Consonant-vowel Interactions Inform Paradigm Organization in Egyptian Arabic

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1 Introduction

In this paper, I present a quantitative study on vowel alternation in Egyptian Arabic verbs. Specifically, the vowels in perfective verb forms (of the prosodic shape CVCVC) and imperfective verb forms (-CCVC) are hard to predict from each other. Examples of alternating and non-alternating verbs are shown below.

(1)	a. [kasar]	'break-perfective'	[-ksar]	'break.imperfective'
	b. [χarag]	'go out.perfective'	[-χrug]	'go out.imperfective'
	c. [rigiʕ]	'return.perfective'	[-rgaʕ]	'return.imperfective'
	d. [libis]	'dress.perfective'	[-lbis]	'dress.imperfective'

This study investigates how probabilistic phonological generalizations involving the root consonants and vowel correspondences help predict the idiosyncratic vowel choice by collecting lexicon statistics and fitting regression models. Following the line of works which has shown that speakers have the ability to internalize statistical patterns into their phonological grammars (e.g., Zuraw 2000, Ernestus & Baayen 2003), the models were used as a means to investigate organization of the perfective-imperfective paradigm. Moreover, by showing that consonant and vowel information play distinct roles in paradigm predictability, this study provides evidence for lexical representations that separate consonants and vowels in Semitic languages (e.g., McCarthy 1979). Quantitative studies on vowel alternation in colloquial varieties of Arabic are rare, and this paper is the first that addresses both paradigm structure and lexical representation.

1.1 *Wazn I verbs* The verbs investigated in this paper are the so-called wazn I verbs in the Arabic verbal system. The term *wazn* (pl. *awzaan*; also called word pattern, form, measure, or binyan) refers to a fixed prosodic template associated with certain morphosyntactic and semantic properties in Arabic. Compared to other verbal awzaan (see Appendix), wazn I verbs are described as the non-derived or basic wazn since they have the simplest morphology and have no unifying morphosyntactic or semantic properties. All other awzaan can be analyzed as deriving from wazn I (e.g., McCarthy 1993).

Wazn I is also unique in having idiosyncratic vowel alternations between perfective and imperfective forms, whereas other awzaan typically have one unique vowel pattern which does not alternate. Surveys and quantitative studies on several Arabic dialects report effects of root consonants on vowel choices which range from gradient (Egyptian: Abdel-Massih et al. 1979; Modern Standard: McCarthy 1994; Hijazi: Ahyad 2019, Ahyad & Becker 2020) to categorical (Muslim Baghdad: Blanc 1964; Palestinian: Herzallah 1990). Predictive generalizations can also be made over the vowels of the two forms (McOmber 1995 on Modern Standard).

The vowel alternation pattern found in wazn I verbs is theoretically interesting in two ways. First, the derivational relationship between perfective and imperfective forms in Arabic is controversial; while most

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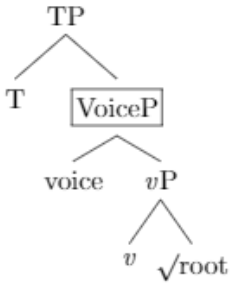
works treat the perfective as the base from which imperfective verbs are formed, others have presented counter-evidence showing that using the imperfective as the base yields better predictability (e.g., McOmber 1995). Investigating output-output correspondence relations between the vowels in the perfective and the imperfective should offer insight on paradigm organization. Second, the partial dependency of vowel choice on root consonants found in these verbs provides a good test case for the status of lexical representations that separate vowels and consonants in Semitic morphology. These representations were famously formulized in McCarthy's (1979, 1981) analysis of Arabic morphology, where consonantal roots and vocalic patterns are interwoven non-concatenatively and fitted into prosodic templates. For example, [katab] 'he wrote' can be analyzed as being composed from the root *k-t-b*, denoting the general meaning of 'writing', the vowel pattern *a*, denoting active voice, and the template *CVCVC*, denoting non-derived perfective verbs. Evidence for the psychological reality of these representations also comes from psycholinguistic works (Boudelaa and Marslen-Wilson 2013, 2015). However, other studies have shown that certain phenomena in Semitic morphology can only be accounted for with output-output correspondences, leaving no role for these abstract morphemes (Bat-El 1994, Ussishkin 1999). Investigating to what extent and in what ways the wazn I vowels might be predictable from root consonants lends insight to lexical representations.

1.2 *Perfective and imperfective* Understanding the syntactic structure of the so-called perfective and imperfective forms in Arabic is relevant for studying their morphological relationships. While both forms are often treated as tense/aspect forms, there is evidence that the imperfective should actually be treated as the infinitive form. Benmamoun (1999) shows that in many Arabic dialects including Egyptian, the perfective form of the verb is always used in past tense clauses, whereas the imperfective form can occur in a wide range of contexts, generally after some other particle that conveys tense information (e.g., *ha-* for future). He concludes that the imperfective verb itself is not specified for tense; perfective verbs, on the other hand, are specified for past tense. Acquisition studies offer additional support for the status of the imperfective as the infinitive form. Aljenaie (2010) found that Kuwaiti children in the age range of 1;8-3;1 use the bare imperfective stem as a non-finite form (see also Omar 1973).

In a morphological framework like Distributed Morphology (Halle & Marantz 1993), in which word-formation is a syntactic process, the above results lend evidence to a structure where the Arabic imperfective is used as the input to derive the perfective, which has a more complex morphosyntactic structure that includes the tense head and its projection. A sketch of Arabic clausal structure, adapted from Tucker (2011), is shown in (2).

(2)



The functional head *v* combines with a root to form a verb, which is then selected by a voice head. Since the imperfective verb always combines with other elements that carry tense information, its structure should not include T but only VoiceP (boxed).[1] On the other hand, the perfective verb is always inflected for past tense, which means that its structure should also include a past tense T head.

[1] The structure of the imperfective should also include aspectual and agreement projections, which are not discussed here, but the crucial difference compared to the perfective is the inclusion of T.

2 Lexicon study

2.1 *Data collection* A corpus of 330 wazn I verbs in Egyptian Arabic was compiled. Only words with the prosodic shape CVCVC in the perfective (traditionally known as sound verbs) were included. The words were extracted from the online dictionary Lisaan Masri (Green 2007) and later checked with a native speaker, Fatema Shokr, over the course of several virtual meetings.

The breakdown of the corpus by vowel alternation pattern is shown below. The perfective vowel can be [a] or [i], and the vowels in the two syllables (C**V**C**V**C) must be identical. The imperfective stem vowel (-CC**V**C) can be [a], [i], or [u]. Note that the imperfective stems occur with an agreement prefix. The prefix vowel is generally [i] but can undergo optional harmony when the stem vowel is [u]. All combinations of vowels in the two forms are attested, though perfective-[i]/imperfective-[u] is very rare.

	Perfective	Imperfective	Meaning	Count
a/a	kasar	ji-ksar	'break'	71
a/i	katab	ji-ktib	'write'	30
a/u	χarag	ji/ju-χrug	'go out'	67
i/a	rigiʕ	ji-rgaʕ	'return'	89
i/i	libis	ji-lbis	'dress'	66
i/u	sikin	ji/ju-skun	'live'	7

Table 1. Breakdown of corpus by vowel alternation type (a total of 330 verbs); in 3sg masculine form

The focus of this study is on colloquial Arabic spoken in Cairo, Egypt. One factor to consider is that Modern Standard Arabic is used alongside the colloquial language, where the former is typically associated with formal contexts (Ferguson 1959, Eid 2007). To control for the differences in the morphophonology of these two varieties of Arabic, verbs that had clear features of Modern Standard Arabic (e.g., having [a] in the imperfective agreement prefix, as in [sabat]/[ja-sbat] 'to be proven') were excluded.

2.2 *Modeling* Logistic regression models with vowel and consonant predictors were fitted using the *nnet* package in R (Venables & Ripley 2002, R Core Team 2020). The goals of modeling are 1) to assess the predictability of perfective and imperfective vowels based on phonological factors and 2) to investigate paradigm structure. Vowel predictors based on the vowels in the form other than the one that the model predicts were used to investigate whether vowel-to-vowel correspondence in the paradigm plays any role. The consonant predictors assess whether a consonant with a particular place of articulation is present in the word; they were used to investigate whether avoidance of more marked consonant-vowel co-occurrences has an effect. Place of articulation was chosen to be the main consonant property investigated because consonant effects on vowel alternations in other dialects generally involve place features (e.g., Ahyad & Becker 2020). The place of articulation classes are listed below.

labial	plain alveolar	pharyngealized alveolar[2]	palatal	velar	uvular	pharyngeal	glottal
b,f,m	t,d,s,z,n,l	tˤ,dˤ,sˤ,zˤ,r	ʃ	k,g	q,χ,ʁ	ħ,ʕ	ʔ,h

Table 2. Consonant natural classes by place of articulation.[3]

In the imperfective forms (-$C_1C_2VC_3$), the second and the third root consonants are directly adjacent to the vowel, so one might expect stronger effects for them compared to the first consonant. To test this, I ran models with positional consonant predictors, which specifies whether a given natural class is present in each of the three positions in the consonantal root. However, because of the relatively small sample size, the models with positional predictors overfitted and thus were not informative. I will briefly return to this issue of consonant position when discussing the results below.

[2] /r/ is included with the pharyngealized alveolars because they pattern together in phonological processes such as pharyngealization, also known as emphasis spreading (Younes 1994, Watson 2002).

[3] This table includes all consonants in Egyptian Arabic except for the two glides {j,w}. The reason is that verbs which contain glides as root consonants generally have different prosodic shapes and different vowel patterns.

2.3 *Predicting the perfective* Vowel-to-vowel correspondences may play a role in predicting the perfective vowel. As shown in Table 3, while the distribution of [a]- and [i]-imperfectives is even, the breakdown of perfective vowel choice for each imperfective vowel differs. There is a strong preference for [a]-perfectives (91%) when the imperfective vowel is [u]. When the imperfective vowel is [i] or [a], there are moderate preferences for [i]-perfectives (69% and 56%, respectively).

		Imp. V			
		a	i	u	Total
Perf. V	a	71 (44%)	30 (31%)	67 (91%)	168 (51%)
	i	89 (56%)	66 (69%)	7 (9%)	162 (49%)
	Total	160 (48%)	96 (29%)	74 (22%)	

Table 3. Perfective and imperfective vowel frequencies in sound verbs.

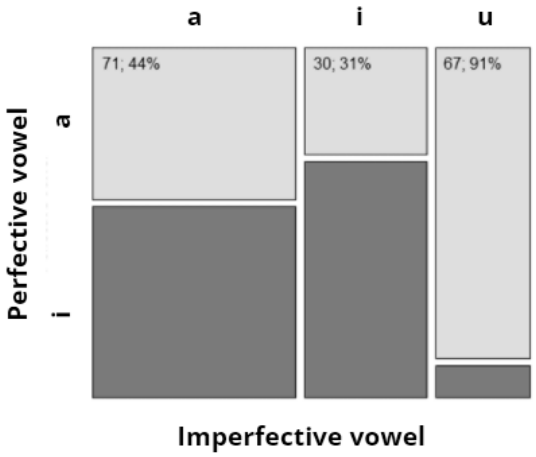


Figure 1. Breakdown of perfective vowel by imperfective vowel for sound verbs.

On the other hand, perfective vowel choice does not seem to be influenced by consonant place of articulation, as shown below. Note that since the presence of a certain class of consonants is recorded for each of the three root positions, each verb is represented three times. Having a root consonant of a particular place of articulation tends not to bias the perfective vowel distribution away from the overall distribution. While pharyngealized alveolars, palatals and uvulars show preferences for [a], the sizes of the effects are quite small.

	a	i
labial	90 (51%)	88 (49%)
plain alveolar	128 (45%)	155 (55%)
pharyng. alveolar	107 (60%)	71 (40%)
palatal	23 (66%)	12 (34%)
velar	24 (44%)	31 (56%)
uvular	34 (68%)	16 (32%)
pharyngeal	59 (47%)	66 (53%)
glottal	39 (48%)	42 (52%)
Total	(51%)	(49%)

Table 4. Effects of consonant natural classes on perfective vowel distribution in sound verbs.

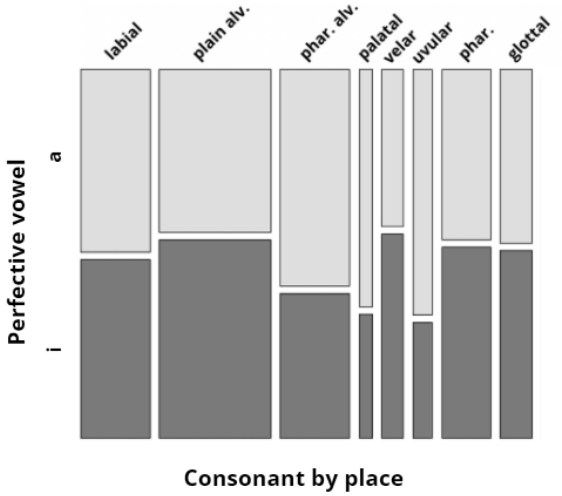


Figure 2. Effects of consonant natural classes on perfective vowel distribution in sound verbs.

A gross inspection of vowel distribution when certain consonants are found in specific positions likewise shows little effects. For example, perfectives that have a pharyngeal as the first root consonant have [a] 44% of the time. This number is 46% if the pharyngeal is the second consonant and 51% if it's the third.

These two observations (that vowel-to-vowel correspondences influence perfective vowel choice and that consonant-vowel co-occurrences do not) are borne out by the regression model, as shown in Table 5. Note that positive coefficients indicate a preference for [i]-perfectives, whereas negative coefficients indicate a preference for [a]-perfectives.

Predictors	Coefficients	p	
imperfective [i]	0.596	0.043	*
velar	0.467	0.175	
plain alveolar	0.255	0.275	
pharyng. alveolar	0.184	0.436	
glottal	0.139	0.633	
labial	-0.023	0.920	
pharyngeal	-0.128	0.596	
palatal	-0.323	0.438	
uvular	-0.653	0.075	.
imperfective [u]	-2.469	0.000	***

Table 5. Imperfective-to-perfective model for sound verbs. Residual Deviance: 378.35, AIC: 398.35; Pseudo R^2: McFadden 0.173, CoxSnell 0.213, Nagelkerke 0.284; Cross validation accuracy: 0.639

Having [u] as the imperfective vowel results in a large preference for [a]-perfectives. The moderate preference for [i]-perfectives when there is [i] in the imperfective is also found to be significant. These two vowel predictors, however, are the only predictors that are significant in the model. None of the consonant biases contributes to predicting the perfective vowel.

2.4 *Predicting the imperfective* As shown in Table 3 and Figure 1 above, imperfective vowel choices also show sensitivity to vowel-to-vowel correspondences. Notably, there is a preference for [u]-imperfectives when the perfective vowel is [a], which mirrors the preference in the other direction – imperfective [u] predicts perfective [a].

Turning to consonant effects, the imperfective vowel distributions for specific consonant places of articulation show a great deal of divergence. The presence of pharyngeal and glottal root consonants is associated with more [a]-imperfectives (70% and 60%, respectively), labials and plain alveolars with more [i]-imperfectives (37% for both), and pharyngealized alveolars with more [u]-imperfectives (36%).

	a	i	u
labial	73 (41%)	66 (37%)	39 (22%)
plain alveolar	130 (46%)	104 (37%)	49 (17%)
pharyng. alveolar	83 (47%)	31 (17%)	64 (36%)
palatal	14 (40%)	8 (23%)	13 (37%)
velar	21 (38%)	20 (36%)	14 (25%)
uvular	21 (42%)	13 (26%)	16 (32%)
pharyngeal	87 (70%)	28 (22%)	10 (8%)
glottal	49 (60%)	15 (19%)	17 (21%)
Total	(49%)	(29%)	(22%)

Table 6. Effects of consonant natural classes on imperfective vowel distribution in sound verbs.

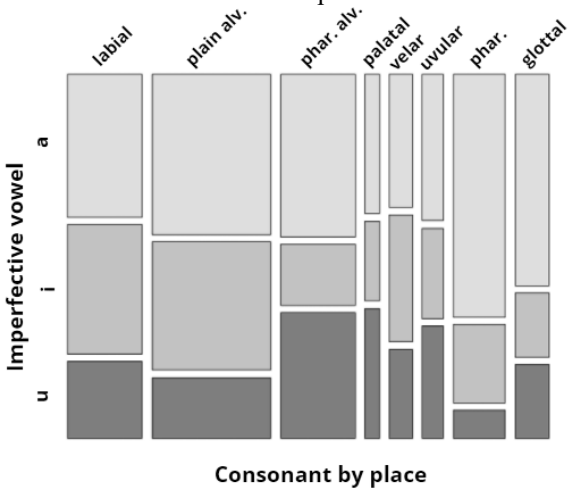


Figure 3. Effects of consonant natural classes on imperfective vowel distribution in sound verbs.

The regression model predicting imperfective vowels is shown below. Since there are three possible imperfective vowels, the model shows pairwise comparisons for [i] vs. [a] and [u] vs. [a]. Positive coefficients indicate preferences for [i]- or [u]-imperfectives compared to [a].

	Predictors	Coefficients	p	
i vs. a	**labial**	0.854	0.001	**
	plain alveolar	0.559	0.034	*
	velar	0.356	0.335	
	palatal	-0.014	0.979	
	uvular	-0.364	0.401	
	perfective [a]	-0.496	0.108	
	pharyng. alveolar	-0.846	0.003	**
	glottal	-1.315	0.000	***
	pharyngeal	-1.601	0.000	***
u vs. a	**perfective [a]**	2.594	0.000	***
	velar	0.007	0.988	
	pharyng. alveolar	-0.118	0.715	
	palatal	-0.275	0.583	
	labial	-0.811	0.017	*
	plain alveolar	-1.022	0.002	**
	uvular	-1.043	0.020	*
	glottal	-1.530	0.000	***
	pharyngeal	-2.884	0.000	***

Table 7. Perfective-to-imperfective model for sound verbs. Residual Deviance: 515.22, AIC: 551.22; Pseudo R^2: McFadden 0.253, CoxSnell 0.411, Nagelkerke 0.469; Cross validation accuracy: 0.606

Consonant predictors make a substantial contribution in this model, consistent with the various consonantal effects discussed above. Moreover, these effects are well-motivated phonetically. Pharyngeal and glottals strongly favor [a]-imperfectives relative to both [i] and [u], and uvulars strongly favor [a] over [u]. These observations are consistent with McCarthy's (1994) finding that pharyngeals, glottals and uvulars in Semitic languages often induce vowel lowering and favor [a] in the imperfectives of Modern Standard Arabic wazn I verbs. These consonants involve retraction of the tongue root, which creates an affinity for low vowels. Pharyngealized alveolars strongly favor [a] over [i] but are neutral between [a] and [u]. Since pharyngealized alveolars also involve tongue root retraction and have the effect of lowering the F2 of surrounding vowels (Norlin 1987, Laufer & Baer 1988, McCarthy 1994), it is more natural for [a] and [u] to occur in their proximity than [i].

A gross inspection of vowel distribution based on the presence of consonants in specific positions show striking positional effects for pharyngeals. The table below shows that the preference for [a]-imperfective is very strong in verbs that have a pharyngeal immediately next to the imperfective vowel (as C2 or C3) but is absent in verbs that have these consonants as C1.

		a	i	u
pharyngeal	C_1	15 (33%)	21 (47%)	9 (20%)
	C_2	29 (78%)	7 (19%)	1 (3%)
	C_3	43 (100%)	0 (0%)	0 (0%)
	Total:	*87 (70%)*	*28 (22%)*	*10 (8%)*
pharyngealized alveolar	C_1	23 (53%)	8 (19%)	12 (28%)
	C_2	35 (45%)	15 (19%)	27 (35%)
	C_3	25 (43%)	8 (14%)	25 (43%)
	Total:	*83 (47%)*	*31 (17%)*	*64 (36%)*

Table 8. Effects of consonant natural classes by position in sound verb imperfectives: pharyngeals and pharyngealized alveolars.

Interestingly, strong effects of consonant position are not found in verbs with a pharyngealized alveolar. The vowel distribution, which shows a preference for [a] and [u] over [i], remains fairly stable regardless of the position of the pharyngealized alveolar in the root. One possible reason is that pharyngealized alveolars tend to influence vowel qualities across the entire word, rather than just locally (e.g., Watson 2002).

2.5 *Comparing the models* The two models' goodness-of-fit is then compared with k-fold cross-validation (k=5). The dataset was randomly divided into 5 parts, and each model was run on 4 of the parts and tested on the other. This process was repeated for all 5 parts, and the average model accuracy from all the trials was calculated by comparing the model predictions on the testing data in each run with the corpus. The imperfective-to-perfective model had an higher average accuracy (0.639) than the perfective-to-imperfective model (0.606), but the difference is very small.

The two models were also compared to chance-level performance. The perfective-to-imperfective model should be compared to a baseline accuracy rate of 0.33 since there are three imperfective vowel choices, whereas the imperfective-to-perfective model, choosing between two alternatives, should be compared to a baseline accuracy rate of 0.5. The perfective-to-imperfective model clearly has greater improvement in predictive power (0.33 to 0.606), compared to the imperfective-to-perfective model (0.5 to 0.639). This intuition is supported by Pseudo R^2 measures. Since the two models predict different dependent variables, they cannot be directly compared with AIC or likelihood measures, and Pseudo R^2 measures are appropriate. All three Pseudo R^2 measures (McFadden, Cox & Snell and Nagelkerke) were higher for the perfective-to-imperfective model, which suggests that it is superior in terms of model fit.

3 Discussion

In summary, the modeling results show that both perfective and imperfective vowels are partially predictable from vowel correspondences and consonant-vowel co-occurrences.[4] The two models instantiating the two paradigm directions had comparable overall accuracy in their predictions, though the perfective-to-imperfective model shows greater improvement from chance-level performance.

The crucial difference between the models lies in the types of phonological factors that are relevant when predicting the vowel in different forms. The imperfective vowel can be predicted based primarily on the consonant predictors, in ways governed by the phonological naturalness of consonant-vowel combinations, while a minor role is played by correspondences to the perfective vowel. The perfective vowel can be predicted based solely on the imperfective vowel, and consonant predictors played no role.

Note that since both models achieve only partial predictability, at least some verb forms must be memorized. However, the asymmetry in the presence of phonologically natural consonant-vowel interactions suggests that there are different mechanisms at play in the formation of imperfectives compared to perfectives, rendering a memorization-only account unsatisfactory. This asymmetry is puzzling given that the phonological environments with respect to consonants and vowels are very similar across both the perfective (CVCVC) and imperfective (-CCVC) forms.

3.1 *Surface-based accounts* The modeling results show that using surface-based correspondence results in relative success in predicting wazn I verbal forms. Notably, in both models, the correspondence between perfective [a] and imperfective [u] is salient and contributes significantly to vowel predictability. These results suggest the possibility that speakers learn bidirectional mappings, consistent with the proposal by Bochner (1993) that predictive generalizations in paradigms are often multidirectional.

Based on the distinct sources of predictability that are active in the two models, one might also consider a single-base analysis, consistent with the hypothesis by Albright (2002), which is that learners select a single most informative paradigm form as the derivational base. The prediction of the perfective vowel relies on two generalizations: 1) [a] if imperfective is [u]; and 2) [i] if imperfective is [i]. As a result, the model prediction is largely biased, having perfect accuracy rates in some categories of vowel alternations but extremely poor performance in others. The prediction of imperfective vowels, on the other hand, relies on phonologically natural constraints related to consonant-vowel interactions. Taken together, these results suggest that the perfective is a better candidate to function as the inflectional base compared to the imperfective. In terms of model fit (shown by Pseudo-R^2 metrics), the perfective-to-imperfective model was also shown to result in more improvement from the null model.

3.2 *Separation of vowels and consonants* Neither the bidirectional nor the perfective-as-base account, however, offers a satisfying explanation for the finding that consonant-vowel interactions governed by phonological naturalness only affect vowel choice in the imperfective. As noted above, this asymmetry cannot be explained by differences in phonological environments, since the perfective (CVCVC) and the imperfective (-CCVC) are very similar in this respect.[5]

Most previous works on the wazn I vowel alternation in Arabic dialects discuss consonant effects on the imperfective vowel, but not the perfective (cf. Blanc 1964). For example, Ahyad (2019) and Ahyad & Becker (2020) found preference for imperfective [a] with pharyngeals and for [u] with pharyngealized alveolars, which mirrors the findings in this study. While they did not discuss the predictability of the perfective vowel, a look at their corpus finds little consonantal effects. The overall distribution of perfective vowels in Hijazi is 73% [a] to 27% [i]. This percentage is 69%/31% in the presence of a pharyngeal and

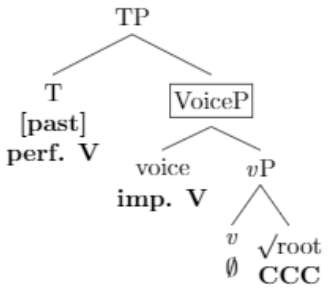
[4] A semantic property (specifically stativity) has been reported to contribute to vowel predictability in Modern Standard Arabic (McCarthy 1994). This corpus also shows gradient effects of transitivity in Egyptian Arabic. Transitive verbs are more likely to have perfective [a] (58%) than intransitives (34%). Opposite trends are found with imperfective [a] (40% if transitive, 69% if intransitive). More detailed work on the effects of morphosyntactic and semantic factors on this vowel alternation pattern is needed.

[5] Ahyad & Becker (2020) argue for a word-based approach based on the evidence that consonants condition imperfective vowels in Hijazi Arabic, but their argument also does not account for the lack of similar effects in the perfective.

76%/24% in the presence of a pharyngealized alveolar, neither of which deviates greatly from the overall distribution. Future work is needed to establish whether the asymmetry regarding consonantal effects indeed holds across Arabic dialects.

3.3 *A serial derivation analysis* I will show that a serial derivation analysis under the framework of Distributed Morphology (Halle & Marantz 1993) aligns with the modeling results and also accounts for the issues discussed above. Under this analysis, the consonantal root, the imperfective vowel and the perfective vowel are all treated as separate morphemes. This analysis is illustrated in (3).

(3)



In this structure, the consonantal root first combines with the functional head *v*, before combining with the imperfective vowel to form the imperfective. According to the view that the imperfective in Arabic is the default (infinitive) form of the verb not specified for tense (section 1.2), this form would originate fairly low in the syntactic structure. The imperfective vowel is merged at the voice head, following Arad's (2005) proposal for Hebrew. The perfective vowel, however, merges in at the T head, consistent with the observation that the perfective always conveys past tense (Benmamoun 1999).

With this structure, the absence of consonant-vowel interactions in the perfective form follows from independently proposed syntactic locality constraints, which disallow allomorph selection between any two elements that are separated by other overt material in the morphosyntactic structure (Embick 2010). Since the consonantal root merges with the imperfective vowel first, it is possible for phonological interactions between consonants and vowels to influence the imperfective form. Further, since the perfective vowel is structurally closer to the imperfective vowel than to the consonantal root, it follows that vowel predictors were the only ones that contributed in the imperfective-to-perfective models.

Consider the following example. To form the imperfective form of 'return', [rgaʕ], the consonantal root *r-g-ʕ* first selects [a] as the imperfective vowel, with avoidance of a marked phonotactic structure (namely, a high vowel next to a pharyngeal consonant) as the motivating factor. This happens below the VoiceP level. The imperfective form can then be used as the input to form the perfective form [rigiʕ]. Due to locality restrictions, phonological information of the lowest embedded morpheme, the consonantal root, is no longer accessible. The selection of [i] as the perfective vowel is based on other factors. While the probabilistic correspondences between imperfective and perfective vowels found in this study do not include one that favors perfective [i] when the imperfective has [a], there are some possible explanations that can be further tested. One is that [i] is emerging as the default perfective vowel in Egyptian Arabic. My native speaker consultant reports that a few words borrowed from Modern Standard Arabic that have now become common in colloquial speech undergo a change in the perfective vowel from [a] to [i]. Another possibility is that transitivity influences perfective vowel choice (see fn. 5).

Recall that in the perfective-to-imperfective model, the perfective vowel predictors played a minor role compared to the consonant predictors, suggesting that it may be possible to predict the imperfective from the consonantal root alone. On the other hand, predicting the perfective seems only to be sensitive to the imperfective vowel. Since the vowel predictors contributed significantly to the perfective-to-imperfective model, predicting the imperfective from consonantal roots alone will surely yield less accurate predictions. However, this sacrifice of predictability may be justified, since it aligns with wug test results in Ahyad (2019) that showed that Hijazi speakers actually do not utilize salient distributional information about the perfective vowel when forming the imperfective. Consonant-vowel interactions, on the other hand, such as the preference of pharyngeals for imperfective [a], were mirrored in wug test responses.

This analysis also aligns with the cross-linguistic pattern in which phonotactic restrictions seem to be stricter in smaller morphological domains, for example, in roots as opposed to morphologically complex words (Gouskova 2018). In Egyptian Arabic wazn I verbs, avoidance of phonotactically marked consonant-vowel sequences is much stronger in imperfective than perfective forms because imperfective forms are morphologically simpler (including just VoiceP and no T projection).

4 Conclusions

This paper presents results from a lexicon study and statistical modeling on a vowel alternation pattern in Egyptian Arabic perfective and imperfective verbs. The results show that the imperfective vowel can be predicted based primarily on the place of articulation of consonants, such that less marked consonant-vowel sequences are preferred. In contrast, the perfective vowel can be predicted based only on the imperfective vowel. Based on these findings, I presented a serial derivation analysis, which attributes the distinct factors at play in forming the perfective and imperfective forms, despite their having similar phonological environments, to their morphological structures. The involvement of the consonantal root in forming the imperfective form and its inaccessibility due to syntactic locality constraints in subsequent morphological processes is a crucial part of accounting for the absence of consonant effects in predicting the perfective vowel. As such, this pattern of vowel alternation in Egyptian Arabic provides additional support for the role of consonantal roots in Semitic morphology (McCarthy 1979, Boudelaa & Marslen-Wilson 2015, among others).

However, this analysis raises a learnability question. It assumes that children are able to extract the consonantal root and vocalic melodies as separate lexical entries, whereas surface-based analyses are free of such assumptions. It also poses a problem for the joint learning of morphology and phonotactics: namely, infants must know that phonotactic restrictions on certain consonant-vowel sequences are active in imperfective verbs but not perfective ones. Given that imperfectives have been found to be much more common than perfectives in the speech of Arabic acquiring infants (Aljenaie 2010), it is possible that phonotactic knowledge is acquired after the mastery of imperfective forms but before that of perfective forms, though much more work on early acquisition of Arabic is needed.

The analysis presented here is currently in the process of being tested with nonce word experiments. Table 9 lays out the predictions by various analyses discussed in this paper with regard to all major types of statistical effects discovered by the modeling work:

Statistical effects in the lexicon	Perfective-as-base	Bidirectional	Serial derivation
Root consonants on imperfective vowel choice	Yes	Yes	Yes
Perfective vowel on imperfective vowel choice	Yes	Yes	No
Imperfective vowel on perfective vowel choice	No	Yes	Yes

Table 9. Predictions on wug test results by various analyses.

In the perfective-as-base analysis, since it supposes that speakers use the perfective form as the base, speakers should be able to use both the perfective vowel and root consonants when they predict the imperfective vowel but should be mostly guessing when asked to predict the perfective vowel. The bidirectional analysis predicts all three types of generalization to be learned. The serial derivation analysis, on the other hand, predicts that only the root consonants should help speakers predict the imperfective vowel, since they should not have access to the perfective vowel at this level of lexical representation. When asked to predict the perfective vowel, speakers should be able to generalize the effects of imperfective vowels. Results from this kind of study will be crucial in analyzing speakers' representation of the perfective/imperfective paradigm.

5 Appendix

Wazn	Perfective	Imperfective	Unifying property
I	faʕal ~ fiʕil	-fʕal ~ -fʕil ~ -fʕul	non-derived/basic
II	faʕ:al ~ faʕ:il	-faʕ:al ~ -faʕ:il	causative/transitive
III	fa:ʕil	-fa:ʕil	associative
IV	ʔa-fʕal	-fʕil	causative (rare)
V	t-faʕ:al ~ t-faʕ:il	-t-faʕ:al ~ -t-faʕ:il	reflexive of wazn II
VI	t-fa:ʕil	-t-fa:ʕil	reciprocal of wazn III
VII	t-faʕal	-t-fiʕil	passive of wazn I
VIII	f-t-aʕal	-f-t-iʕil	intransitive (rare)
IX	fʕal:	-fʕal:	color or defect (rare)
X	sta-fʕal ~ sta-fʕil	-sta-fʕal ~ -sta-fʕil	consideration or request

Table 10. EA triconsonantal verb patterns for sound roots; listed in stem (uninflected) form; f-ʕ-l are used as placeholder consonants (Harrell et al. 1963, Abdel-Massih et al. 1979)

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