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Dialectal vs. Standard Arabic Formant Frequencies as Potential Forensic Phonetics Parameters

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Abstract

Formant frequencies are among the most commonly used and reliable parameters for forensic phonetics (FP) analysis (Lindh, 2006; Loakes, 2006), and they continue to be preferred to other parameters such as segment duration despite an ongoing debate as to which formants are the most robust. However, most previous work on the use of formants for FP examines data from languages with a relatively crowded vowel space, such as English, which exhibits vowel closeness more than languages with a tri-vowel system, such as Modern Standard Arabic (MSA). The current experimental study investigates the carry-over of formant frequencies from two distinct Arabic dialects, Najdi Arabic (NA) and Hejazi Arabic (HA), in the production of MSA by the speakers of those two respective dialects. This provides insight into the potential for utilizing the formant frequencies and formant spacing of long vowels as parameters in Arabic FP analysis. Forty single-gender (male) participants were divided into two numerically equal groups based on their dialectal background, NA vs. HA. The participants were asked to record a list of tokens that were carefully selected and judged to occur in both HA-NA dialectal Arabic and standard Arabic, albeit with barely recognizable phonological divergences. The data were gathered in two separate sessions (dialectal production and MSA production) for each group, with a lag period of three weeks between the two sessions. The findings show that the F1 and F2 of long vowels are promisingly robust in their ability to differentiate between NA and HA speakers producing their shared standard variety (i.e., MSA). Formant spacing in particular can thus be utilized as a potential parameter for Arabic FP profiling. As anticipated, formants for all three vowels, particularly the formants of /a:/ and /u:/ in NA and the formants of /a:/, /u:/, and /i:/ in HA, appeared to be carried over from the dialects to MSA production. This indicates that, despite the limited number of participants and dialects covered in this explorative study, there seems to be potential for utilizing formant frequencies as an FP parameter for MSA speakers' dialect profiling.

Keywords**:** *Modern Standard Arabic, dialectal Arabic, Formants, Forensic Phonetics*

Introduction

Forensic phonetics (FP) is the integration of phonetics and forensic science; specifically, FP is the application of general knowledge stemming from phonetics to law enforcement procedures, in which forensic evidence is collected from speech samples (Jessen 2008). Various FP domains have been utilized in law enforcement procedures as well as in academic research. *Forensic speaker identification* is probably the most significant domain in FP (Broeders 2001; Jessen 2008; Nolan 2007; Rose 2002). The feasibility of performing FP analyses and obtaining fruitful outcomes relies on the essential theory of forensic speaker identification, which states that every individual human's speech is unique and can be distinguished through FP analysis (Rose 2002). Vowel formants (F1, F2, F3, and F4) have been the most commonly used phonetic parameters in forensic speaker identification and have been a widely studied and documented feature in forensic phonetics (FP) analysis (e.g., Rose 2002). The first four formants of a vowel seem to be the most important formants in speaker identification, whereas higher formants than F4 might not be as effective as the lower ones (Lindh 2006). However, these claims have been challenged and debated. For instance, Rose (2002, p.231) argued that higher formants (F3 and up) are the most informative in speaker identification because they better reflect the unique characteristics of a speaker than lower formants. According to him, F3 provides useful information about vocal tract length, while F4 and F5 can provide information about a speaker's voice quality. However, Gold and French (2011, p.753) in a survey of international forensic speaker comparison/identification practices, reported that among forensic phoneticians who undertake vowels formant examination in their practice, 100% of them measure F2, 86% measure F1 as well as F3, and only 18% measure F4. Based on this survey, we can infer that F2 is the most effective and robust formant utilized in FP analysis, followed by F1 and F3, and F4 and above may not serve the desired FP outcome. Recently, Aldholmi (2022) observed that emphaticness (i.e., emphatic consonants) in Arabic presents a challenge for forensic linguists performing talker gender classification because emphatics appear to bias listeners' (especially native speakers') perception to the male voice.

Numerous studies in FP have been conducted, particularly in forensic speaker identification with data from various languages, each of which has been studied with special focus on its unique linguistic properties. However, to the best of our knowledge, the Arabic language still lacks such research, and studies that support Arabic FP scholarship are desperately needed. Researchers in the Arabic FP domain could thus target the *unique properties* of the Arabic language that have potential to provide insights into the utilization of Arabic phonetic features as a special parameter for forensic analysis. One of these features is Arabic's diglossia phenomenon, in which there is both a common Standard Arabic and regional dialects distributed among various Arab communities. This feature prompts an interesting inquiry about the possibility of some linguistic features being carried from a dialect to the standard counterpart. Hence, this study aims to investigate the inter- and intraspeaker variation of certain vocalic features in Modern Standard Arabic (MSA) as parameters in forensic speaker identification. Specifically, the study aims to investigate whether the variation of the acoustic features of F1, F2 and F3 formants in MSA spoken by Najdi (henceforth, NSA) or Hijazi (henceforth, HSA) can be attributed to speakers' dialectal background. This information can be obtained by evaluating and comparing the acoustically measured vocalic information of MSA to that of the target dialects. The findings should provide implications for forensic MSA speaker profiling. The proposed Saudi dialects in this study are two frequently studied dialects in the linguistics literature, NA and HA. These dialects also have large communities in Saudi Arabia, which means that the current research will serve as an unprecedented foundation for speaker profiling in Saudi Arabia.

Methodology

Stimuli

The stimuli consisted of 12 target CVCVC imperfective verbs that are commonly used in both MSA and the target dialects. These items were controlled in terms of both syntactic and phonetic environments that might affect the vowel quality being analyzed. The items were inserted into a carrier sentence (carrier stimulus) twice in two fixed positions, i.e., sentence-initially once and sentence-finally once. This approach allowed the researchers to control for prosodic factors that might affect vowel quality. The carrier stimulus is structured as follows (note that the blank indicates the position of the target words):

(1) Carrier sentence for the target words in the initial position:
__________ hija ʔaːχir/u kalimah/t-in samiʕtuhaː fi lmukaːlamah
__________it last-NOM word-F-GEN heard-1P-it in the-phone call
__________ 'is the last word I heard in the phone call.'

(2) Carrier sentence for the target words in the final position:
ʔaːχir/u kalimah/t-in samiʕtuhaː fi lmukaːlamah hija__________
last-NOM word-F-GEN heard-1P-it in the-phone call it___________
'The last word I heard in the phone call is'___________.

The target words are CVCVC forms, in which the target vowel is always the second one, such as /taχaːf/ 'you fear', /tafuːz/ 'you win', /taʁiːb/ 'you are absent'.

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(3) Carrier sentence for the target words in the initial position:
__________ hija ʔaːχir/u kalimah/t-in samiʕtuha: fi lmukaːlamah
__________it last-NOM word-F-GEN heard-1P-it in the-phone call
__________ 'is the last word I heard in the phone call.'

(4) Carrier sentence for the target words in the final position:
ʔaːχir/u kalimah/t-in samiʕtuha: fi lmukaːlamah hija_________
last-NOM word-F-GEN heard-1P-it in the-phone call it___________
'The last word I heard in the phone call is'__________.

The target words are CVCVC forms, in which the target vowel is always the second one, such as /taχaːf/ 'you fear', /tafuːz/ 'you win', /taʁiːb/ 'you are absent'.

Participants

All participants were either current or former university students, with ages ranging between 19 and 35. The participants were divided into two experimental groups according to their dialectal background (NA vs. HA): The first group consists of 20 native NA speakers, and the second group consists of 20 native HA speakers. Such division was assumed to make it possible to implement the MSA profiling experiment. During the recruitment procedure, the experimenters targeted participants who share as many characteristics as possible, such as age and monolingualism vs. bilingualism. All NA speakers were from the Riyadh region, having been raised and lived in the urban area, i.e., Riyadh city. This approach ensures that all speakers were native NA speakers who speak the urban, rather than the Bedouin, NA. Similarly, all HA speakers were from the Makkah region, having been raised and lived in the urban cities of Jeddah and Makkah, and thus they all speak the urban version of HA.

Data collection

The data collection was conducted in two groups: 1) NA participants and 2) HA participants. The recording of speech samples was performed in two sessions for each group. In the first session, we presented the dialect stimuli (the carrier sentence with the target words) to the participants. Each participant (individually) was asked to read the stimuli sentences aloud three times and was recorded via a high-quality recorder in a quiet room. In the second session, the same process was repeated using the MSA stimuli. The process began with the dialect to ensure that the presentation of MSA, which is the formal language variety, would not have a carryover effect on participants' production when recording in their dialects. We also allowed for a substantial period of time (lag) between the two sessions to avoid any sequential effects. We segmented all target words and extracted each vowel within the target words in the stimuli, using Praat software (Boersma & Weenink 2020). Then, we measured the F1, F2, and F3 frequencies for the dialects and MSA. The comparative analysis between NA and HA was implemented based on the frequencies and the formant spacing between F1 and F2, as well as between F2 and F3. Each formant's value was the frequency mean value calculated automatically by Praat. Finally, these measured data were analyzed statistically to obtain quantitative results, using a repeated-measures ANOVA.

Results and general discussion

NA vs. NSA results

The overarching results showed that within both NA and NSA, the formant means for each vowel were similar across the two varieties. For means comparison, the data were separated by *vowel* *type* and *formant type*, because these two factors play a major role in the determination of formant frequency values. Hence, for F1, the NA means are as follows: /aː/ (M = 622.79, SD = 28.16) /uː/ (M = 376.05, SD = 27.30); /iː/ (M = 348.43, SD = 36.17). NSA appears to have similar F1 means: /aː/ (M = 621.74, SD = 29.50); /uː/ (M = 377.14, SD = 32.76); /iː/ (M = 352.59, SD = 30.91). The F2 means for NA are as follows: /aː/ (M = 1327.84, SD = 69.30); /uː/ (M = 1118.40, SD = 90.36); /iː/ (M = 2225.10, SD = 147.24). For NSA, the F2 means are as follows: /aː/ (M = 1329.93, SD = 71.52); /uː/ (M = 1123.50, SD = 88.03); /iː/ (M = 2221.95, SD = 143.51). Both varieties also show a degree of similarity. Lastly, the F3 means for NA are as follows: /aː/ (M = 2413.68, SD = 112.09); /uː/ (M = 2470.07, SD = 119.69); /iː/ (M = 2771.89, SD = 178.91). Again, the F2 means for NSA are similar: /aː/ (M = 2415.92, SD = 108.34); /uː/ (M = 2475.78, SD = 123.21); /iː/ (M = 2777.14, SD = 175.63).

The main and interaction effects were tested by performing a repeated-measures ANOVA after ensuring that the test assumptions were met. The test reveals a main effect for *language variety* (NA vs. NSA) but with a small effect size, $F(1, 19) = 6.349$, $p = 0.021$, $\omega^2 = 0.250$. However, this interim result still necessitates further investigation to include *vowel type* and *formant type* factors. This is done by testing the three-way interaction between *language variety*, *vowel type*, and *formant type*. The test demonstrates a significant interaction among these factors, F (4, 76) = 3.588, $p = 0.010$, $\omega^2 = 0.159$. This three-way interaction result (*language variety*, *vowel type*, and *formant type*) must undergo further investigation regarding where specifically the significant interactions lie because this interaction contains a three-level vowel type factor (/aː/, /uː/, /iː/) and formant factor (F1, F2, F3). Therefore, we performed a repeated-measures *contrast* test. The test indicates that the significant interaction among *language variety*, *vowel type*, and *formant type* derives from the interaction between two vowels, namely, /uː/ (Level 2) and /iː/ (Level 3), which interact at all formant levels, i.e., between Level 1 (F1) and Level 2 (F2), $F(1, 19) = 11.915$, $p = 0.003$, $\omega^2 = 0.385$, and between Level 2 (F2) and Level 3 (F3), $F(1, 19) = 8.812$, $p = 0.008$, $\omega^2 = 0.317$. However, the vowels /aː/ (Level 1) and /uː/ (Level 2) showed no statistically significant interaction at all formant levels, i.e., between Level 1 (F1) and Level (F2), $p = 0.419$, and between Level 2 (F2) and Level 3 (F3), $p = 0.159$. This result means that NA and NSA share similar formants (F1, F2, and F3) within the vowels /aː/ and /uː/.

HA vs. HSA results

The result of the formant means for each vowel in both HA and HSA (combined) indicated that there is a degree of difference between these varieties; each vowel is simply different, which was predicted as each vowel is a phoneme in both HA and HSA. In contrast, when we compare HA results to HSA, the two varieties seem to show a proximal similarity. Below is the means comparison.

The F1 means for HA (/aː/: M = 677.51, SD = 37.07; /uː/: M = 427.09, SD = 30.87; /iː/: M = 345.78, SD = 39.30) showed close results to those for HSA (/aː/: M = 678.20, SD = 34.82; /uː/: M = 423.93, SD = 32.23; /iː/: M = 343.08, SD = 43.74). The F2 comparison means for HA (/aː/: M = 1288.43, SD = 88.96; /uː/: M = 988.31, SD = 73.88; /iː/: M = 2254.39, SD = 115.16) were also close to those for HSA (/aː/: M = 1291.35, SD = 93.63; /uː/: M = 985.07, SD = 78.94; /iː/: M = 2251.15, SD = 119.69). The last formant, F3, was also similar between HA and HSA. Compare the results for HA (/aː/: M = 2477.15, SD = 76.74; /uː/: M = 2378.95, SD = 126.48; /iː/: M = 2787.56, SD = 177.52) with those for HSA (/aː/: M = 2474.48, SD = 81.29; /uː/: M = 2382.37, SD = 130.74; /iː/: M = 2792.22, SD = 171.92).

To test the main and interaction effects, we performed a repeated-measures ANOVA. The test showed that *language variety* had no main effect, $p = 0.462$. This result suggested that there is no statistically significant difference between HA and HSA, but further investigation that includes the three-way interaction between *language variety*, *vowel type* and *formant type* factors is still needed, as these factors play an essential role in creating any potential difference. The results showed no statistically significant interaction, $p = 0.130$, indicating that HA and HSA likely share similar formants values; this result corroborates the initial results that showed an absence of a main effect for *language variety*.

Since our main focus is on language variety in relation to vowel type and formant type, the three-way interaction result must be investigated further, since it comprises three levels in the *vowel* *type* factor (/aː/, /uː/, /iː/) and in the *formant type* factor (F1, F2, F3). Accordingly, we performed a repeated-measures *contrast* test to investigate any possible level of a significant interaction effect. The test confirmed the initial result and showed no statistically significant interaction at all levels. Specifically, there was no significant interaction between the vowels /aː/ (Level 1) and /uː/ (Level 2) at all formant levels, i.e., between Level 1 (F1) and Level 2 (F2), $p = 0.387$, and between Level 2 (F2) and Level 3 (F3), $p = 0.207$. Furthermore, there was no significant interaction between the vowels /uː/ (Level 2) and /iː/ (Level 3) at all formant levels, i.e., between Level 1 (F1) and Level (F2), $p = 0.087$, and between Level 2 (F2) and Level 3 (F3), $p = 0.214$. This result indicates that the formants F1, F2, and F3 of the vowels /aː/, /uː/, /iː/ appear to have similar values in HA and HSA.

NA vs. HA comparison results

The comparison between NA and HA aimed to determine whether they differ in terms of long vowels' formants. This data provides us with provisional information about the possibility of using long vowel formants as a parameter in FP, specifically, in FP profiling. To do this comparison, we measured the formant spacing between F1 and F2 (known as compact-diffuse in the literature, e.g., Kent & Vorperian 2018) and between F2 and F3, and then implemented the comparison based on these variables.

The first formant spacing (F1-F2) overall means for NA (M = 1107.397, SD = 97.15) were similar to those for NSA (M = 1108.369, SD = 96.35), whereas they appear to differ for HA (M = 1027.284, SD = 80), which is very similar to its standard counterpart HSA (M = 1027.378, SD = 79.21). To test the first formant spacing difference between NA and HA dialects, we performed a repeated-measures ANOVA test that used NA vs. HA as a between-subject independent factor and formant spacing value as a dependent variable. The test showed a statistically significant difference between NA and HA with a medium effect size, $F(1, 38) = 22.836$, $p < 0.001$, $\omega^2 = 0.375$. A within-subjects test also showed a statistically significant effect for the interaction between vowel type and NA vs. HA with a medium effect size, $F(2, 76) = 18.497$, $p < 0.001$, $\omega^2 = 0.327$. This result indicated that the two dialects differ in terms of vowel-type formants, which adds a positive indication to the previous between-subjects test.

The second formant spacing (F2-F3) overall means for NA (M = 997.40, SD = 127.46) were similar to those for NSA (M = 996.75, SD = 128.13), and the means for HA (M = 1036.92, SD = 139.17) and HSA (M = 1037.82, SD = 138.34) reflected a slight difference from NA and NSA. The difference between NA and HA in terms of the second formant spacing was tested with a repeated-measures ANOVA, using the same between-subject and within-subject factors as above. The test revealed no statistically significant difference for second formant spacing, $p = 0.142$. The within-subjects test revealed no significant interaction between vowel type and NA vs. HA, $p = 0.107$. This result confirmed that F2-F3 formant spacing does not create a significant difference between NA and HA.

General discussion

The study investigated the three formant frequencies F1, F2, and F3 of the long vowels /aː/, /uː/, and /iː/ in each dialect and compared the findings to each one's MSA counterpart through the appropriate statistical tests. Formants have been studied extensively in a number of languages and have shown promising results; therefore, they appear to be the most favorable parameter in FP (e.g., Kent & Vorperian 2018; Lindh 2006; Loakes 2006; Nolan 2002; Rose 2002).

The current study found that NA speakers produce similar long vowel formants when they speak MSA. Nonetheless, the significant main effect for *language variety* and the significant interaction of the three-way factors – *language variety, vowel type,* and *formant type* – necessitated contrast testing for the sake of precision. The contrast test revealed the origins of the differences and similarities and showed that the similarity between NA and its MSA came from /aː/ and /uː/. Accordingly, /iː/ formants should be excluded from the NA FP profiling of MSA speakers. HA speakers also demonstrated similar formant frequencies when they speak MSA. Moreover, there were no significant interactions between the *language variety, vowel type,* and *formant type* factors, nor did the contrast tests show any significant interactions. These results thus confirm that HA speakers produce similar formants of the three long vowels when they speak MSA.

A comparison was then performed using the more sensitive variable of formant spacing. According to Kent and Vorperian (2018, p.91), this dynamic parameter can be more informative. The first formant spacing (F1-F2) revealed a significant difference between NA and HA, whereas the second (F2-F3) did not. Thus, F1-F2 spacing is an effective parameter that could successfully differentiate between NA and HA speakers, which can be explained by the fact that vowels are universally captured by F1 and F2 (Leuzzi et al. 2016). Moreover, Kent and Vorperian (2018, p.81) stated that F1 and F2 are the most commonly used formants in speech science studies. Alghamdi (1998, p.6) compared the vocalic information of three Arabic dialects and concluded that in terms of vowel quality difference, F1 was the main parameter that captured the significant difference among the three dialects and thus could have positive implications for dialect identification. In addition, numerous FP studies have emphasized the potential of the F2 formant as a parameter. Gold and French (2011, p.753) stated that F2 is the most widely used parameter in FP. Likewise, Nolan (2002, p.78) argued that F2 is the most effective FP parameter in terms of robustness. The current finding corroborates the well-established notion of the importance and effectiveness of F1 and F2 formants in the field of FP.

In this study, the formants of the long vowels in the two dialects appeared to extend to the standard variety, i.e., MSA. The phenomenon of dialect-to-standard traces has been discussed in some studies, which have claimed that regional dialects can penetrate the standard variety and leave certain linguistic traces on it, most of which are phonetic (e.g., Grondelaers, Hout, & Steegs 2010; Harst, Velde, & Hout 2014). This interesting aspect should be further investigated by including other Arabic dialects as well as other phonetic parameters in studies that seek to determine which phonetic parameters are carried over to MSA and to what extent they are significant. Such studies will contribute to the under-researched field of Arabic FP studies. In an attempt to be as precise and cautious as possible and to be consistent with the FP parameter requirements suggested by Nolan (1983, p.11), we may draw a generalization that works for both dialects that incorporates two key findings. First, F1 and F2 appeared to be the significant variables in difference between NA and HA. Second, /iː/ showed a degree of variability between NA and NSA, meaning that it is prone to change and not sufficiently robust for FP and thus should be excluded. This leaves us with the following preliminary conclusion: The promising effective formant parameters in NA and HA FP profiling and comparison are F1 and F2 of the vowels /aː/ and /uː/.

Conclusion

The parameter used was formant frequencies of long vowels (F1, F2, and F3), which was motivated by the promising potential of formant parameters in FP found in other studies. The observed differences between NA and HA and the standard variety (MSA) led to the following hypotheses: a) that there might be specific vocalic information that is sufficiently unique to each dialectal variety to make it a promising FP parameter candidate, and b) that there might be an aspect of dialect-to-standard phonetic carryover that could be a good FP profiling parameter. Overall, the conclusion that arises from this study is that long vowel formants are promising candidates since they successfully differentiated between NA and HA, and both dialects carry over their formant measurements to the standard variety, MSA. More specifically, the promising effective formants parameters were F1 and F2 of the vowels /aː/ and /uː/. This finding suggests that FP practitioners and researchers should pay attention to the potential of utilizing the F1 and F2 of long vowels to yield significant outcomes.

It is recommended for future studies to extend the current study to include other formants as well as other dialectal varieties of Arabic. Moreover, it would be ideal to conduct similar studies with a larger sample size to produce more robust results and, consequently, a generalizable conclusion.

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