The Effects of Microgravity on Tongue Height

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1 Introduction

A previous investigation comparing astronaut speech during and after the Apollo 11 mission reported a significant increase across all formants during microgravity exposure, which was interpreted as evidence the tongue is lower in the mouth during articulation in microgravity conditions [1]. However, the microgravity (space) condition speech used in this analysis was routed through telephone channels while the earth condition was not. As telephone speech is known to result in an increase to formant values [2], it is unclear whether any observed effect was due to microgravity or telephone bandwidths. Furthermore, comparing speech during and after microgravity exposure is problematic because adaptation effects to microgravity can be observed in the vowel space following prolonged exposure to microgravity [3]. Using higher quality audio from the STS-129 and 135 missions and linear mixed effects models, we compare the first vowel formant (F1) of two astronauts immediately before and during exposure to microgravity during space travel.

2 Methods

The North American Space Association (NASA) provides audio-logs for all missions through the public NASA audio archive (https ://archive.org/details/nasaaudiocollection). Audio files featuring speech from Charlie Hobaugh during the STS 129 and and Chris Ferguson during the STS 135 missions were selected. These files were chosen because they provide high quality audio interviews conducted preflight (serving as 1g condition data), and midflight (serving as microgravity condition data) by each Astronaut. All preflight condition speech was produced on Earth shortly before departure, and all midflight speech was produced aboard the International Space Station.

For each participant, approximately 90 seconds of speech were extracted from each condition for analysis. Each file was manually transcribed and subsequently assessed using semi-automated alignment and formant extraction via the Dartmouth Linguistic Automation suite (DARLA) [4], using the Montreal Forced Aligner [5] and FAVE-extract [6]. Stop-words were omitted from the analysis along with unstressed vowels and tokens where the formant bandwidth exceeded 300Hz. The quality of automatic alignment was verified manually for each file, and formant extraction values were examined for impossible values, of which none were observed. A total of 7 vowels met the selection criteria of providing at least ten tokens in each condition. Selected vowels and their counts in each condition are outlined in Table 1.

Table 1: Number of vowel tokens for each condition

	AA	AE	EH	EY	IY	OW	UW
Preflight	13	15	31	18	25	17	21
Midflight	14	26	29	38	28	20	11

A variable-slope linear mixed-effect model evaluating F1 was fit to the data in R [7] using the lme4 package [8] and the optimx optimizer [9]. This model was designed to evaluate the effect of condition (1g, microgravity) while controlling for the effect of speaker and vowel. Our model included random intercepts by speaker and vowel ; random slopes over condition by speaker and random slopes over condition by vowel. The corresponding lme4 formula in R is as follows :

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F1 ~ condition +
         (1 + condition | speaker) +
         (1 + condition | vowel)
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Statisistical significance of the main effect was calculated using a likelihood-ratio test comparing our model to one omitting the main effect of condition.

3 Results

Results of the linear mixed effects regression are outlined in Table 2. The first column denotes condition, while the second and third columns provide the F1 (in Hz) and standard error of the mean as calculated for each condition. Note that the mean F1 between conditions are similar, although standard error of the mean in the microgravity condition is substantially higher.

Table 2: F1 per condition as calculated via LMER

	F1 (Hz)	**St. Err**
Preflight	487.6	8.5
Midflight	491.2	38.6

The results of our LRT-based model comparison demonstrate that condition did not have a significant effect on F1 (χ^2 = 0.17, df = 1, p = 0.68). In other words, we found no evidence to support the claim that vowels are articulated lower in the mouth in microgravity conditions.

For illustrative purposes, a cross-conditional vowel plot illustrating the mean F1 and F2 of all vowel tokens for both speakers is provided in Figure 1. F1 is provided on the Y axis with values inverted, F2 is provided on the X axis. Midflight tokens are indicated in orange and preflight tokens in blue. Note that both height and backness of the vowel space does not differ noticeably between conditions.

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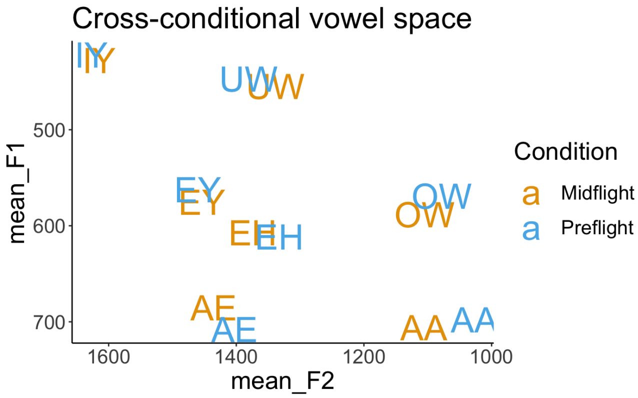

Figure 1: Cross-conditional vowel plot illustrating mean F1 and F2 for both speakers

4 Discussion and Conclusion

The results of our linear mixed effects model found no effect of microgravity on tongue height. Overall, no difference in vowel space could be observed for speech produced prior or during microgravity exposure. These results do not support previous observations of increased F1 (decreased tongue height) in microgravity conditions [1]. We note that the previous investigation used audio data from the Apollo 1969 moon landing mission. All in-flight audio in the Apollo 1969 missions was transmitted through telephone channels in Houston. Considering that previous work made use of speech routed through telephone channels in the microgravity condition, but not for the control condition, it is unsurprising that an increase to all formants was observed. A sharp increase to formants in telephone speech is a well-documented phenomenon known as the ”telephone effect” [2]. As the authors made no mention of controlling for the telephone effect, this remains the likeliest explanation for the discrepancy between our findings.

In the present study, microgravity condition speech was transmitted to earth from the ISS using satellite-broadcast Ku-band radio frequencies [10]. The high quality nature of this signal avoids the characteristic frequency warping of telephone speech.

We also note that [1] used speech from post-flight interviews as the control condition data. Recent work demonstrates speech following prolonged exposure to microgravity is characterized by a generalized lowering of the vowel space [3]. This reflects adaptation to microgravity conditions where articulatory effort to counteract gravity is not required.

5 Conclusions

Our results do not support previous work describing an increase to formants in microgravity conditions. An increase to formants observed in previous work was likely the result of telephone bandwidth alterations. We conclude that future investigations of astronaut speech must take care to ensure audio bandwidth is comparable across conditions, and that data serving as the control condition is taken prior to microgravity exposure rather than after.

Acknowledgments

This work was funded by NIH Grant DC-002717 awarded to the second author.

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