The Effects of Outer Space on Vowel Space

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1 Introduction

After returning from the *Expedition 35* space mission, astronaut Chris Hadfield reported "I could feel the weight of my lips and tongue and had to change how I was talking... I didn't realize I had learned to talk with a weightless tongue." [1]. Such comments indicate that adaptation to changing gravity conditions can have a substantial effect on speech articulation. Previous work has investigated the effects of altered gravity during space travel on speech production [2], and found some effects on vowel space. However, the audio assessed in [2] was from the 1969 Apollo Moon landings, and thus of poor quality due to technological limitations. These limitations resulted in a lack of appropriate data, eg; F1 and F2 were only assessed for one vowel, with only F1 investigated for the remaining vowels. Further, the previous work did not evaluate speech from astronauts immediately before leaving earth, and instead limited itself to speech produced throughout space travel, the surface of the moon, and a news interview after landing. The present analysis makes use of higher quality audio from the more recent STS-134 mission in 2011, and investigates F1 and F2 measurements for five vowels produced by astronaut Mark Kelly immediately before, during, and immediately after the STS-134 mission.

Plotted vowel spaces from each condition suggest substantial reduction of vowel spaces in both the in-space and post-landing conditions. Single factor ANOVAs independently comparing F1 and F2 across all conditions indicate significant differences for the F1 of high vowels, which corresponds to vowel height. These observations corroborate Chris Hadfield's descriptions that altered gravity results in observable impairments to speech motor control.

2 Materials & Methods

The North American Space Association (NASA) provides audio-logs for all missions through the public NASA audio archive (see: https://archive.org/details/nasaaudiocollection). The audio files from the STS-134 mission were selected because they feature substantial speech data from Mark Kelly across various points in the mission.

Approximately 90 seconds of audio from each condition (1. pre-launch interview, 2. in-space interview, 3. post-landing tarmac interview) was assessed using automated alignment and formant extraction via the Dartmouth Linguistic Automation suite (DARLA). Stopwords were omitted from the analysis along with unstressed vowels and tokens where the formant bandwidth exceeded 300Hz. As all samples came from a single speaker, formant normalization was not employed. All vowels for which a comparable number of tokens were obtained (4 or more in each condition) were included in the analysis. For each vowel assessed, F1 and F2 were compared independently using single-factor ANOVAs. Following application of the selection criteria, five vowels were included in the analysis: The low front vowel /ae/, the mid front vowel /ɛ/, the near high front vowel /ɪ/, the high front vowel /i/, and the low-mid back vowel /ʌ/. A 5 level Holm-Bonferroni correction was applied to the ANOVAs for F1 and F2 independently, with a rank 1 significance level set at 0.01.

3 Results

Results from the DARLA formant analysis are provided in Table 1 below. Table 1 provides the mean F1 and F2 for all three conditions (pre-flight, mid-flight, post-flight). The first column designates each vowel and the following columns specify the condition. Results for each condition are found in the rows below, with F1 values on the left, and F2 on the right, The final column provides the p-value as obtained by single-factor ANOVA for the vowel in each row along with the Holm-Bonferroni corrected significance threshold in parenthesis, with the p-value for comparisons of F1 on the left, and F2 on the right.

Table 1 : F1 values for each condition

	Pre-flight		**Mid-flight**		**Post-flight**		**P-value**	
	F1	**F2**	**F1**	**F2**	**F1**	**F2**	**F1**	**F2**
i	380	2132	368	2122	451	2071	<.0001 (.01)	=.49 (.025)
ɪ	447	1818	459	1753	518	1660	=.0002 (.012)	=.06 (.016)
ɛ	544	1765	620	1601	613	1551	= .027 (.025)	=.03 (.01)
æ	662	1626	661	1685	735	1617	= .08 (.05)	=.50 (.05)
ʌ	556	1194	672	1264	650	1348	= .11 (.016)	=.09 (.012)

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Figure 1 below consists of a vowel plot illustrating the differences in vowel space between each condition. Arrows are used to illustrate the difference in position (height/backness) between the mean pre-flight and post-flight measurements. Pre-flight measurements are represented by a green circle, mid-flight measurements by a red triangle, and post-flight measurements by a blue square. The X axis of the plot displays the inverted range of F2, and the Y axis displays the inverted range of F1.

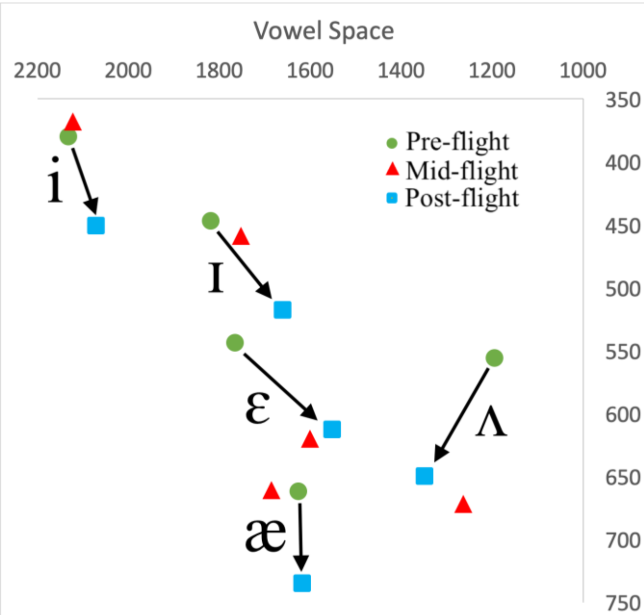

Figure 1: Cross-condition vowel space

4 Discussion

Formant values have been correlated to the height and backness of a speakers tongue, with the value of F1 bearing an inverse relationship with tongue height, and F2 relating to degree of backness [3]. Accepting this, a general effect on the vowel space can be observed between the pre-flight and post-flight conditions, with all vowels lowering and centralizing in the post-flight condition. Mid-flight vowels were variable, although some degree of reduction can be observed relative to the pre-flight condition.

Chris Hadfield's statement that he had grown accustomed to speaking with a weightless tongue in space is reflected in these results. We assume that if someone grew accustomed to a weightless tongue in space, the degree of passive muscle activation employed to keep the tongue elevated during speech would no longer be sufficient upon returning to earth's gravity. With muscle activations insufficient to counteract the forces of gravity, the tongue would be expected to fall short of its usual vowel targets, with the most substantial shortcomings reflected in vowels which are furthest from the resting configuration and require more effort to counteract the forces of gravity.

It is no surprise then that the F1 of the higher vowels (/i/ & /ɪ/), those which require the greatest degree of tongue movement against the forces of gravity, easily surpassed the Holm-Bonferroni corrected significance thresholds. The front mid-vowel /ɛ/, which had a p-value of .027, was very close to the Holm-Bonferroni threshold of .025, however the back mid-vowel /ʌ/ displayed significance (.011) despite the low significance threshold of .016. It is also unsurprising that the lowest vowel, /ae/, was furthest from achieving its unadjusted significance threshold of .05.

Although no measures of F2 produced significance levels below that of the Holm-Bonferroni corrected alpha, a general trend of vowel reduction towards the center can be observed between pre-flight and post-flight conditions, although mid-flight measurements did not show this trend consistently.

Unfortunately, not enough tokens containing the high back vowel /u/ and mid back vowel /o/ were obtained to compare to the high front vowels assessed. Thus a comparison of how backness interacts with vowel height was not possible in this preliminary analysis, but the authors plan to investigate this in future work.

5 Conclusion

The results of the formant analysis demonstrate that adaptation to changing gravity related to space travel may alter speech production. This further corroborates the anecdotal report by Chris Hadfield that astronauts learn to speak with a weightless tongue in space, and must adapt to Earth's gravitational forces upon return. As mechanical alteration to the speech production system is known to affect speech perception as well [4], it is reasonable to assume that astronauts' ability both to send and receive spoken information may be compromised during mission-crucial transitions in gravity.

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