Question 3

Currently, there is a call for research on speech articulation modeling by the NIH. Prepare a small grant (e.g., NIH R03 format) in which you propose to use finite element modeling to characterize upper and lower lip movement during production of a simple speech task (e.g. /u/). In your proposal, discuss the application of your model to study the influence of deformities such as those associated with a repaired unilateral cleft of the lip on speech performance. You will need to include the following sections of the grant:

1. Introduction
2. Specific Aims
3. Significance
4. Literature Review
5. Hypotheses
6. Methodology

Note: I did not follow page format suggestions for small grant proposals. The appendices were added so not to clutter up the manuscript with more equations than needed. I felt that the information was necessary to have in recreance to the paper but did not feel it necessary to force everyone to read it unless they were so inclined.

1. INTRODUCTION

The lip is important both cosmetically and functionally. Beauty of the lip (or lack thereof) can notably add or detract from one's appearance. Beyond the cosmetics is the functionality of the lip. The lip is important for mastication, facial expression, and speech. When there is a problem with the lip, whether congenital (e.g. cleft of the lip) or from an accident, care and surgery has progressed to the point that, cosmetically, the problems can be well hidden and, functionally, the lips are usable, though the functions may be skewed and performance changed.

Lip motion plays a particularly important role in speech. Without the full use of the lips, many speech sounds shaped or produced at the lips are in jeopardy of poor production. Plosives, /b, p/, labio-dental fricatives, /f, v/, and other heavily lip involved consonants would be possible problems. According to Stevens and Haus (19??), who promoted the tube theory of vowel production, the degree of lip rounding plays a necessary role in vowel formant positioning, with the vowel /u/ being most dependent.

Even after satisfactory results of repair, there is always deformity, whether it is scarring, minimal displacement of the alar base or nose, or some asymmetry of the alar cartilage. The main goal of cleft lip repair is to create a symmetric pliable lip with minimal scarring. Yet, it is difficult to assess the results of the muscle reconstruction and other internal structures. Most speech clinicians acknowledge that persons with repaired unilateral cleft lip are usually able to produce all speech sounds involving lip movement, but when compared with normal speakers, there is a notable difference in the lip movement pattern performed by these persons. Quantifying this difference is difficult. A quantitative model could help. If such a model was based on anatomy, then speech performance and other lip function, both pre and post repair, could be assessed. To make a step towards better understanding of lip movement during speaking gestures, a finite element of the upper and lower lip could be developed.

2. SPECIFIC AIMS

The long-term objectives of this research are to quantify and describe the affects of lip deformities on lip functional performance by the development of an anatomically correct model of the lips. Eventually the model could be driven by muscle activation measures by associating movement to lip EMG findings (Wohlert, et at, 1994; Goffman, 1994). This is only a piolet study, there for the aims set only a ground work to obtain the long term goals. The objectives of this research is to study the influence of deformities on the lip, such as those associated with a repaired unilateral cleft on the lip, by designing a finite element model to characterize upper and lower lip movement for a simple speech task.

The proposed model would be designed to capture essential features of lip function in a dynamic 3-D finite element model. It is desired that the model will predict realistic geometries and movement during the production of /u/. When that model is validated, simple “deformities” of such as associated with the repaired unilateral cleft of the lips will be modeled. The affect such deformities have on lip movement and speech production will be examined. To put this in one question, it would be:

> *To what* ***degree*** *can a 3-D Biomechanical model simulate the* ***range****,* ***speed****, and* ***type*** *of human lip (upper and lower) movement during production of a simple speech task of /u/?*

The following are the specific research objectives to be accomplished in one year.

7) To determine through the literature, the tissue properties and histologies of normal upper and lower lip.

8) To determine through the literature the characteristics of upper and lower normal lip movement during the production of the simple speech task /u/.

9) To develop and test a relatively simple three-dimensional finite element model of lip motion during speech production.

10) To address the application of the model in studying the influence of deformities, particularly those associated with repaired unilateral cleft of the lip, on speech performance of /u/.

3. SIGNIFICANCE

The significance of this study is that a biomechanical model could help in studying the influences of lip deformities on speech performance and to make a step towards better understanding of lip movement during speaking gestures. The narrow objectives of this project may be just more than an exercise in modeling but the implications and ground work has significant implications. If successful, then the use of this model could be expanded to many levels of health research and care on functionality and performance of the lips in a variety of situations.

It is acknowledged by speech clinicians that most persons with repaired unilateral cleft lip are able to produce all speech sounds involving lip movement, but, when compared with normal speakers, there is a notable difference in the lip movement pattern performed by these persons. In the clinic, the model could be used in therapy with a patient with a repaired cleft. A model with deformities similar to the patience's could demonstrate techniques and possibilities that the patient may not yet be able to accomplish. This type of tool could also help clinicians and physicians plan therapy and quantitatively gauge improvement.

An anatomically correct model may help accelerate that search or felicitate better use of old techniques to help facilitate speech performance. Even after satisfactory results of repair, there is always deformity, whether it is scarring, minimal displacement of the alar base or nose, or some asymmetry of the alar cartilage. The main goal of cleft lip repair is to create a symmetric pliable lip with minimal scarring. Yet, it is difficult to assess the results of the muscle reconstruction and other internal structures. No single repair technique has proven itself satisfactory for all types of unilateral cleft lip. The search for ideal technique is still continuing (Fernandes and Hudson, 1993). This could, for example, lead to the possibility to determine what effect aberrant muscle size and location would have on phonation and any other lip function and, subsequently, what effect change in these parameters would have on function.

Such things as scarring and other deformities could be modeled by changing tissue stiffness properties and geometries at those locations in the model. So, such a model could be used to help quantify the degree of the cleft and degree of success of repair. It is difficult to assess the results of surgery, especially muscle reconstruction. A model could not only help in quantifying the problems but assist in choosing optional repairs.

There is also use of such a model in the basic research of speech motor control theory. Supralaryngeal articulators are considered major participants in the complex movement of coordination motor patterns in the voice system during speech production. Of all the superlaryngeal structures, the jaw and lips have often been studied because of their accessability. With an anatomically correct model that could be adjusted to run on muscle activations or other quasi-neural inputs, comparisons could be made to speech motor studies done on the lips. Studies with the model could be expanded to include perturbation or invasive speech motor experiments that could not be done on a human subject.

Lip kinematic studies from the model could be used to compare try to understand the speech motor control system as discussed by Gracco (1990). Combining this model with similar quantitative models of other speech structures (e.g. soft palate, tongue, larynx, vocal tract), a model of the entire speech system could be developed and used to further our understanding of the normal process of speech motor control and production (Sanguineti, et al., 1998).

4. LITERATURE REVIEW

Many of the building blocks needed to complete this research have been acomplished but never assembled. Supralaryngeal articulators are major participants in the movement of coordination motor patterns in the voice system during speech production. Of all the supralaryngeal structures, the lips have often been studied because of their accessability. Many differing methods have been used to track their movement and coordination including EMG, visual recordings (both cinema radiographic and visual techniques), strain gauge, and many others (McClean et al, 1990, Conture, et al, 1988; Caruso, et al., 1988). Initial literature reviews have also resulted in studies that quantify lower and upper lip movements, facial analysis, and lip soft tissue analysis (Nanda, 1996, wood, 1994, Neely, 1992, Gross, 1996).

The finite element modeling process has been used in all kinds of mechanical and biomechanical systems. Some quantitative models of articulators have been developed. These include the soft palate (Berry, et al, 1999), the tongue, (Wilhelms-Tricarico, 1994), and the larynx and surrounding structure (Alipour and Titze, 1985, Berry et al., 1994, Wilhelms-Tricarico, 1998, Dang and Honda, 1998).

Finite element modeling has been used some in relation to the lips. McAlarney and Chieu (1997) used several numerical modeling techniques, including FEM, to model ageing and growth, cleft palate dental arch form change, to cleft lip and palate. They didn’t apply it to repair or function of deformed tissue, only as a way to quantify growth.

Why are the building blocks in place to model the lip movement in speech yet a model has not been created? The upper and lower lip system is extremely complex. There are complex muscle interaction from numerous facial muscles. These contribute but are only part of the complex boundary conditions of the lips. For example, the orbicularis oris muscle does not have any direct connection to bone, only soft tissue.

5. HYPOTHESES

This research assumes that an anatomically simplified 3-D finite element model can be constructed and used to study human lip movement in speech performance. Given a simplified version of the anatomy where the sphincter muscle, the orbicularis oris, is modeled by a bunch of little elements with individual forces, and all other muscular interactions assumed as boundary conditions, this model will perform the movement of the simple speech task /u/. By the nature of finite element modeling, it is reasonable to assume that this is possible. Although the degree of simulation will depend on the accuracy of all the components of the model (e.g. boundary conditions, used tissue constants, assumed anatomical structures, simplification of anatomy).

6. METHODOLOGY

The discussion of the methods to be used in this research project will be in the same order as the specific aims.

A. Objectives

1. To determine through the literature, the tissue properties and histologies of normal upper and lower lip.

The tissue properties and histologies of the upper and lower lip for both the normal and abnormal lip is essential to the finite element model construction. There are two important sets of information needed, (1) determine the general geometry of the lips and internal sections, (2) determine the physiologic properties of each section.

Set 1. Through extensive literature search on the anatomy of the lips, an averaging technique will be used to get the general dimensions of the lip. For the purpose of modeling, the upper lip is assumed to have the same basic structure as the lower lip. This structure will be simplified from six to roughly three different layers all with different thicknesses. The surface, muscle and mucosa. These thicknesses need to be obtained. The lips approximately have the shape of a rectangular parallelepiped. There is some considerable tapering at the lateral ends. The lips are about 5 cm horizontally by 2 cm high and 1 cm thick. More precise dimensions need to be obtained (Namnoum, et al, 1997).

Set 2. Through literature search on the tissue properties of the lips, the active properties of the orbicularis oris muscle will be obtain (or approximated) along with the passive properties of the muscle, surface, and mucosa.

The passive properties of the muscle, surface layer, and mucosa are expressed in the transverse shear modulus (μ), Poissons's ratio (*í*), and tissue viscosity (ç), for the dynamic modeling. These properties, except for possibly tissue viscosity, are readily available in the literature (Al-Waheidi, et al. 1998) and a further literature search would only be needed to substantiate data. The active property is a force-velocity relation and the maximum active stress under isometric conditions will also be needed.

Potential Difficulty: It is possible that these properties have not been measured specifically for the orbicularis oris muscle. In that case, an approximation will have to be made with a similar muscle. This may require extra time.

2. To determine through the literature the characteristics of upper and lower normal lip movement during the production of the simple speech task /u/.

An extensive review of lip movement needs to be accomplished so that validation of the normal model can be done. The three main comparative factors that need to be found for the speech task /u/ will be **range** or extent of movement, **velocity** as a function of time and position during a movement, and **type** of overall movement or displacement. The model will have the upper lip and the lower lip independent of one another in contraction capabilities. Two sets of important data needs to be found: (1) kinematic movement, range and velocity, (2) type of movement or overall displacement.

Set 1. Extensive movement literature for lips has been done (Smith, et al, 1995; Wood, 1994; Neely, 1992, Gross, 1996). In many of these, the lip tip displacement and velocity is measured in time for a speech task. The maximum displacement from rest and velocity contour in time for a speech production of /u/ must be found.

Potential Difficulty: It may be the case that a performance of /u/ does not appear by alone in the literature for in many studies, speech sounds are produced in a carrier phrase. In such a case, it may be necessary to adjust either the initial conditions of the model to match the affect of the carrier phrase or cut the /u/ out of the carrier phrase.

Potential Difficulty: Upper and lower lip movements for normal lips are usually measured for up and down movements, sometime for forward and back movements, and seldom is there a medial-lateral measure. For the future possibility of modeling deformities where movements may occur frequently in all directions, the model needs to be validated for all directions. For this study, the up and down and possibly the forward and back may be all that is obtainable.

Potential Difficulty: Many differing methods have been used to track their movement (e.g., visual recordings (both cinema radiographic and visual techniques), strain gauge, and many others). One type of movement tracking will need to be settled on depending on data availability and individual equipment style limitations.

Potential Difficulty: If, by chance, no truly relevant data can be found on the lip motion, equipment is available within the department, so that measures could be donelocally. On site is a strain-gauge lip tracking setup that allows three-dimensional tracking of the tips of the lips. This would involve more people and time.

Set 2. Extensive movement literature for lips has been done but what of type of overall movement or displacement; the cosmetics? Usually these types of data are photographs showing before and after shots of a treatment or measurement technique. Photographic data of this type can be found in most phonetic books. An extensive search will be done to locate some qualitative data to show overall look of the speech performance /u/ qualification.

3. To develop and test a relatively simple three-dimensional finite element model of lip motion during speech production.

A finite element model of the simplified anatomy found in the above objectives will be made primarily of the orbicularis oris surrounded by passive tissue. This model will be compared to real lip data. There are two important parts to this objective: (1) the creation of a model and (2) testing the model

Set 1. Stated briefly, general finite element modeling involves the following basic procedure:

A. Discretization of the geometric domain into a suitable number of elements, each defined by a certain number of nodal points (for a 3-D brick element, nodes are the corner points of the brick).

B. Specification of material properties, loadings, and boundary conditions.

C. Derivation of element equations.

D. Assembly of element equations into a system of equations of motion.

E. Solve the system of equation numerically to yield displacement nodal displacement.

The principle investigator has experience in three-dimensional finite element modeling of simple tissue structures with muscle properties but not dynamically with time and inertial dependence. For lip movement, time and inertial properties along with non-linearities from large deformation need to be addressed. Appendix A illustrates the theoretical basics of finite element modeling. Here, the extension of that information will be to describe (1) the nonlinear large deformations extension of small-deformation assumption, (2) the introduction of time dependance to make the model dynamic.

Set 1.1. Large deformation through the Newton-Raphson method

For static problems using the finite element method, displacement of nodes can be found by solving this system of equations (see equation A37; in Appendix A), in matrix notation:

$$\boldsymbol{K}\boldsymbol{d} - \boldsymbol{R} = 0 \qquad \mathbf{(1)}$$

where ***d*** represents a vector displacement variables for each node, ***K*** the stiffness matrix for the system, and ***R*** the forces applied to the system at the nodes. This system of equation was generated for static, small amplitude displacements. This can be solved for nonlinear system if an iteration technique is used for large displacement systems. Imagine there is an applied load $\boldsymbol{R}_A$ and somehow we determined the corresponding displacement $\boldsymbol{d}_A$. For the non-linear situation we redefine the stiffness matrix ***K*** to be a modified stiffness or tangent of the force-displacement curve. In other words, we rewrite equation 1 as:

$$(\boldsymbol{K_0} + \boldsymbol{K_{NA}})\boldsymbol{d_A} - \boldsymbol{R_A} = 0 \qquad \textit{where} \qquad \boldsymbol{K_{NA}} = f(d_A) \qquad \mathbf{(2)}$$

where $\boldsymbol{K_0}$ is the old linear system stiffness matrix, a constant, and $\boldsymbol{K_{NA}}$ is a term that depends on the deformation. If the load $\boldsymbol{R_A}$ was increased to a value of $\boldsymbol{R_B}$ and the corresponding displacement $\boldsymbol{u_B}$ is wanted, we start with a truncated Taylor series expansion of $\boldsymbol{R} = f\,(\boldsymbol{d}\,)$.

$$f(\boldsymbol{d_A} + \text{Ä}\boldsymbol{d_1}) = f(\boldsymbol{d_A}) + \frac{\partial \boldsymbol{R}}{\partial \boldsymbol{d}}\Big|_A \text{Ä}\boldsymbol{d_1} \qquad \textbf{(3)}$$

With

$$\frac{\partial \boldsymbol{R}}{\partial \boldsymbol{d}}\Big|_A = \frac{\partial}{\partial \boldsymbol{d}}(\boldsymbol{K_0}\,d + \boldsymbol{K_N}\,d) = \boldsymbol{K_0} + \frac{\partial}{\partial \boldsymbol{d}}(\boldsymbol{K_N}\,d) = \boldsymbol{K_t} \qquad \textbf{(4)}$$

and $\boldsymbol{K_t}$ is called the tangent stiffness. So, we seek Ä$\boldsymbol{d}_1$ for the situation where $f\,(\boldsymbol{d}_A + \text{Ä}\boldsymbol{d}_1) = \boldsymbol{R}_B$. Substituting this condition, $\boldsymbol{K_t}$, and $\boldsymbol{R} = f\,(\boldsymbol{d}\,)$ evaluated at $\boldsymbol{A}$, equation 3 becomes:

$$(\boldsymbol{K_t})\big|_A\, \text{Ä}\boldsymbol{d_1} = \boldsymbol{R_B} - \boldsymbol{R_A} \qquad \textbf{(5)}$$

where $\boldsymbol{R}_B$ - $\boldsymbol{R}_A$ is the load imbalance, or the difference between the applied load $\boldsymbol{R}_B$ and the force $\boldsymbol{R}_A$ as in equation 1, when there is a displacement $\boldsymbol{d}_A$ on the system.

After computing Ä$\boldsymbol{d}_1$, the displacement estimate is updated to $\boldsymbol{d}_1 = \boldsymbol{d}_A + \text{Ä}\boldsymbol{d}_1$. The next iteration is done by obtaining a new tangent stiffness $(\boldsymbol{K}_t\,)_1$ using equation 4 but with $\boldsymbol{d} = \boldsymbol{d}_1$, and a load imbalance, $\boldsymbol{R}_B$ - $\boldsymbol{R}_1$, where $\boldsymbol{R}_1$ is from equation 1 with $\boldsymbol{d} = \boldsymbol{d}_1$. The updated displacement update is then $\boldsymbol{d}_2 = \boldsymbol{d}_1 + \text{Ä}\boldsymbol{d}_2$, where Ä$\boldsymbol{d}_2$ results from solving $(\boldsymbol{K}_t\,)_1\ \text{Ä}\boldsymbol{d}_2 = \boldsymbol{R}_B - \boldsymbol{R}_1$. This iteration is to continue until the load imbalance, and consequently Ä$\boldsymbol{d}$, are zero.

Set 1.2. Time dependance in a FEM model

Appendix A (eqn. A36) derived the following equation for a dynamic finite element.

$$\boldsymbol{K}\boldsymbol{d} + \boldsymbol{D}\dot{\boldsymbol{d}} + \boldsymbol{W_F}\ddot{\boldsymbol{d}} - \boldsymbol{W_P} = 0 \qquad \textbf{(6)}$$

For time dependent problems, the time derivatives can be split into discrete steps by a finite difference scheme (where *n* will denotes the time step). The time derivatives can be approximated by first order central differences as follows...

$$\dot{\boldsymbol{d}} = \frac{d_{n+1} - d_{n-1}}{2\Delta t} \qquad \textbf{(7)}$$

and

$$\ddot{d} = \frac{d_{n+1} - 2d_n + d_{n-1}}{\Delta t^2} \quad . \qquad \textbf{(8)}$$

The stiffness can be replaced (Crank-Nicholson technique, Nickell, 1973) by the average at times of *n* and *n*+1, or

$$\boldsymbol{K d} = \boldsymbol{K} \frac{d_{n+1} + d_n}{2} \quad . \qquad \textbf{(9)}$$

With these substitutions, the equation 6 above can be rewritten as:

$$\left(\frac{1}{2} D\Delta t + \frac{1}{2} K\Delta t^2 + W_F\right) d_{n+1} + \left(2W_F - \frac{1}{2} K\Delta t^2\right) d_n + \left(W_F - \frac{1}{2} D\Delta t\right) d_n \quad . \qquad \textbf{(10)}$$

With this definition of equation 6, displacements of nodes for particular time, $\boldsymbol{d}_n$, can be solved for in terms of past displacements.

Other notes about the model:

- The boundary conditions and other specifics of the model will be determined by the anatomical data. The dental boundary condition may be model as a slice of a cylinder oriented vertically to model the most rostral curvature of the jaw and teeth.

- Muscle contraction of the orbicularis oris will be done only in the sagittal plane. This means that protrusion during contraction for the /u/ movement will be the result of boundary conditions and incompressible tissue protruding into free space.

- Before implementing the large deformations model through iteration, a small deformation model was compared* to the same model on the commercial FEM package, ANSYS.

- Before implementing the dynamic model, a static case of the model will be compared* to the same model on the commercial FEM package, ANSYS.

- Finite element modeling, like any other modeling, is a simplified, approximate version of our environment. It has its limitations as a modeling scheme like any other.

*Note: This will be done to verify my own FEM model and methodology. I will write my own computer program to keep the option open to expanding or linking this model to other articulator models (Sanguineti, et al., 1998; Berry, et al, 1999; Wilhelms-Tricarico, 1994; Alipour and Titze, 1985, Berry et al., 1994, Wilhelms-Tricarico, 1998, Dang and Honda, 1998).

Set 2. The three main comparative factors that need to be found for the speech task /u/ will be **range** or extent of movement, **velocity** as a function of time and position during a movement, and **type** of overall movement or displacement. The model will have the upper lip and the lower lip independent of one another in contraction capabilities. Two sets of important data needs to be obtained and compared: (1) kinematic movement, range and velocity, (2) type of movement or overall displacement.

Set 2.1. Finite element models are wonderful for obtaining displacement data. Finite element solutions are solved at the nodes of the elements. The solutions are displacements. To obtain maximum displacement or range, one just simply looks at the time history for the maximum. Velocity can be obtained from the time history displacement data. Displacements are known explicitly at each node and can be found, through interpolation, at anywhere between nodes.

Specific values to compare with actual data will be, time from onset of performance to completion, time of peak velocity during the interval, and displacement. These values can all be read from the time history data. The sampling rate will be decided by the time dependencies of the model. Time steps will be less than 10 ms. Usually, articulation movement will be on the order of tens of ms. The comparison of values will be done through a simple difference scheme and shown to be significant by using the standard deviation of the real data measures from repeated performances. This treats the model as a system to accept or reject.

Set 2.2 Comparing overall movement or cosmetics will be done with three judgment tasks.

Test 1. Subjects will be asked, after seeing the model perform some “unknown” vowel, to choose the vowel being performed visually and two secondary choices. They will have all choices from the vowel quadrangle to choose from.

Test 2. Subjects will be asked to rate how realistic or lifelike the performance was. They will use a scale from 1-10 where 10 represents the most lifelike.

Test 3. Subjects will be asked to rate how the perceived health (lack of abnormalities) of the lips. They will use a scale from 1-10 where 10 represents the most healthy.

Mean response and standard deviation will be computed for each test.

Note: These tests were chosen for two primary reasons. First, these test will initially help in creating and refining the model against an ideal case. Second, if these tests prove appropriate, then they would be the style of tests used when modeling deformed lips and/or rating the repair of cleft lip.

4. To address the application of the model in studying the influence of deformities, particularly those associated with repaired unilateral cleft of the lip, on speech performance of /u/.

The development of a finite element model of lip movement will greatly enhance our ability to evaluate non-invasively the effects of unilateral cleft lip repair. Once a model has been made, how to apply it to the study of deformities is straight forward. The description of use in the study of deformities requires three steps: (1) identification of deformity characteristics, (2) how to apply the characteristics to the model, (3) methods of comparison to normal lips.

Set 1. Research needs to be done to identify the deformity characteristics. This includes the place of the deformity and the material properties. Is it muscle weakness, scar tissue, or geometrical asymmetries. For example, Al-Waheidi, et al. (1998) published data concerning hard and soft tissue changes following repaired cleft of lip.

Set 2. Applying the characteristics of the deformity to the model is like trading the small blocks (elements) from the normal model with the abnormal model. The replacement element can have higher stiffness characteristics if it is scar tissue than the normal block or different active properties if the muscle is skewed. Once these elements have been changed, the model is rebuild. Future studies, using this technique will be outlined.

Below is an example of a real study. Included are ideas that the deformity could be integrated.

Schender (1991) found that in the scarring area is increased connective tissue (stiffness change). Also, there is abnormal growth leading to asymmetry and abnormal geometry (element size change). Asymmetrical fiber distribution and abnormal fiber insertion info is available (active muscle property direction change). Even up to 1 cm from a cleft scar, only a few muscles were found in a bed of connective tissue. Abnormal skeletal development in cranio-facial region is known to occur (boundary condition change).

Set 3. The model could then be compared to the normal one by taking kinematic and judged data from the deformed model using the procedures above. Expected results, other possible findings, and other uses of the model will be discussed.

B. TIME-LINE

The proposed research is designed to last a year. This time-line is an approximate scheduling of the objectives.

Complete by:	Objective	Set	Comments
week 2	1	1	-anatomical books are readily available
week 5	1	2	-tissue properties may not be easily found
week 8	2	1-2	-much information on lip kinetics, possible problem finding individual /u/
week 12	3		-geometry and tissue type design of the simplified model
week 24	3		-working static, small-deformation version of the model, compare with ANSYS results (this step should be the heaviest time investment)
week 29	3	1.1	-large deformation properties added to static, small-deformation version, compare with ANSYS
week 34	3	1.2	-dynamic time dependence extended version of static, small-deformation version of model
week 39	3	1.1-1.2	-large deformation properties and time dependence in the final model
week 42	3	2.1	-kinetic measures of velocity and range of movement of model performance of /u/ taken
week 44	3	2.2	-subjects judge other aspects of the model quality
week 47	3	2.1-2.2	-analysis of model's kinematic and judged data
week 49	4	1-2	-outline and discuss ways model could be applied to study the influence of deformities such as those associated with repaired unilateral cleft lip on speech performance
week 52			-conclude study with findings and future research report

LITERATURE REVIEW

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