PATTERNS OF TONGUE MOVEMENT

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ABSTRACT

This paper discusses the pivot pattern of tongue movement. In this pattern, there is a point in the vocal tract where there is no motion, but there is motion at points of the vocal tract anterior and posterior to the pivot point. Based on tongue edge tracings of frames from ultrasound and x-ray dynamic imaging of the vocal tract, I will show that the pivot pattern is used in a variety of sequences, and I will discuss the possible causes of the pattern.

1. INTRODUCTION

A central question of speech production is how the tongue changes its configuration as it moves from the configuration for one lingual segment to that of another. For instance, to perform the [a-i] sequence, the tongue needs to perform a pharyngeal constriction, and then, as it undoes that constriction, to make a palatal one. How do different parts of the tongue move to simultaneously make one constriction and undo another? Also, is the pattern of tongue movement actuated in [a-i] similar to the pattern for other sequences? That is, are there general patterns of movement that are used by the tongue to perform a variety of transitions? The answer to the last question may inform investigations of lingual coarticulation, since general patterns of movement would constrain the variation seen in coarticulation. It may also illuminate problems regarding the articulatory basis of formant transitions, since tongue movement is a major factor in determining the changes in the dimensions of the vocal tract acoustic filter. Knowledge of general patterns of tongue movement may also have technical applications in informing the development of general transition rules for use in articulatory speech synthesis.

This paper will discuss the "pivot" pattern of tongue movement, previously pointed out by Stone [1]. In this pattern, there seems to be a point in the vocal tract where there is no motion, but there is motion at points of the vocal tract anterior and posterior to the pivot point. This movement pattern can also be seen in tongue motion tracings in various publications [2,3,4]. Based on tongue edge tracings of frames from ultrasound and x-ray dynamic imaging of the vocal tract, I will show that the pivot pattern is used in a variety of sequences, and I will discuss the possible causes of the pattern.

2. EXPERIMENTAL WORK

In order to investigate the existence of general patterns of tongue movement, tracings of the tongue edge from x-ray and ultrasound motion pictures were made. The x-ray data analyzed is from a publicly available database [5]. The ultrasound data was collected on a RT-3000 GE ultrasound imaging system. The data is all from Canadian and American English. A total of 450 vocalic and consonantal sequences were analyzed, where each sequence begins and ends at points where either the oral or pharyngeal parts of the tongue changes direction of movement. The tongue edges were traced with a mouse, since various edge-tracing techniques attempted needed too much subjective intervention for proper detection.

3. THE PIVOT PATTERN

There's a variety of ways in which the tongue could deform in going from the configuration for one segment to the configuration of another. And it is possible that the deformation of the tongue during a transition is entirely dependant on the starting and ending configurations. So the way that the tongue moves during [t-i] may be entirely different from the way it moves during [z-a], for instance. If we take a single type of sequence, like [a-i], we can imagine several ways in which the deformation could take place. In Figure 1, below, are three of the many possible tongue deformations during [a-i]. The black edge represents the configuration during [a], and the dotted edge represents the configuration for [i], with the middle edge representing one of the several edges in between the starting and ending configurations.

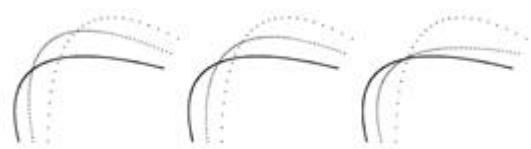

Figure 1. Schematic deformation for [a-i]

In the database of sequences investigated, [a-i] occurs 14 times, and all of the three possible deformations above do occur, but the most common deformation is the pivot pattern, which is the third pattern in Figure 1. In Figure 2, below is an example from the database analyzed of the [a-i] realized with the pivot motion.

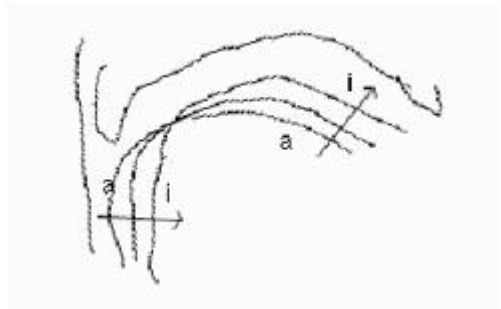

Figure 2. Tracing of [a-i]

The pivot pattern is not used only in accomplishing the [a-i] sequence. Below, in Figure 3, are four examples of the pivot movement in a variety of different contexts. The arrows indicate the direction of movement anterior and posterior to the pivot point.

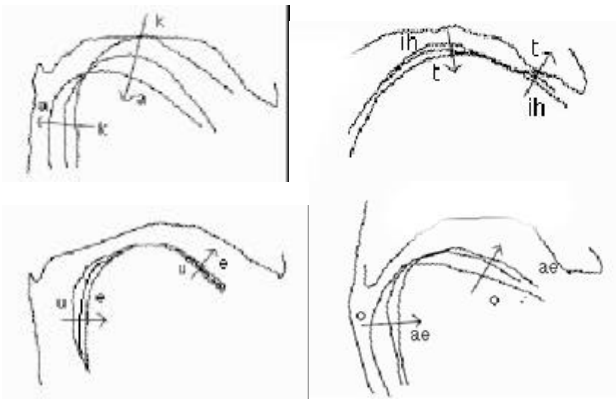

Figure 3. Tracings of [k-a], [ih-t], [u-e], and [o-ae]

The pivot pattern looks like a rotational movement, where one point of a body remains fixed, and the other points rigidly rotate around it. But the tongue is a highly deformable body. What seems to be actually occurring in the pivot pattern is that, even though every flesh point on the edge of the tongue does move, the movement is coordinated in such a way that there is a cross-section of the vocal tract whose area doesn't change, since there is always a fleshpoint a fixed distance from a hard structure at that cross-section. The proper characterization of the pattern, therefore, is as an area-function pivot. That is, the highly elastic movement of the tongue proceeds in such a way that the change in the area-function during a transition seems like a rigid rotation of the sides of the tube.

At this point this is a qualitative observation, rather than a quantitatively valid finding. For this observation to be put on a solid quantitative footing, one needs to investigate the movement of individual pellets at the same time as tracing the movement of the entire edge of the tongue [3]. If the observation is valid, then the pellets at various points of the tongue would be shown to move despite the occurrence of apparent lack of movement at a certain cross-section of the vocal tract.

4. POSSIBLE CAUSES OF THE PATTERN

There are two general types of causes for the presence of the pivot pattern in a variety of transitions. The pattern may be actively carried out to achieve some acoustic goal, or it may be a passive result of some aspect of tongue or jaw dynamics. If the pivot pattern is actively controlled, it may be for the purpose of achieving optimal formant transitions, especially if the pattern is really a method of controlling the area-function. This is consistent with work on formant transitions Carre and Chennoukh [6]. On the other hand, the pattern maybe a result of jaw rotation, or a consequence of the incompressibility of the tongue and the nonlinear characteristics of the stress-strain relation of tongue tissue. Jaw rotation probably does contribute to the pattern, but it doesn't do so as a primary cause, since the pattern is readily seen in ultrasound tracings, even though the ultrasound transducer rides along with the jaw, and therefore doesn't detect its motion. To investigate the contribution of acoustic output, incompressibility, and tissue nonlinearity to the presence of the pivot pattern, I am currently carrying out simulations of a finite element model of the tongue tissue and the vocal tract acoustic cavity.

5. CURRENT RESEARCH

In order to classify the various tongue patterns, a method of quantifying each pattern and departure from it is required. An attempt is under way to classify the patterns by first fitting the edge of each frame with an interpolatory Hermite polynomial, and then classifying the sequences by the changes in the coefficients of the polynomials. The goal is to classify the investigated sequences by automatic means in order to verify the subjective procedure currently used.

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