International Journal of Linguistics, Literature and Translation
ISSN: 2617-0299 (Online); ISSN: 2708-0099 (Print)
DOI: 10.32996/ijllt
Journal Homepage: www.al-kindipublisher.com/index.php/ijllt

IJLLT
AL-KINDI CENTER FOR RESEARCH AND DEVELOPMENT

| RESEARCH ARTICLE

An Optimality Theory Analysis of Schwa Epenthesis in Moroccan Arabic Tri-Consonantal Verbs

Adil Mrhar[1]✉ and Ahmed Smirkou[2]
[1]*Doctoral Student, Faculty of Languages, Letters, and Arts, English Department, Ibn Tofail University, Kenitra, Morocco*
[2]*University Professor, Faculty of Languages, Letters, and Arts, English Department, Ibn Tofail University, Kenitra, Morocco*
Corresponding Author: Adil Mrhar, E-mail: adil.mrhar@uit.ac.ma

| ABSTRACT
This study explores the phenomenon of vowel epenthesis in Moroccan Arabic (MA) using the framework of Optimality Theory (OT). Based on data collected from native speakers, this article focuses on alternations in schwa placement across different verb forms. The analysis examines the constraints that govern schwa insertion and offers a critical evaluation of the Syllable Structure Assignment Algorithm (SSAA), proposed by Benhallam (1990). The study reveals that schwa epenthesis is a crucial strategy employed by MA to ensure the parsing of consonants into syllable structures rather than to avoid the formation of complex syllable margins, which is achieved by allowing minor syllables. Notably, the position and frequency of schwa insertion are not uniform but vary depending on the specific morphological environment. The results demonstrate that the interaction between the markedness constraint ONSET and the alignment constraint Align-R-Major-σ is key in determining both the location and number of epenthetic vowels. These insights challenge the predictive capacity of Benhallam's SSAA and contribute to a deeper understanding of morpho-phonological patterns in MA. The study advances the broader discussion of phonological theory by highlighting the importance of constraint interaction in shaping phonological outcomes.

| KEYWORDS

Epenthesis, Moroccan Arabic, Optimality theory, Schwa, Syllabification.

| ARTICLE INFORMATION

ACCEPTED: 10 November 2024 **PUBLISHED:** 26 November 2024 **DOI:** 10.32996/ijllt.2024.7.12.5

1. Introduction

The phenomenon of schwa epenthesis in Moroccan Arabic (MA) offers valuable insights into the phonological structure and syllabification processes of the language. In MA, schwa [ə] serves as an epenthetic vowel, playing a crucial role in resolving phonotactic constraints, particularly in tri-consonantal verbs. Schwa insertion is not arbitrary; it functions to break up illicit consonant clusters, ensuring that syllables are well-formed and facilitating smoother pronunciation (Benhallam, 1990; Boudlal, 2001; Dell & Elmedlaoui, 2002). However, the placement and frequency of schwa epenthesis in MA are governed by a complex interplay of morphological and phonological factors, making it a fascinating subject of study in linguistics.

Previous research, most notably Benhallam's (1990) Syllable Structure Assignment Algorithm (SSAA), has proposed a rule-based framework for understanding schwa insertion in MA. According to the SSAA, schwa is systematically inserted between each pair of consonants in four-consonant sequences, creating a consistent syllable structure from right to left. While this approach offers a foundational understanding of the process, it fails to fully explain the variations observed in different morphological contexts, particularly between the perfective and imperfective forms of tri-consonantal verbs. The limitations of the SSAA suggest the need for a more dynamic theoretical framework capable of capturing the intricacies of MA's phonological patterns.

This paper employs Optimality Theory (OT) as a more flexible and explanatory framework for analyzing schwa epenthesis in MA tri-consonantal verbs. Unlike traditional rule-based approaches, OT allows for the interaction of multiple constraints, offering a more nuanced understanding of how the morphological context influences schwa insertion. Specifically, this study focuses on

the markedness constraint ONSET, which prohibits onsetless syllables, and the alignment constraint Align-R-Major-σ, which requires the right edge of the stem to align with the right edge of the major syllable. By examining the interaction of these constraints and how they determine the optimal placement and number of schwas, the study challenges the predictions made by the SSAA and presents a more accurate model for understanding syllabification in MA.
The analysis is grounded in data collected from native speakers of MA, focusing on the variations in schwa placement across different verb forms. The findings indicate that the position and frequency of schwa insertion are not uniform but vary according to the morphological environment, particularly in the presence of prefixes or suffixes. This variability highlights the significance of constraint interaction in phonological theory, underscoring the importance of considering both morphological and phonological factors in understanding language patterns. Ultimately, this study contributes to a deeper understanding of MA's phonological structure, demonstrating the complex relationship between morphology and phonology and emphasizing the role of constraint interaction in shaping linguistic outputs.

2. Literature Review

2.1. Syllable structure and syllabification

MA exhibits unique syllable patterns that contribute to its distinct phonetic and phonological characteristics. Scholars such as Benhallam (1990) and Al Ghadi (1990) have proposed frameworks to explain syllable formation in MA, particularly focusing on verbs, adjectives, and nouns. MA's vowel inventory consists of three vowels [i, u, a] and an epenthetic schwa [ə]. Benhallam (1990) has introduced two types of syllabification: full-vowel syllabification and schwa syllabification. He has proposed the Syllable Structure Assignment Algorithm (SSAA), which operates as follows:

a) **Onset and Rime Assignment**: Full-vowel syllables are formed by assigning vowels [i, u, a] as nuclei and distributing adjacent consonants to onset positions.
b) **Schwa Syllabification**: For sequences of unsyllabified consonant clusters (CC), a CəC structure is assigned starting from right to left.
c) **Coda Assignment**: Remaining unsyllabified consonants are allocated to the coda positions of syllables lacking a coda.
d) **Marginal Consonant Assignment**: Stray consonants are linked to form complex onsets or codas by attaching them to adjacent syllable margins.

As a means of illustration, the syllabification of the word [tqəb.lat] from the input /tqbl-at/ 'She got accepted' is processed, following the four steps of the SSAA, accordingly. First, following step (a), the full vowel [a] is assigned as the nucleus of the second syllable, while the adjacent consonant [l] fills the onset position, resulting in the structure [<tqb>.la.<t>]. Next, in step (b), the unsyllabified consonant cluster <tqb> triggers the insertion of a schwa sound, proceeding from right to left, yielding [<t>qəb.la.<t>]. In step (c), the consonant [t] is assigned to the coda position of the second syllable, forming [<t>qəb.lat]. Finally, step (d) links the remaining stray consonant [t] to the onset of the first syllable, creating a complex onset and finalizing the structure as [tqəb.lat].
The SSAA effectively syllabifies a wide range of MA items. However, it encounters limitations with items such as verbs ending in gemination and certain nouns that exhibit a CəCC structure. Benhallam suggests that these exceptions possess underlying syllabic templates distinguishing them from forms predictable by the SSAA. In such cases, the occurrence of schwa is considered irregular and necessitates a separate underlying representation.
Addressing the SSAA's shortcomings with nominal forms, Al Ghadi (1990) proposes that the relative sonority of the consonants involved largely influences schwa epenthesis in tri-segmental nouns. To resolve $C_1C_2C_3$ sequences, schwa insertion follows these principles:

- **CəCC Formation**: If the second consonant (C_2) is more sonorous than the third consonant (C_3), schwa is inserted after the first consonant (e.g., [dərb] 'neighborhood').
- **CCəC Formation**: If C_3 is more sonorous than C_2, schwa is inserted after the second consonant (e.g., [ʒbəl] 'mountain').
- **Equal Sonority Scenario**: When C_2 and C_3 share equal sonority, schwa is typically inserted after C_2 (e.g., [smən] 'clarified butter').

Al Ghadi's approach refines the understanding of nominal syllabification by incorporating the sonority hierarchy, providing a more comprehensive explanation for schwa placement that the SSAA alone does not fully capture. Therefore, syllabification in MA is governed by distinct mechanisms depending on the lexical category. For verbs and adjectives, Benhallam's SSAA offers a systematic method for syllable formation through structured assignment rules. In contrast, noun syllabification is better explained by considering consonantal sonority, as detailed by Al Ghadi. Together, these frameworks contribute to a better understanding of MA's phonological structure and highlight the complexity of its syllabification processes.

2.2. Subject pronouns in MA

According to Hawkins (2011), verbs in MA are inflected for two tenses: past and non-past. Each tense is associated with an aspect; the past tense corresponds to the perfective aspect, and the non-past tense corresponds to the imperfective aspect. For simplicity, the terms "perfective" and "imperfective" will be used throughout this study to refer to past/perfective verbs and non-past/imperfective verbs, respectively.

In MA, subject pronouns are realized as affixes attached to the base form of verbs. These affixal pronouns display positional and affixal allomorphy. In the imperfective paradigm, they occur as prefixes or circumfixes, while in the perfective paradigm, they appear as suffixes (Hachoumi, 2020). The following table summarizes the subject pronoun affixes in the perfective and imperfective aspects:

1)

	Perfective	**Imperfective**
1S	-t	n-
2SM	-ti	t-
2SF	-ti	t-_____-i
3SM	Ø	y-
3SF	-at	t-
1P	-na	n-_____-u
2PM	-tu	t-_____-u
2PF	-tu	t-_____-u
3PM	-u	y-_____-u
3PF	-u	y-_____-u

2.3. Motivation for schwa epenthesis in MA

It is widely agreed in the literature that schwa in MA is an epenthetic vowel rather than an underlying one (Benhallam 1980; Al Ghadi 1994; Boudlal 2001, 2009). Bensoukas and Boudlal (2012) provide two pieces of evidence for this claim: (i) the predictable distribution of schwa and (ii) its behavior in morphologically related words.

Schwa placement in verbs and adjectives is governed by Benhallam's SSAA, while its distribution in nouns is determined by sonority principles, making its placement largely predictable. The fact that schwa appears only in specific environments supports its epenthetic status. Furthermore, in morphologically related words, schwa either disappears or changes position, as illustrated below:

2)

ktəf → ktaf ('shoulder' sg./pl.)
sbəʕ → sbuʕa ('lion' sg./pl.)
ktəb → kətbu ('write' sg./3pl.)

Scholars generally agree that the primary motivation for schwa insertion in MA is to break consonantal clusters, as argued by Benhallam (1980, 1989/1990, cited in Boudlal, 2011). This view holds that schwa epenthesis is a phonotactic repair strategy aimed at resolving sequences of consonants that are otherwise prohibited in the language. Prince and Smolensky (1993/2004), however, emphasize the importance of parsing consonantal segments into syllables, particularly in the case of consonantal roots. These roots, composed entirely of consonants, resist syllabification due to the lack of a vowel to license their positions within the syllable. As a result, schwa insertion serves as a necessary mechanism for ensuring that these consonantal segments are successfully parsed into a syllabic structure.

Building on this, Boudlal (2001) argues that MA does not merely prohibit consonantal clusters but furtherly disallows complex syllable margins, both in onsets and codas. The phonotactic restrictions in MA are better understood as constraints against complex syllable boundaries rather than simply the presence of adjacent consonants. To address these constraints, MA allows the creation of minor syllables by assigning moraic status to marginal consonants. This strategy circumvents the formation of complex syllable margins without relying exclusively on schwa insertion.

The traditional view, which centers on the schwa epenthesis as a way to avoid complex consonant clusters, can be reconsidered. Instead, it is more accurate to claim that schwa epenthesis is primarily driven by the need to parse consonantal segments into syllables. Once a vowel is inserted to allow for this parsing, the remaining consonantal material does not require further epenthesis to avoid clusters. Instead, the avoidance of complex syllable margins is achieved through the formation of minor syllables, where consonants are assigned moraic status to ensure proper syllabification.

Thus:

- Schwa is inserted to enable the parsing of consonantal material into syllables.
- The remaining clusters are avoided through the creation of minor syllables, not additional schwa epenthesis.

2.4. Theoretical framework

The analysis in this paper is grounded in the constraint-based framework of Optimality Theory (OT), as developed by Prince and Smolensky (1993/2004) and further elaborated by McCarthy and Prince (1993) and others. OT represents a significant advancement in generative linguistics, proposing that Universal Grammar (UG) comprises a set of ranked and violable constraints against which linguistic structures are evaluated. This marks a departure from earlier phonological theories, such as Chomsky's (1965) and Chomsky and Halle's (1968) SPE phonology, which rely on rule-based mechanisms.

Kager (1999) describes OT as a linguistic model where surface forms of language reflect resolutions of conflicts between competing constraints. This implies that the forms observed at the surface level are the result of a language-specific hierarchy of constraints, with the optimal structure being the one that minimally violates the most critical constraints. The universal nature of these constraints suggests that they are present across all languages, yet the ranking of these constraints is language-specific, allowing for cross-linguistic variation.

Since its inception in the early 1990s, OT has become a pivotal framework in phonological and morphological studies, offering novel insights into language universals and variation. Its constraint-based approach provides a more detailed understanding of linguistic phenomena, particularly in areas where diverse strategies converge to avoid undesirable configurations—a concept less adequately addressed by earlier generative theories. As such, OT has significantly contributed to our understanding of both language-specific and universal linguistic patterns.

McCarthy and Prince (2004) articulate five fundamental principles underlying OT:

- **Universality**: Universal Grammar provides a set of constraints (Con) present in all grammars.
- **Violability**: Constraints are violable, but the violation is minimal.
- **Ranking**: Constraints are ranked on a language-specific basis.
- **Inclusiveness**: The constraint hierarchy evaluates a set of candidate analyses.
- **Parallelism**: Constraint satisfaction is computed over the entire hierarchy and candidate set simultaneously.

These principles collectively define OT's approach to linguistic analysis, emphasizing the interaction of universal constraints and their language-specific rankings.

The OT framework comprises three main components: the Lexicon, Generator (GEN), and Evaluator (EVAL) (Prince & Smolensky, 1993/2004). The Lexicon serves as the repository of lexemes and morphemes, providing inputs for the generative process. A crucial property of OT is the "richness of the base," which posits no language-specific restrictions on inputs (Kager, 1999). GEN produces an infinite set of output candidates for each input. The "freedom of analysis" principle allows GEN to generate any conceivable output, regardless of its deviation from the input (McCarthy & Prince, 1993). EVAL assesses candidate outputs against a hierarchy of ranked constraints. This component is responsible for selecting the optimal output based on minimal violation of higher-ranked constraints (Prince & Smolensky, 1993/2004). OT recognizes three primary types of constraints:

- **Faithfulness** constraints: These require the preservation of input properties in the output.
- **Markedness** constraints: These motivate changes from input to output to achieve well-formedness.
- **Alignment** constraints: These require the alignment of edges between prosodic or morphological categories.

An OT tableau illustrates how candidates are evaluated based on constraint ranking. Below is a sample tableau showing how OT determines the optimal candidate for a hypothetical linguistic input:

3)

/Input/	**Constraint 1 (C1)**	**Constraint 2 (C2)**	**Constraint 3 (C3)**	**Constraint 4 (C4)**
a. [Cand1]	*!	**		*
b. [Cand2]		*!	***	
☞ c. [Cand3]		*	**	

- **Candidates** are the possible linguistic outputs generated by GEN for a specific input. In the tableau, Cand1, Cand2, and Cand3 are all potential outputs for the input.
- Each **constraint** is ranked hierarchically. In the tableau above, C1 is ranked higher than C2, and C2 is ranked higher than C3 and C4. This ranking reflects the importance of constraints—higher-ranked constraints dominate lower-ranked ones.

- A **solid line** between constraints in a tableau expresses a strict hierarchy between these constraints (C1 dominates C2).
- A **dotted line** in the tableau separates constraints of equal ranking, indicating that these constraints are equally important and neither dominates the other. In the tableau above, C3 and C4 are of equal hierarchy.
- The asterisk **(*)** symbol indicates a violation of a constraint. The number of asterisks a candidate receives expresses the number of violations it incurs regarding the constraint in question.
- The exclamation mark **(!)** symbol denotes a fatal violation. When a candidate violates a higher-ranked constraint, it is eliminated from the competition. For instance, Cand1 violates C1, which is a fatal violation, as C1 is more important than the others.
- The **optimal** candidate is marked by a pointing finger (☞). This is the candidate that survives the evaluation process with the least serious violations. In the tableau, Cand3 is chosen as the optimal output because it avoids a fatal violation and incurs fewer or less serious violations than the other candidates.

3. Methodology

This study examines the phenomenon of schwa epenthesis in MA, focusing specifically on tri-consonantal verbs. The data were collected from 20 native speakers of MA from Kenitra city, as well as from my own speech, given that I am a native speaker of the dialect under study. The primary focus was on the occurrence and patterning of vowel epenthesis within these verb forms.

3.1. Data Collection

Participants were asked to conjugate a carefully curated list of tri-consonantal verbs with all subject pronouns, both in the perfective and imperfective aspects. The list included common verbs that are regularly used in everyday speech, ensuring that the responses reflected natural linguistic behavior. The aim was to observe and document how vowel epenthesis, particularly the insertion of schwa, manifests in the verb conjugations provided by the respondents.

3.2. Data Analysis

Upon analyzing the collected data, it was found that there was a high level of consistency among the respondents in their pronunciation of the conjugated verbs. No variations were observed in the use of schwa across different pronouns, with the exception of the third person singular feminine form (3SF). In this case, some respondents pronounced the 3SF morpheme as -at (e.g., kətb-at "she wrote"), while others used -ət[1] (e.g., kətb-ət "she wrote"). Notably, some individuals alternated between these two forms in different instances.

The data were transcribed phonetically to capture subtle variations in pronunciation and were analyzed within the framework of Optimality Theory (Prince & Smolensky, 1993/2004).

The objectives of this study are twofold:

1. **To account for the alternations in terms of the site of schwa epenthesis in MA verbs**: This involves identifying and analyzing the specific positions within tri-consonantal verb forms where schwa is inserted and understanding the constraint interaction that governs these epenthetic sites.
2. **To account for the alternations in terms of the number of epenthetic vowels**: This objective seeks to examine the variations in the number of schwa insertions across different verb forms and conjugations, providing an explanation for why some forms may exhibit a single schwa insertion while others may display multiple instances.

The findings from this research contribute to a deeper understanding of vowel epenthesis in MA, specifically within the context of tri-consonantal verbs.

3.3. Data presentation

Tri-consonantal verbs, characterized by roots containing three consonants, present an intriguing phonological phenomenon in MA. The absence of vowels in these verbal roots necessitates the employment of epenthesis to legitimize the surface realization of their consonantal segments. The affixation of subject pronouns to these verbs reveals noteworthy alternations in the location and the number of epenthetic vowels.

[1] Given that the variation between -at and -ət does not significantly impact the analysis of schwa epenthesis in the larger context of this study, the form -at will be consistently used in the data presented throughout this paper. The implications of this variation will be addressed in a future article.

Consider the following data set illustrating subject pronoun affixation to the perfective form of the verb 'ktb' (to write), as a representative example of standard[2] tri-consonantal verbs:

4)

a)	**1S**	/ktb-t/	[kt**ə**bt]	'I wrote'
	2S	/ktb-ti/	[kt**ə**b.ti]	'You wrote'
	3SM	/ktb-Ø/	[kt**ə**b]	'He wrote'
	1P	/ktb-na/	[kt**ə**b.na]	'We wrote'
	2P	/ktb-tu/	[kt**ə**b.tu]	'You wrote'
b)	**3SF**	/ktb-at/	[k**ə**t.bat]	'She wrote'
	3P	/ktb-u/	[k**ə**t.bu]	'They wrote'

Several significant observations can be drawn from the data presented: All subject pronouns in the perfective are realized as suffixes (hyphenated in the input) attached to the verbal stem. Additionally, the insertion of the epenthetic vowel schwa [ə] is evident between radical consonants, suggesting a phonological process to facilitate pronunciation. Furthermore, a notable alternation in the placement of the epenthetic vowel is observed. For instance, in set (4a), schwa is epenthesized after the second radical segment, as in [ktəb-t], whereas in set (4b), epenthesis occurs after the first segment, as in [kətb-at]. These patterns highlight the intricate interplay between morphology and phonology in the language's structure.
The data in (5) illustrates the conjugation of the verb 'ktb' (to write) in the imperfective:

5)

a)	**1S**	/**n-**ktb/	[n**ə**k.t**ə**b]	'I write'
	2SM	/**t-**ktb/	[t**ə**k.t**ə**b]	'You write'
	3SM	/**y-**ktb/	[y**ə**k.t**ə**b]	'He writes'
	3SF	/**t-**ktb/	[t**ə**k.t**ə**b]	'She writes'
b)	**2SF**	/**t-**ktb-**i**/	[t.k**ə**t.bi]	'You write'
	1P	/**n-**ktb-**u**/	[n.k**ə**t.bu]	'We write'
	2P	/**t-**ktb-**u**/	[t.k**ə**t.bu]	'You write'
	3P	/**y-**ktb-**u**/	[y.k**ə**t.bu]	'They write'

Upon close inspection of the data above, we notice that subject pronouns in the imperfective are prefixes (5a), or circumfixes (5b). As far as vowel epenthesis is concerned, two vowels are inserted to parse the verbs in (5a), while only one vowel is inserted in the data in (5b).

4. An OT analysis of verbal syllable structure in MA

The driving force behind schwa epenthesis is to enable the parsing of the radical consonantal segments of tri-consonantal verbs into syllables. In OT terms, epenthesis is triggered by a constraint that requires segments to be parsed into syllables. This constraint is labeled PARSE-seg and which Prince and Smolensky (1993) state as follows:

PARSE-segment (PARSE-seg): Every segment must belong to a syllable.

Satisfying this constraint is achieved at the expense of violating a faithfulness constraint militating against epenthesis. This constraint is Dependency-IO (or DEP-IO) as defined after McCarthy and Prince (1995):

DEP-IO: Output segments must have input correspondents. (No epenthesis)

The only way to parse the segments of the input /ktb/ into a syllable is by epenthesizing a vowel. Hence, satisfying PARSE-seg involves the violation of DEP-IO. Therefore, PARSE-seg dominates DEP-IO (PARSE-seg >> DEP-IO).
Additionally, MA does not allow complex margins (Boudlal, 2001). This is translated by the undomination of the constraint *COMPLEX defined below:

[2] In this paper, the term standard tri-consonantal verbs is used to refer to verbs where the final two consonants are distinct, distinguishing them from geminate verbs, whose final two consonants are identical. These geminate verbs exhibit different behavior with respect to vowel epenthesis, which will be explored in a future article.

***COMPLEX:** Complex onsets and codas are prohibited (Prince & Smolensky, 1993/2004).

This constraint eliminates all candidates containing a complex onset or coda. Boudlal (2001) argues that, in a syllable where a CC sequence precedes or follows a vowel, the consonant that is adjacent to the vowel occupies the onset or the coda of that syllable, respectively, while marginal consonants are considered to be minor syllables (/CCVC/ →[.C.CVC.] ; /CVCC/→[.CVC.C.]).
Minor syllables are universally marked as they violate Selkirk's (1981) Strict Layer Hypothesis, which requires every prosodic constituent to be dominated by a constituent of the immediately superordinate type. That is to say, the mora has to be dominated by the syllable, which must be dominated by the foot, which is, in turn, dominated by the prosodic word. This means that a segment is to be branched either as an onset, nuclei, or a coda but not to be directly dominated by the syllable. For this reason, Boudlal (2001) introduces a markedness constraint that forbids minor syllables:

***MINOR SYLLABLE (*Min-σ):** Minor syllables are prohibited.

*COMPLEX and *Min-σ are in direct conflict since satisfying the undominated constraint *COMPLEX involves the violation of *Min-σ (*COMPLEX >> *Min-σ).
We turn now to discuss the ranking of this constraint (*Min-σ) with regard to the anti-epenthesis constraint DEP-IO. It follows that MA tolerates violation of both constraints for the sake of satisfying highly ranked ones; DEP-IO is violated to satisfy PARSE-seg, and *Min-σ is violated to satisfy *COMPLEX. It is worth mentioning that satisfying the latter constraint could also be achieved via excessive epenthesis. However, MA favors syllabic consonants rather than excessive epenthesis in order to satisfy *COMPLEX (/ktb-t/: [.k.teb.t.] > [.kət.bət.] 'I wrote'). Therefore, DEP-IO must outrank *Min-σ. The ranking of the constraints presented so far is as follows:

PARSE-seg, *COMPLEX >> DEP-IO >> *Min-σ

To illustrate the interaction between these constraints, consider the tableau below for the input /ktb-t/ 'I wrote':

6)

Input : /ktb-t/	**PARSE-seg**	***Complex**	**DEP-IO**	***Min-σ**
☞ **a- .k.təb.t.**			*	**
b- ktbt	* !***			
c- .kətb.t.		* !	*	*
d- .ktəbt.		* ! *	*	
e- .kət.bət.			**!	

Candidate (6b) is ruled out for its fatal violation of the undominated constraint PARSE-seg as their segments are not parsed into syllables. The constraint *Complex rules out candidates (6c) and (6d) as one or both syllable margins are branched (6c) and (6d), respectively. The optimal candidate is candidate (6a) as it satisfies both undominated constraints PARSE-seg and *Complex through inserting one vowel and allowing two minor syllables. Candidate (6e) avoids having minor syllables through double schwa epenthesis. It is, then, ruled out for its second violation of the constraint DEP-IO.

5. Epenthesis site alternation

The difference between candidate (6a) and candidate (6c) in the tableau above is in terms of the placement of schwa. Candidate (6a) is optimal because inserting schwa after the second segment avoids having a complex coda, (6c). Therefore, when the input contains four consonants, parsing the consonantal segments and satisfying *Complex cannot be achieved without (i) inserting schwa after the second segment and (ii) allowing two marginal minor syllables. However, the attentive reader may wonder what blocks a candidate such as *[.kət.b.] (instead of the optimal [.k.təb.]) from the three-consonantal segment input /ktb/ 'he wrote' from surfacing though it does not contain complex margins and its consonants are parsed into a syllable. Consider the tableau below for illustration:

7)

Input : /ktb/	PARSE-seg	*COMPLEX	DEP-IO	*Min-σ
☞a- .k.təb.			*	*
☜[3]b- .kət.b.			*	*

Note that this set of constraints cannot determine the optimal candidate as both candidates tie in everything. The only difference between the competing candidates resides in the way their major syllables are aligned with regard to their minor ones. While candidate (7a) has a minor syllable followed by a major one, candidate (7b) represents the opposite order; the major syllable is followed by the minor one. While Al Ghadi (1990) argues that schwa epenthesis is governed by sonority principles in nouns, Boudlal (2001) contends that, in verbs, it is inserted in a position that ensures major syllables to be aligned to the right. To ensure right-to-left epenthesis of schwa, he posits the constraint Align-R-Maj-σ that is defined after McCarthy and Prince (1993) as follows:

ALIGN-R Maj-σ : The right edge of the stem aligns with the right edge of a major syllable.

The inclusion of this constraint breaks the tie between the two candidates and rules out candidate (7b) as its major syllable is not right aligned. The constraint Align-R-Maj-σ is decisive in determining the site of schwa epenthesis in tri-consonantal verbs. It ensures right-to-left epenthesis of schwa. By claiming its undomination[4,] the set of constraints is now capable of generating the optimal candidate.
Let’s now consider the items in the set (4b). These items differ from those in (4a) in two key ways: They are misaligned as the right edge of the stem [b] is not aligned with the right edge of the major syllable, and schwa is inserted after the first segment. This is because, unlike the items in (4a) where the pronoun suffixes are consonant-initial, in the items in (4b), the personal pronoun suffixes (’-at’ and ’-u’) start with a vowel. Those vowel-initial suffixes force the last radical consonant to occupy the onset of the following syllable [<kt>.bat.] because onsetless syllables are not allowed. Schwa is then inserted between the two first radical consonants to allow their parsing [.kət.bat.]. At this point, it is relevant to introduce the constraint ONSET, which prohibits onsetless syllables. Prince and Smolensky (1993: 85) define it as follows:

ONSET : Syllables must have an onset.

This constraint eliminates candidates containing an onsetless syllable, such as *[.k.təb.at.]. When dealing with vowel-initial subject pronoun suffixes, satisfying the ONSET constraint is achieved by assigning the last radical consonant to the onset position of the following syllable. This results in a violation of the Align-R-Maj-σ constraint and consequently causes a shift in the placement of schwa epenthesis. The alternation in terms of the site of epenthesis is due to the interaction between ONSET and Align-R-Maj-σ. Hence, Align-R-Maj-σ is to be demoted. The ranking of the constraints adopted so far is presented as follows:

PARSE-seg, *COMPLEX, ONSET >> ALIGN-R Maj-σ >> DEP-IO >> *Min-σ

Nevertheless, this constraint ranking is unable to rule out a candidate such as *[.k.tə.bat.] as it satisfies all undominated constraints. Such a candidate inserts schwa after the second segment without violating ONSET. The matter of fact is that this candidate is eliminated because it has an open syllable with schwa as a nucleus. It is an established fact that schwa syllables in MA are always closed. Bensoukas and Boudlal (2012) explain the fact that schwa cannot occur in open syllables by being a moraless vowel and, therefore, schwa syllables have to have a coda consonant with which schwa shares a single mora. Therefore, introducing a constraint that bans open schwa syllables is necessary. They propose a constraint dubbed *ə]σ, which has the effect of ruling out open schwa syllables:

***ə]σ:** Open schwa syllables are prohibited.

Note that satisfying *ə]σ requires schwa syllables to have a coda. Taking the universally marked status of a coda position into consideration, a constraint banning candidates containing a coda is to be introduced:

NoCoda: Syllables must not have codas (McCarthy & Prince, 1993, Prince &Smolensky, 1993).

[3] The symbol "☜" refers to a candidate that, while not optimal, performs just as well as the optimal candidate under the given constraint ranking. This indicates that the current constraints are insufficient to determine the optimal output, and an additional constraint is required to make a decisive selection.

[4] This constraint will be demonstrated as dominated in subsequent analyses.

The fact that open schwa syllables are not attested in MA proves that *ə]σ is undominated. A reasonable question to ask here is: what hierarchy can be established between NoCoda and DEP-IO? Schwa is inserted to allow the parsing of consonantal segments into syllables. Because schwa syllables are always closed, violating DEP-IO (inserting schwa) involves the violation of NoCoda (assigning a coda to a schwa syllable). If NoCoda is ranked higher than DEP-IO, then all candidates with schwa will be eliminated (since they all must be closed in satisfaction of *ə]σ). If this is the case, schwa epenthesis will not be attested in MA; only candidates with vowels other than schwa will be allowed to surface. In other words, since schwa is the default epenthetic vowel, MA ranks NoCoda lower on the scale to allow candidates with schwa to surface. Therefore, DEP-IO dominates NoCoda.

Let's now discuss how NoCoda is ranked with regard to *Min-σ. Although minor syllables are attested in MA, they are tolerated only when there is a CC sequence. That is to say, an initial minor syllable is allowed only when the onset position of the main syllable is occupied, and a final minor syllable is allowed only if the coda position of the main syllable is occupied. This means that a single post-vocalic consonant is syllabified as a coda rather than a minor syllable. Therefore, for the last consonant of a /CVC/ structure to be syllabified as a coda [.CVC.] and not as a minor syllable [.CV.C.], *Min-σ has to outrank NoCoda. The ultimate ranking of all the constraints adopted is presented as follows:

8)

***COMPLEX, PARSE-seg, ONSET, *ə]σ >> ALIGN-R Maj-σ >>DEP-IO >> *Min-σ >> NoCoda**

To make sure this final ranking is capable of determining optimal candidates for cases where schwa is inserted after the first segment and also cases where it is epenthesized after the second one, let's test an input from each set against it. The tableau in (9) evaluates an item from the set (4a) against the constraint ranking provided above. It shows how this ranking is capable of selecting the optimal candidate for the input /ktb-t/ 'I wrote':

9)

Input : /ktb-t/	*COMPLEX	PARSE-seg	ONSET	*ə]σ	ALIGN-R Maj-σ	DEP I-O	*Min-σ	NoCoda
☞ a- .k.təb.t.						*	**	*
b- .kət.bət.					*!	**		**
c- .ktəb.t.	*!					*	*	*
d-.ktəbt.	*!*				*	*		*
e- .kət.bt		*!*			*	*		*

Candidates (9c, d, and e) are ruled out because of violating one of the undominated constraints. Candidate (9c) is eliminated due to its violation of *COMPLEX by containing a complex onset. Candidate (9d) is also ruled out by the same constraint as it has a syllable whose margins are both complex. Candidate (9e) is blocked by PARSE-seg as it has two unparsed segments. Candidates (9a) and (9b) satisfy all undominated constraints. However, candidate (9b) is eliminated as it incurs a violation of Align-R-Maj-σ. Although candidate (9a) violates DEP-IO, *Minor-σ and NoCoda, it wins the competition because it is the most harmonious candidate.

10)

Input : /ktb-at/	*COMPLEX	PARSE-seg	ONSET	*ə]σ	ALIGN-R Maj-σ	DEP I-O	*Min-σ	NoCoda
☞ a- .kət.bat.					*	*		**
b- .ktəb.at.	*!		*!			*		**
c- .k.təb.at.			*!			*	*	**
d-.ktə.bat.	*!			*!	*	*		**
e- kt.bat		*!*			*			*

The tableau above represents the constraint interaction in generating an output out of the input /ktb-at/ 'she wrote'. Candidate (10b) has a complex onset along with an onsetless syllable. It therefore incurs two fatal violations of undominated *COMPLEX and ONSET. Although candidate (10c) has repaired the onset complexity, it still incurs a fatal violation of ONSET. *COMPLEX eliminates candidate (10d) which violates also *ə]σ by containing an open schwa syllable. Candidate (10e) violates PARSE-seg by including two unparsed segments. Although Candidate (10a) is misaligned (as it violates Align-R-Maj-σ), it wins the competition as it satisfies all undominated constraints.

Accordingly, as far as perfective verbal affixation is concerned, an optimal output never contains unparsed segments. It also does not include a complex margin or an onsetless syllable. It never has an open schwa syllable. If the subject pronoun suffix starts with a consonant, Align-R-Maj-σ has to be satisfied. However, if the subject pronoun suffix starts with a vowel, Align-R-Maj-σ is violated to secure ONSET. Therefore, ONSET's domination of Align-R-Maj-σ is responsible for the alternation in terms of the placement of schwa epenthesis.

6. Number of epenthetic vowels alternation

This section is meant to account for the alternations in terms of the number of epenthetic vowels attested in the imperfective.

It has been stated before that subject pronouns change as we move from the perfective to the imperfective, as shown in Figure (1). The figure shows that while subject pronouns are all in the form of suffixes in the perfective, in the imperfective, they are consonant prefixes with singular pronouns (except 2SF) and circumfixes with plural pronouns and 2SF. Those circumfixes are all single consonant prefixes and vowel suffixes. The data in (5) illustrate the effect of the nature of subject pronoun affixes on the number of epenthetic vowels. While epenthesis of one single vowel is sufficient to parse prefixed verbs (5a), double epenthesis is needed in the case of circumfixed verbs (5b). The sub-sections that follow show how the constraint ranking achieved so far is able to account for the alternations in terms of vowel epenthesis with regards to subject pronoun affixation in the imperfective.

6.1. Prefixed verbal forms

With prefixal subject pronouns, vowel epenthesis is needed to syllabify an input composed of four consonants /C-CCC/ (a consonantal subject pronoun prefix plus three radical consonants). The tableau[5] below illustrates the evaluation of two candidates against the constraint hierarchy achieved:

[5] For space economy, the tableau above does not include any candidate that violates any of the undominated constraints taking for granted they are out of the competition.

11)

Input : /n-ktb /	*COMPLEX	PARSE-seg	ONSET	*ə]σ	ALIGN-R Maj-σ	DEP -IO	*Min-σ	NoCoda
☞ a- .nək.təb.						**		**
b- .n.kət.b.					*!	*	**	*

It can be noticed that the optimal candidate (11a) inserts two vowels, while candidate (11b) inserts only one vowel. Though epenthesis is minimal, this candidate is eliminated for its violation of Align-R-Major-σ as the right edge of the stem [b] is not aligned with the right edge of the major syllable (the consonant [b] forms a minor syllable). Satisfying this constraint is therefore, impossible without recourse to double epenthesis.
An intriguing observation that can be made is that MA parses a four-consonant cluster in two distinct ways. Benhallam's SSAA posits that a sequence of four consonants in MA is uniformly parsed by inserting a schwa between each pair of consonants, proceeding systematically from right to left. This parsing strategy leads to a consistent form such as [.CəC.CəC.]. While this model aims to provide a straightforward mechanism for schwa insertion, it fails to account for the different syllabification patterns observed between the perfective and imperfective aspects in MA tri-consonantal verbs.
The limitations of Benhallam's approach in accounting for the different syllabification patterns observed in MA are the following:

a) Inadequacy in addressing morphological variations:
Benhallam's SSAA does not differentiate between the morphological contexts of the perfective and imperfective aspects. The algorithm suggests a uniform insertion of schwas between consonants, which would result in the form [.CəC.CəC.] regardless of whether the verb form is perfective or imperfective. However, empirical data from MA shows a clear distinction: in the perfective aspect, a four-consonant cluster is parsed with only a single schwa insertion, resulting in a syllable structure like [.C.CəC.C.]. In contrast, in the imperfective aspect, the same cluster undergoes double schwa insertion, yielding [.CəC.CəC.]. This discrepancy reveals a limitation in the SSAA's ability to account for the morphological influences on syllable structure in MA.

b) Lack of sensitivity to syllable alignment constraints:
The SSAA's failure to account for the different syllabification patterns can be further explained by its lack of consideration for the constraint Align-R-Major-σ, which plays a crucial role in determining the optimal placement of schwa in different morphological contexts. In the perfective aspect, the alignment constraint requires that the right edge of the root's final consonant (C3) aligns with the right edge of the major syllable, resulting in minimal schwa insertion: [.C.CəC.C.]. The SSAA does not accommodate this alignment requirement, leading to an overgeneralized and inaccurate syllabification pattern.

c) Failure to account for prefix-suffix interactions:
The SSAA does not adequately consider the role of affixation in influencing syllabification. In the perfective, where consonant clusters are followed by a suffix (/$C_1C_2C_3$-C_{suff}/), the schwa insertion is minimal due to the presence of a consonantal suffix that supports the parsing of the cluster without violating the alignment constraint. However, in the imperfective, the presence of a prefix (/C_{Pref}-$C_1C_2C_3$/) disrupts the alignment, requiring an additional schwa to achieve a well-formed syllable structure. The SSAA overlooks this critical interaction between prefixation and syllable alignment, resulting in a failure to predict the correct number of schwas inserted in different contexts.

These limitations clearly demonstrate the algorithm's inability to accurately model the syllabification process in MA, highlighting the need for a more flexible framework that accounts for morphological context and constraint interaction. Unlike the rigid rule-based approach of the SSAA, OT allows for a dynamic interaction of constraints, including Align-R-Major-σ and ONSET, which can better capture the observed variations in schwa insertion. This framework provides a more nuanced understanding of how morphological context influences phonological processes, offering a more accurate account of syllabification in MA.

6.2. Circumfixed verbal forms
Unlike the items in (5a) where the parsing requires the insertion of two schwas, in the items in (5b), only one schwa is inserted. Those items illustrate circumfixed subject pronouns. Conjugating a verb with those pronouns in the imperfective involves circumfixation to the verb. Those circumfixes are in the form of a consonant prefix and a vowel suffix. In satisfaction of ONSET,

the last consonant of the root is branched as an onset of the following syllable (e.i /n-ktb-u/; 'we write': [<nkt>.bu.]). Therefore, only three segments remain unparsed; epenthesis of one schwa only suffices to do the parsing perfectly ([.n.kət.bu.]). It can be noticed that this output is misaligned as it violates Align-R-Major-σ. However, this violation is justified by the interaction between the constraint ONSET and Align-R-Major-σ. The constraint hierarchy suggested in (8) is also able to successfully evaluate plausible candidates of that set of data and select the optimal one as the tableau below shows:

12)

Input : /n-ktb-u /	*COMPLEX	PARSE-seg	ONSET	*ə]σ	ALIGN-R Maj-σ	DEP -IO	*Min-σ	NoCoda
☞ a- .n.kət.bu.					*	*	*	*
b- .nək.təb.u.			*!			**		**

This tableau represents the evaluation of two plausible candidates of the input /n-ktb-u/ against the posited constraint hierarchy. It is evident that although candidate (12a) is not well aligned (it violates Align-R-Major-σ), it is the optimal candidate because it satisfies all undominated constraints. Candidate (12b), on the other hand, satisfies Align-R-Major-σ, nevertheless, it is ruled out because of its fatal violation of ONSET. Therefore, violating Align-R-Major-σ is tolerated only because it is in direct conflict with an undominated constraint, namely ONSET.

7. Conclusion

This paper has explored vowel epenthesis in tri-consonantal verbs in MA, proposing a constraint hierarchy within Optimality Theory that effectively generates the correct verbal forms across different pronouns. The analysis accounts for the observed alternations in both the site and the number of epenthetic vowels, attributing them to the interaction between the markedness constraint ONSET and the alignment constraint Align-R-Major-σ. The study demonstrates that schwa insertion occurs to facilitate consonant parsing rather than to avoid complex syllable margins, which is achieved by allowing moraic minor syllables. Specifically, schwa is inserted after the second consonant of tri-consonantal verbs to satisfy Align-R-Major-σ, except when the verb is followed by a vowel-initial suffix. In such cases, the high-ranking ONSET constraint takes precedence, leading to schwa insertion after the first consonant, even at the expense of violating Align-R-Major-σ. The interaction between these constraints also explains the variation in the number of epenthetic vowels in the imperfective form. When prefixal pronouns are used, a single schwa insertion is insufficient to satisfy Align-R-Major-σ, necessitating double schwa epenthesis. Conversely, with vocalic suffix pronouns, only one schwa is inserted, prioritizing ONSET over perfect alignment.
While Benhallam's SSAA provides a foundational approach to understanding syllable structure in MA, it falls short in accounting for the complex interactions between morphology and phonology that dictate schwa insertion patterns. A constraint-based approach, such as OT, offers a more comprehensive and explanatory model that accommodates the variability and complexity observed in the data. Unlike rule-based theories that merely describe the environments in which a phonological process occurs, the OT analysis presented here identifies the specific constraints that drive these processes and explains how conflicting constraints lead to variations in linguistic output. This analysis successfully accounts for vowel epenthesis alternations in MA, both in terms of the site and the number of epenthetic vowels, illustrating the power of constraint interaction in explaining linguistic inconsistencies.

Funding: This research received no external funding.
Conflicts of Interest: The authors declare no conflict of interest.
ORCID iD: 0009-0009-0128-8177

References

[1] Al Ghadi, A. (1990). Moroccan Arabic plurals and the organization of the lexicon [Master's thesis, Mohammed V University].
[2] Al Ghadi, A. (1994). An OT account of Moroccan Arabic prosody [Unpublished manuscript]. University of Delaware and Mohammed V University.
[3] Benhallam, A. (1980). Syllable structure and rule types in Arabic [Doctoral dissertation, University of Florida].
[4] Benhallam, A. (1989/1990). Moroccan Arabic syllable structure. Langues et Littératures, 8, 177–191.
[5] Bensoukas, K., & Boudlal, A. (2012). An Amazigh substratum in Moroccan Arabic: The prosody of schwa. Langues et Littératures, 21, 51–65.

[6] Boudlal, A. (2001). Constraint interaction in the phonology and morphology of Casablanca Moroccan Arabic [Doctoral dissertation, Mohammed V University]. Available at http://roa.rutgers.edu, ROA#650.
[7] Boudlal, A. (2009). The prosody and morphology of a Moroccan Arabic dialect: An Optimality-Theoretic account. VDM Verlag Dr. Müller.
[8] Boudlal, A. (2011). On the special behavior of schwa in Moroccan Arabic prosody. Langues et Littératures, 21, 51–65.
[9] Chomsky, N. (1965). Aspects of the theory of syntax. MIT Press.
[10] Chomsky, N., & Halle, M. (1968). The sound pattern of English. Harper and Row.
[11] Dell, F., & Elmedlaoui, M. (2012). Syllables in Tashlhiyt Berber and in Moroccan Arabic (Vol. 2). Springer Science & Business Media.
[12] Hachoumi, H. (2020). An optimality-theoretic account of Moroccan Arabic subject personal pronoun affixes. International Journal of Arabic Linguistics, 6(1–2), 209–241.
[13] Hawkins, S. (2011). Moroccan Arabic multiverb constructions and the verbal prefix *k-*[1].
[14] Kager, R. (1999). Optimality theory. Cambridge University Press.
[15] McCarthy, J. J., & Prince, A. (1993). Generalized alignment. In Yearbook of morphology 1993 (pp. 79–153). Springer.
[16] McCarthy, J. J., & Prince, A. (1995). Faithfulness and reduplicative identity. In University of Massachusetts Occasional Papers in Linguistics (Vol. 18, pp. 249–384).
[17] McCarthy, J. J., & Prince, A. (2004). The emergence of the unmarked. In Optimality theory in phonology: A reader (pp. 483–494).
[18] Prince, A., & Smolensky, P. (1991). Optimality. Arizona Phonology Conference, 4.
[19] Prince, A., & Smolensky, P. (1993). Optimality theory: Constraint interaction in generative grammar [Unpublished manuscript].
[20] Selkirk, E. O. (1981). On prosodic structure and its relation to syntactic structure. In T. Fretheim (Ed.), Nordic prosody II: Papers from a symposium (pp. 111–140). Tapir.