Second formant behavior in the presence of non-local and local constrictions

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Abstract

To build knowledge of the relationship between articulation and acoustics in speech, we consider the relationship between a simple three sub-tube area function and the second formant. In a previous manuscript (McGowan, 2019), we examined constrictions that are local, or short, in the axial direction compared to the wavelength of sound of the first two formant frequencies. An accumulation of kinetic energy density in these constrictions means that they limit formant frequency increases, or they diminish formant frequencies substantially. Here we examine how non-local constrictions can increase the second formant frequency substantially. In non-local constrictions there can be patterns of pressure and volume velocity that are indicative of acoustic standing waves without excess kinetic energy density. These patterns permit the tube to pack more parts of a shorter wavelength and higher frequency standing wave into the overall tube. As constriction length is made smaller, the situation in the constriction gradually reverts to one where the air flow is approximately incompressible with relatively large kinetic energy density. We suggest that an articulatory description of sonorants include constriction length, along with place and degree of constriction.

Introduction

We explore the ways that constrictions in an acoustic tube affect the second formant and its frequency, $F2$. This is part of a larger project to understand articulatory-acoustic relations in speech production, particularly for the production of *sonorants*[1]. An important application of the knowledge of articulatory-acoustic relations is to put what Ladefoged (1993; pp. 78-80) calls articulatory phonetics on more of a truly articulatory footing, particularly when describing vowel production. We concluded a previous manuscript (McGowan, 2019) with the recommendation that constrictions be described by their location, degree, and axial length[2]. In the present manuscript we strengthen the argument that axial length is an important aspect of forming a constriction when speech is produced.

In the previous manuscript, we studied local constrictions and expansions for their effects on the first two formant frequencies. In that manuscript we used the term "short" in place of local, where short means small axial extent compared to the wavelength of sound under consideration. In the parlance of physicists and mathematicians, the term short means that the constriction or expansion is *acoustically compact* (Howe, 2007; p. 409) for one-dimensional plane waves propagating in the axial direction of the tube. The main conclusion of that study is that short constrictions either limit the raising of formant frequencies, or they lower the formant frequencies substantially. This is due to a concentration of acoustic kinetic energy density in the constriction. Also, we indicated that non-local constrictions can substantially raise formant frequencies in two examples. One of the examples in McGowan (2019) is the raising of $F2$ with a non-local constriction in the mid-to-front portion of the tube. Here, we continue our examination of the behavior of the second formant in the presence of various constrictions.

After some preliminary definitions and a presentation of a naive theory for $F2$ raising, we optimize for $F2$ raising by adjusting the lengths of three sub-tubes that comprise

[1]Sonorants are speech sounds made when the vocal tract is made with an upper vocal tract that neither contains constrictions that completely block air flow, nor produce significant turbulence noise. The other speech sounds are called *obstruents* (Ladefoged, 1993; 62-3)

[2]The axial direction is the direction along the axis of the tube, and axial location is denoted here with the variable x. Constriction length is the length of the constriction in the axial direction x.

the overall tube for various fixed degrees of constriction of the middle sub-tube (Figure 1). We examine the acoustic field to understand how $F2$ is raised substantially with a non-local constriction. We further explore this configuration by systematically reducing its axial length without changing its position, or place, to exhibit the transition from a non-local to a local, or short, constriction. We also make the same systematic changes of constriction length with the constriction place at different locations in the tube. The work concludes with some thoughts about the future directions of the research presented here.