse shear modulus of the vocal fold superficial layer (*μ1*). Cluster analysis for the male simulation showed two groups of solutions. The first group had the superficial layer longitudinal shear moduli (*μ'1*) roughly equal to that of the muscle (*μ'3*). The second group had a ratio of *μ'1/μ'3* between 10-20. This indicated that, for a male voice output around 100 Hz, the tissue parameters are most optimal if the superficial layer and muscle had similar stiffness, or if the superficial layer is about 10-20 times stiffer than the muscle. The translayer ratio of *μ'2/μ'3* also showed two main clusters: one close to 1 and another at a ratio of around 100. This indicated that, for an average male voice, the vocal ligament and muscle should have comparable stiffness, or if the ligament is about 100 times stiffer than the muscle. On the other hand, cluster analysis for the female simulation only showed one solution group, with both *μ'1/μ'3 and μ'2/μ'3* ratios of around 1. This indicated that, for a female voice output around 100 Hz, the superficial layer, muscle, and ligament layers all should have comparable stiffness levels.

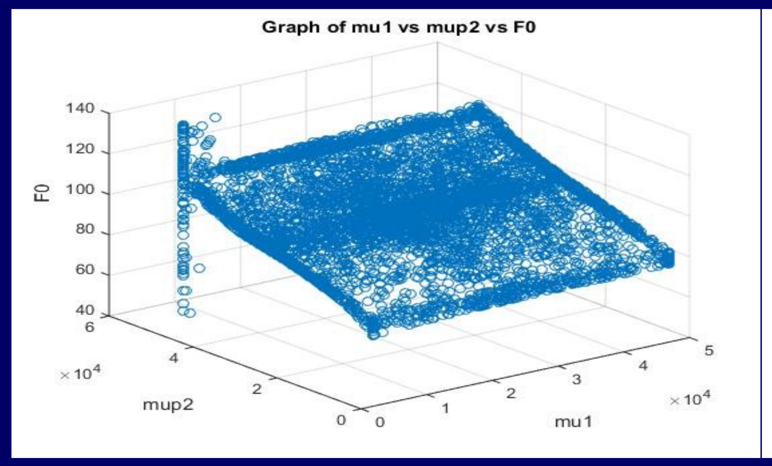

Figure 5. 3D Plot demonstrating the linear dependence of pitch on µ'2, as opposed to other variables such as µ1.

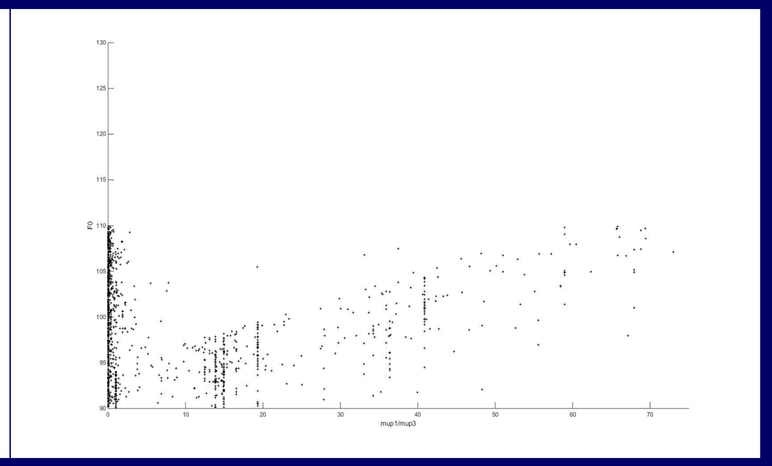

Figure 6. Cluster Analysis of Male Simulation showing 2 groups of solutions of translayer ratios of µ'1/µ'3: one at equal ratios and one at a ratio of between 10-20.

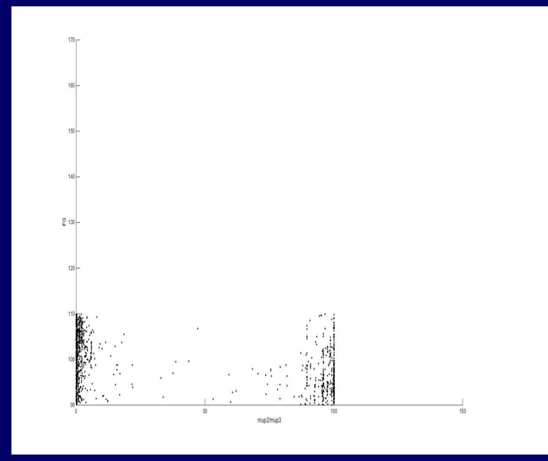

Figure 7. Cluster Analysis of Male Simulation showing 2 groups of solutions of translayer ratios of µ'2/ µ'3: one at equal ratios and one at a ratio of 100.

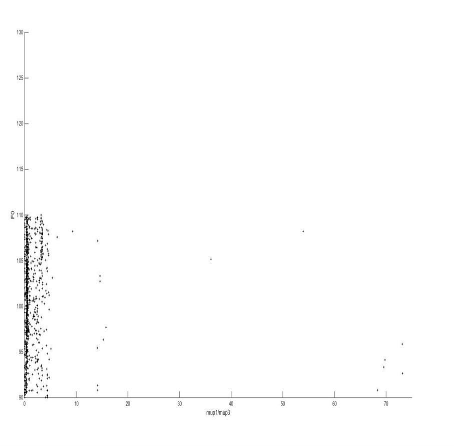

Figure 8. Cluster Analysis of Female Simulation show one grouping of solutions of translayer ratios of µ'1/µ'3: at equal ratios

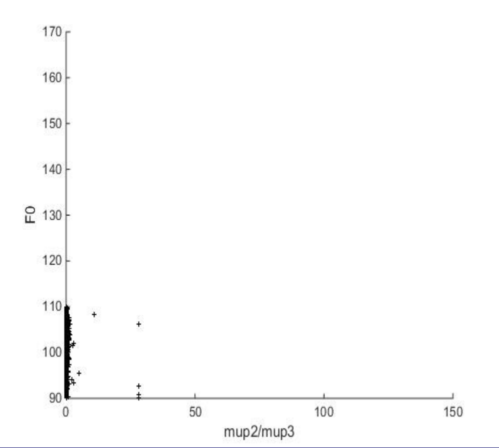

Figure 9. Cluster Analysis of Female Simulation show one grouping of solutions of translayer ratios of µ'2/µ'3: at equal ratios

CONCLUSIONS

By creating a GUI for the NCVS voice simulator, we are now enabling clinician users to perform simulations to investigate the relationship between voice output and the anatomy that underlies it in a virtual environment. This allows systemic exploration of each tissue parameter, as we have demonstrated with the series of simulations during the summer research internship. We have shown that simulations for female geometric parameters calculate different clusters than those for male parameters, given the same target pitch and SPL. Further utilization of the GUI-driven voice simulator will allow us to better understand how various morphological defects and changes can affect the human voice, ultimately leading to improved clinical outcomes.

REFERENCES

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