Measuring the dispersion of density in head and neck cancer patients' vowel spaces: The vowel dispersion index

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1 Introduction

Head and neck cancer patients who undergo surgical treatment present a variety of physiological and anatomical changes [1–3]. Because of these changes, the patients' speech is impacted. To create intelligible speech, these patients must adopt new communication strategies. The present paper introduces a measure of vowel dispersion that can be used in analyzing patient communication strategies. The measure is termed the "vowel dispersion index," and it is an extension of Story & Bunton's work on vowel space density [4].

Changes in patients' speech may be reflected in their F1-by-F2 vowel space. Per Lindblom's H&H theory [5], hyperarticulated speech will use formant configurations that tend toward the extremes of the vowel space. Lindblom has described this style of speech as more effortful, but also easier for a listener to interpret. On the other hand, hypoarticulated speech uses formant configurations that tend toward the center of the vowel space [6]. Following cancer treatment, the head and neck cancer survivors may need to enhance acoustic contrastiveness in their speech. It is reasonable to expect that they will produce speech closer to the extremes of the available vowel space than the central region if they are to be understood. Indeed, it has been found that the area of patients' vowel space is reduced after surgery with partial restoration after rehabilitation [7].

Working with vowel space requires choosing a representation that can be reasoned about. One such representation is the convex hull, which Story & Bunton use to examine vowel space density [4]. In their work, vowel space density is a reflection of what proportion of time a speaker spends in a given region of the vowel space for running speech. The vowel dispersion index is an extension based off Story & Bunton's work on vowel space density. It provides an indication of how diffuse a patient's vowel productions are.

The remainder of the present paper is as follows. First, the method of calculating the vowel dispersion index is briefly described. Next, several illustrative examples of the vowel dispersion index and the vowel space density for a patient are presented. Finally, the paper concludes with a discussion of the patients' results and potential applications of the vowel dispersion index.

2 Method

To calculate the vowel dispersion index, the vowel space density from Story & Bunton is calculated as in [4]. First, the formant tracks are calculated from a recording. Second, at each point in a grid of possible formant values, the number of points within a given radius is counted, giving an indication of the density in that section. Third, the density values are scaled to the invterval between 0 and 1. And, fourth, a convex hull is calculated around the points that are at a value of 0.25 or higher.

Once the vowel space density has been determined, the vowel dispersion index can be calculated. To find it, the magnitudes of all the discrete gradient values are summed over the vowel space. The result is what's generally known as the total variation, and here is referred to as the vowel dispersion index. When considering the vowel space density as a topographic map, where dense areas represent high elevations and sparse areas represent low elevations, the vowel dispersion index indicates how hilly the area is.

A high vowel density index indicates that there are many elevation changes, and it represents diffuse vowel productions. In turn, diffuse vowel productions show a more diverse use of the vowel space, indicating that the speaker is hyperarticulating. A low value indicates that there are few elevation changes, and the vowel produces are clustered together. In such a case, a speaker is using little of the vowel space and could be said to be hypoarticulating.

3 Results

The vowel space density, vowel dispersion index, and vowel space area are presented here for two patients. A waiver of consent was obtained to use their data and the protocol was approved by the Health Research Ethics Board of Canada Cancer Committee (HREBA.CC-18-0689). At different stages in their treatment, they recorded the zoo passage, which is the recording that was analyzed for the present study. The patients were recorded before their treatment, 1 month post-treatment, 6 months post-treatment, and 1 year post-treatment. The values for the vowel dispersion index and the vowel space area were calculated in a normalized space, but the images are presented in the Hertz scale for ease of interpretation.

A female patient's speech may be seen in Figure 1. Note the single large peak in the upper-right quadrant of the vowel space pre-treatment, indicating a locus of where the majority of the vowel productions occurred. There are also singular large peaks in the space at 1 and 6 months post-treatment, suggesting the patient is using similar speaking strategies to their pre-operation strategies at 1 and 6 months after treatment. However, at 1 year after their operation, they show a

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visually greater degree of dispersion. The vowel dispersion index is also higher at the 1 year mark, suggesting that the patient is using more of the overall vowel space. Such a strategy may indicate that the patient is heightening the acoustic contrastiveness of the segments in their speech to compensate for their altered anatomy and physiology.

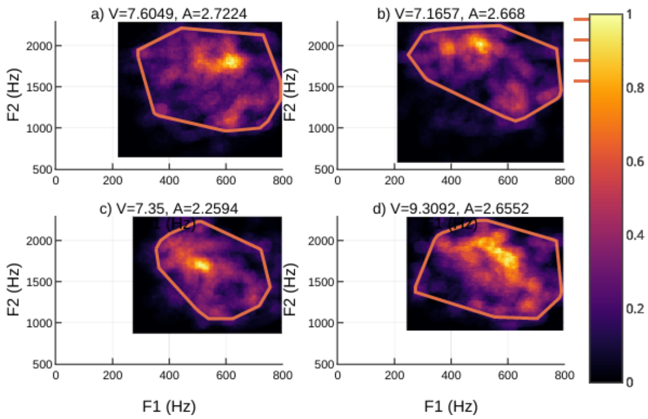

Figure 1: A female patient's vowel space densities. Black is low density, while yellow is high density. a) Pre-treatment. b) 1 month post-treatment. c) 6 months post treatment. d) 1 year post-treatment.

A male patient's speech may be seen in Figure 2. The pre-operation, 1 month post operation, and 1 year post operation recordings are visually similar, with single masses of density surrounded by lower density regions. The mass in the 1 month post operation recording is smaller, however, permitting more variation in the rest of the space, which is reflected numerically in the vowel dispersion index. The 6 months post operation recording stands out as showing greater dispersion, which is also reflected in the vowel dispersion index.

Note from these two examples how the vowel dispersion index and vowel space area are related to each other. While some degree of correlation is expected between the two measures, they are conceptually distinct. The vowel dispersion index offers an additional dimension to vowel space size in describing speech production acoustics.

4 Discussion & Conclusion

The present paper introduced the vowel dispersion index. It indicates the degree to which a speaker's vowel productions are diffuse in the vowel space throughout running speech. For head and neck cancer patients, it can be used to study communication strategies they employ in compensation for anatomical changes after their treatment. It is another tool for researchers in objectively studying the speech of these patients.

But, the vowel dispersion index is not limited to the study of head and neck cancer patients' speech. It could be used to study reduction patterns in speech, like those discussed in [5] and [6]. Additionally, it could be used to investigate the degree of acoustic contrast a speaker is employing in challenging situations, such as speech in noise, speech with objects in the mouth, or speech where a part of the mouth is numbed.

Future work should focus on validating the vowel dispersion index against other known variables, such as intelligibility for head and neck cancer patients and vowel centralization for reduction studies. Other forms of representing the vowel space density could be studied as well, such as Gaussian mixtures. The vowel dispersion index is a quantitative tool for speech science.

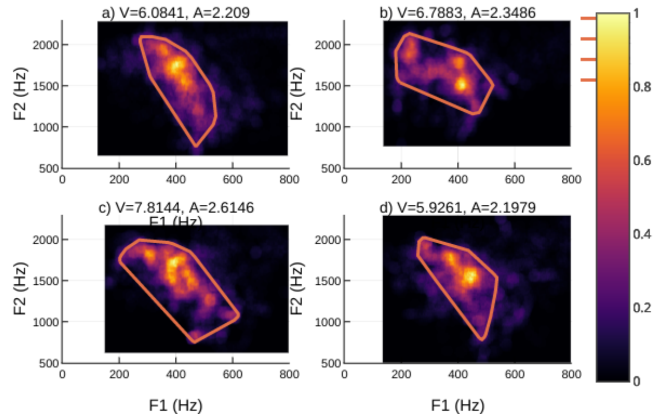

Figure 2: A male patient's vowel space densities. Black is low density, while yellow is high density. a) Pre-treatment. b) 1 month post-treatment. c) 6 months post treatment. d) 1 year post-treatment.

References

[1] Feras Al Halabi. Quality of life among patients with tongue cancer: Primary closure versus free flap reconstruction. In Tanya R. Fitzpatrick, editor, *Quality of Life Among Cancer Survivors*, pages 87–108. Springer International Publishing, Cham, 2018.

[2] Agnieszka Dzioba, Daniel Aalto, Georgina Papadopoulos-Nydam, Hadi Seikaly, Jana Rieger, Johan Wolfaardt, Martin Osswald, Jeffrey R. Harris, Daniel A. O'Connell, Cathy Lazarus, Mark Urken, Ilya Likhterov, Raymond L. Chai, Erika Rauscher, Daniel Buchbinder, Devin Okay, Risto-Pekka Happonen, Ilpo Kinnunen, Heikki Irjala, Tero Soukka, Juhani Laine, and Head and Neck Research Network. Functional and quality of life outcomes after partial glossectomy: a multi-institutional longitudinal study of the head and neck research network. *Journal of Otolaryngology - Head & Neck Surgery*, 46(1):56, September 2017.

[3] Giovanni Nicoletti, David S. Soutar, Mary S. Jackson, Alan A. Wrench, Gerry Robertson, and Chris Robertson. Objective assessment of speech after surgical treatment for oral cancer: Experience from 196 selected cases. *Plastic and Reconstructive Surgery*, 113(1):114–125, January 2004.

[4] Brad H. Story and Kate Bunton. Vowel space density as an indicator of speech performance. *The Journal of the Acoustical Society of America*, 141(5):EL458–EL464, May 2017.

[5] B. Lindblom. Explaining phonetic variation: A sketch of the H&H theory. In William J. Hardcastle and Alain Marchal, editors, *Speech Production and Speech Modelling*, NATO ASI Series, pages 403–439. Springer Netherlands, Dordrecht, 1990.

[6] Matthew Aylett and Alice Turk. Language redundancy predicts syllabic duration and the spectral characteristics of vocalic syllable nuclei. *The Journal of the Acoustical Society of America*, 119(5):3048–3058, April 2006.

[7] Jun Takatsu, Nobuhiro Hanai, Hidenori Suzuki, Masahiro Yoshida, Yasuhiro Tanaka, Seiya Tanaka, Yasuhisa Hasegawa, and Masahiko Yamamoto. Phonologic and acoustic analysis of speech following glossectomy and the effect of rehabilitation on speech outcomes. *Journal of Oral and Maxillofacial Surgery*, 75(7):1530–1541, July 2017.