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ABSTRACT

The traditional respiration-phonation-articulation-resonation model of speech production which permeates introductory literature is not the only suitable model of this process. The pump-valve model, which derives from the acoustic theory of speech production, is a viable alternative. This newer model is also consistent with modern theories. It focuses upon the parallel mechanisms within the overall system and suggests relationships between their activities and their consequent sound code product. The pump-valve model is particularly useful because it provides for a straightforward treatment of the speech code. Each of the articulators is given equal weight, and the functioning of one is not emphasized at the expense of others. The treatment of prosodic or suprasegmental features such as pitch and loudness may be deferred until the segmental features are considered, or they may be omitted entirely. (EE)

The Pump-Valve Model of Speech Articulation*

by Donald Dew

Introduction: Our fundamental orientation to the processes of speech production has been shaped by early presentations of relevant material organized in the framework of the traditional Respiration-Phonation-Articulation-and-Resonation structure. This familiar organization has been used in the most popular introductory textbooks that deal with normal structure and use of the speech mechanism (e.g., Gray and Wise, 1959; Judson and Weaver, 1965; Kaplan, 1971; Zemlin, 1968; ect.). Accepted without question, the outline seems reasonable and has served the purposes of teachers, scientists and practitioners for many years.

Although never formally presented as a model, the traditional organization has been influencial and does suggest a particular orientation. Specifically, by lumping articulation and resonation together and by paying separate and more extensive attention to either phonation or respiration, emphasis is placed on the latter at the expense of the former. Moreover, the laryngeal production of voicing is given special emphasis which leads to the widely accepted beliefs that the larynx is the only sound generator of the entire mechanism and that the only sound it generates is voicing. Although well suited to the interests of the investigators and teachers of voice, such an attitude is not generally applicable nor can it be substantiated. As so many other traditions, the Respiration-Phonation-Articulation-and-Resonation structure has been accepted intuitively without concern for justification. The organizational structure is treated as

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an implicit model in this paper, because it has served to orient our consideration of speech production and it has been influencial. It is not, however, the only appropriate model, useful alternatives are conceivable.

Obviously, the larynx is a sound generator in the sense that it interacts with the air flow of respiration to create a sound. In brief, the forces exerted by muscles located in the torso and neck are converted to sound energy. Furthermore, the laryngeal mechanism is used to generate a quasi-periodic complex wave which listeners recognize as voice. As so aptly demonstrated by Gunnar Fant in his classic Acoustic Theory of Speech Production (1960), however, the larynx is not the only source of sound in the speech mechanism nor is it limited merely to the production of voice. The larynx is one of several sound sources and the quasi-periodic complex wave is one of several kinds of sound it generates.

Unfortunately, many of our colleagues and nearly all of our students in the field of speech lack sufficient technical background and training to fully comprehend and appreciate Fant's theory. Assured that the theory provides for accurate and quantifiable predictions, we must rely on others for a translation into readily understandable concepts. Several excellent contributions of this nature (notably Stevens and House, 1961, and Liberman, 1972) have been made, but they are intentionally confined to a treatment of vowels. This allows for the introduction of the major principles of resonance as well as those of voice production, but it does not encompass the full scope of speech production. The lesser known (but equally important) principles concerning consonant sources and filtering generally have been slighted. In this regard, Fant has demonstrated that additional sound sources are used and that different principles of resonance do apply to the production of consonants, but the demonstration is highly technical.

Purpose: The purpose of this paper is to offer a perspective of speech production other than that provided by the traditional Respiration-Phonation-Articulation-and-Resonation Model. This is called the Pump-Valve Model and is intended to represent the full scope of the Acoustic Theory of Speech Production in terms simple enough to be understood by college sophomores.

Description: In the Pump-Valve Model, the respiratory system is identified as the pump and is treated in much the same way as in the traditional model. In addition, all the articulators are treated as valves, valves which close and open in various degrees; this includes the labial valve, the lingual valve, the velar valve, as well as the laryngeal valve. Thus, not only is the larynx treated as an articulator, it also is emphasized no more than the other articulators, and its function of producing sounds other than voicing is recognized.

Three of the valves (viz., the labial, lingual and laryngeal valves) are sound generators. Each is capable of generating three kinds of sounds - a burst, noise or tone. There is not just one sound generator and that sound generator is not limited to a single type of sound.

First let us consider the generation of a burst. In quiet breathing, the respiratory pump causes a flow of air thru the vocal cavities. When a valve closes, the flow of air is stopped and the pump causes an increase in pressure within the closed system. When the valve opens, a burst of pressure (or sound) is released. This can be accomplished by the lips in the production of the labial stops, by the tongue in the production of the alveolar and veolar stops, and by the larynx in the production of the glottal stop.

Secondly, let us consider the production of noises. In this instance, the valve is not entirely closed but forms a very narrow constriction at some point along the vocal tract. Directed through this narrow constriction by pumping action, the air flow becomes turbulent within the constriction. This turbulance is a noise sound source. Such sounds can be created by the lips in the production of labio-dental fricatives, by the tongue in the production of lingua-dental and lingua-alveolar fricatives, and by the larynx in the production of the glottal fricative. In addition, of course, the lingual valve is capable fo producing foreign sounds such as velar, uvular, or pharyngeal fricatives.

The production of the third kind of sound, a complex periodic wave has received considerable attention and has been satisfactorily explained by the Myoelastic Aerodynamic Theory of Voice Production (van den Berg, 1958, and Flanagan, 1958). As with the burst and the noise, the tone is produced by the interaction of the pump and the valve. Though the laryngeal valve is recognized as the most adept mechanism for producing this kind of sound, it is necessary to indicate that the labial and the lingual valves also are capable of producing such vibrations. Indeed, the basic principle of this theory can be and usually are illustrated by the "Bronx Cheer" in which the labial vibrations can be observed readily; with the appropriate degree of tension and opening, they are alternately sucked into the air stream and blown apart in the very same way that the vocal folds interact with the air stream to produce voicing. Similarly, the lingual valve can produce such a complex periodic in the production of a "rolled r," for example. Even the velar valve (which is not ordinarily used for a sound source in speaking) seems capable of producing a quasa-periodic signal when interacting with an inflow of air thru the nasal cavities. In particular, I am suggesting that snoring may be expalined by the Myoelastic Aerodynamic Theory.

Surely, my major point must be evident by this time. The larynx is not the only sound generator in our speech system. It is important to recognize that the labial and lingual valves also are sound generators. These generators may operate sequentially or simultaneously as they do in the production of voiced fricatives and voiced stops. Furthermore, voicing is but one of several types of sound produced by the larynx, it also produces both bursts and noises. Furthermore, all three types of sources are produced by the labial and lingual valves as well.

I propose the Pump-Valve Model as an alternative to the traditional Respiration-Phonation-Articulation-and-Resonation Model in order to offer a simple, fundamental explanation of speech production. Undoubtely, those having a primary interest in laryngeal functioning will continue using the traditional model; it is well suited to their purposes in that an emphasis is placed upon phonation. Others who are interested in the general articulatory process should find the Pump-Valve model well suited to their purposes. This includes the investigators of normal articulatory functioning, clinicians whose most prevelant problem is mis-articulation, and practioners in general having a need to understand the speech code.

As I have shown, the Pump-Valve Model derives from the Acoustic Theory of Speech Production. In addition, it is consistent with Distinctive Feature Theory and with modern theories of speech perception.

Let us consider distinctive features first. From this perspective (Jakobson, Fant and Halle, 1952), a sound is considered to be a bundle of features which occur simultaneously. A distinctive feature analysis suggests a parallel operation of the speech mechanism rather than a sequential one. For example, at the time

that the larynx generates a tone, the labial, lingual and velar valves make adjustments which shape the vocal cavity configurations. Individual adjustments within the system are not entirely independent, but simultaneously the labial valve can open or close or be rounded, the lingual valve can produce a burst or noise on the alveolar ridge or the velum or it can assume a configuration necessary for a vowel, the velar valve can open or close, and the laryngeal valve can produce a tone, noise or burst. This simultaneous activity is consistent with simultaneous features which are obtained from the composite product of the speech mechanism. A recent investigation illustrative of the parallel activity of lips, jaw, tongue and larynx was reported by Lindbloom and Sundberg (1971).

How difficult it has been to consider co-articulation within the framework of the traditional respiration, phonation, articulation and resonation model. When instead, co-articulation is approached from the perspective of the Pump-Valve Model, it is easy enough to see that each of the valves are adjusted at different rates. Thus, the relatively slow lip rounding or velar closing must be anticipated several sounds before their target and might last several sounds after. If we assume that articulatory activity is monitored primarily by the private feedback loops (such as taction and proprioception) rather than by public feedback loops (such as audition and vision), as suggested by Layne and Tranel (1971), there are parallel neural pathways leading to and from each of the valves to accomodate such monitoring.

The parallel monitoring of parallel activity within the mechanism could also be available for decoding as well as for encoding. In other words, the system we have available for self-monitoring may be useful for decoding the speech of

others. This is consistent with the Motor Theory of Speech Perception (Liberman, 1957). Also it is consistent with the generative rules operation described as part of the Analysis by Synthesis Model of Speech Perception (Stevens, 1960).

As a phonetician, I have found the Pump-Valve Model to be particularly useful. It provides for a direct straightforward treatment of the speech code. Each of the articulators is given equal weight, the functioning of one is not emphasized at the expense of the others. The treatment of prosodic or suprasegmental features such as pitch and loudness may be deferred until the segmental features are considered or they may be omitted entirely if one sees fit to do so.

Summary: In sum, I have suggested that the traditional Respiration, Phonation, Articulation, Resonation Model of speech production which permeates our introductory literature is not the only suitable model of this process. I have suggested an alternative, namely the Pump-Valve Model, which derives from the Acoustic Theory of Speech Production. Also, I have shown that this new model is consistant with other modern theories. In a simple (or perhaps simple-minded) fashion, it focuses upon the parallel mechanisms within the overall system and suggests relationships between their activities and their consequent sound code product. I hope you find it a useful tool for your purposes.

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