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Prefixed Nouns and Verbs in Arabic: Evidence for Dual-Route Processing in Auditory Word Recognition

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ABSTRACT

The process of accessing and retrieving the morphological components of complex words during word recognition has led to the development of various models that explain morphological representation and processing. This area of research is particularly significant in the context of Arabic, where it has been suggested that lexical processing predominantly relies on root-based obligatory morphological decomposition, as opposed to stem-based processing. To investigate this proposal, we conducted an experiment focusing on morphologically complex prefixed words. These words were carefully matched for surface and stem frequencies, allowing us to isolate the variable of root type frequency, or family size, to observe its specific effects. We analyzed the impact of root type frequency on response times for lexical decisions concerning spoken prefixed nouns and verbs in Arabic. Our findings revealed that response times for lexical decisions were significantly influenced by root type frequency, but only for prefixed nouns. This suggests that the proposed model of root-based obligatory morphological decomposition may not be universally applicable to all types of prefixed words in Arabic. Instead, these results indicate a need for a more nuanced understanding of morphological processing, supporting dual-mechanism approaches over single-mechanism theories. This research contributes to the ongoing discourse on morphological processing in language, particularly highlighting the complexities involved in recognizing morphologically rich languages like Arabic.

Keywords: Morphologically Complex Words; Perception; Dual-Route Models

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1. Introduction

The process of accessing and retrieving the morphological components of complex words during word recognition has led to various models of morphological representation and processing. Despite numerous empirical studies testing these models, inconsistent results and cross-linguistic differences have been reported [1–5]. While some studies support morphological decomposition in the lexical processing of morphologically complex words, others suggest that complex words can be processed through their whole-word representations. This paper argues that examining prefixed nouns and verbs in Arabic can offer insight into the conditions that determine different routes of lexical processing within the same language.

In Arabic, the lexicality of morphological constituents varies between nouns and verbs. Specifically, affix-stripping of the prefix [ta] from a morphologically complex verb in Arabic (e.g., /taqaTTaʕ/ ‘cut’ intransitive, reflexive) results in a free stem (/qaTTaʕ/ ‘cut’ transitive), which is a real word in Arabic. Conversely, affix-stripping the same word in a noun pattern (i.e., /taqaTTuʕ/ ‘the act of cutting’) leaves a bound stem (/qaTTuʕ/), which is not a valid word in Arabic. In this study, we explore whether this distinction between complex prefixed nouns and verbs influences the routes of lexical processing in Arabic, and if so, whether existing models of morphologically complex word processing can explain these differences.

1.1. Models of Processing Morphologically Complex Words

How does a native English speaker process a complex word such as *unbeatable?* Different approaches have been proposed to address this question. On one hand, single-mechanism approaches suggest two main independent routes for processing. The first approach, known as full parsing, suggests that complex words are obligatorily decomposed into their morphemic components (e.g., un+break+able) and through the representation of the stem (i.e., break) the word is recognized [5–7]. Taft's decomposition-based Interactive Activation model emphasizes two stages in the recognition of morphologically complex words. The first stage involves the early obligatory decomposition of the word into its morphemes, while the second stage involves recombining the functional information of the stem and affix representations. He argues that the time taken to complete this stage varies depending on difficulty of combining a specific stem with a particular affix.

Conversely, the other single-mechanism approach claims that complex words are fully listed and that only the whole-word representation (e.g., *unbeatable*) is available for processing [8]. Models of whole-word processing in spoken word recognition posit that only words sharing the same phonemes are activated and compete for recognition based on the auditory signal. The activation levels of word candidates change as more of the auditory signal unfolds over time [9, 10]. Is one of these two routes (i.e., decompositional or whole-word) the sole route for recognition or is a particular route favored over the other when processing certain complex words for which the other route may not be successful? Dual route models offer an answer to this question.

Hybrid dual-route models adhere to the view that morphologically complex words can be processed both as decomposed (stem+affix) units or as whole words depending on a number of factors. For example, in their dual route Augmented Addressed Morphology model (AAM), Caramazza et al. [11] posit that the direct whole-word route is typically the main processing route. However, the decomposition route can be used when the complex word is novel or unfamiliar. Similarly, the Morphological Race (MR) model [12] allows access to both routes in processing. In another dual route model, namely the Parallel Dual-Route model (PDR), the decomposition route and whole-word route are activated in parallel [13, 14]. In these dual-route models, representations of whole words and constituent morphemes can coexist and connect. Several factors will govern the relative contribution of these routes to the processing and recognition of complex words, include word formation type and affixal productivity [1].

Although most of these models were developed based on data from visual word recognition, similar models of spoken word recognition were postulated. For example, Wurm [15] proposes a dual-route model of lexical processing in spoken word recognition. According to Wurm, spoken word recognition proceeds through both a continuous route which processes whole words and a decompositional route which segments decomposable words into their constituent morphemes. However, Wurm[15] proposes a constraint on the morphemic route in this dual-route model. That is, after affix-stripping, only free stems (e.g., *take* in *retake*), but not bound stems (i.e., stems that are not existing words in their own right; e.g., juvenate in *rejuvenate*) can be considered. A later study supported the constraint proposed on the decompositional route. Using an auditory lexical decision task, Wurm[16] showed that auditorily presented nonwords that contained real stems in English (e.g., po-ceive) were rejected more slowly than those which had no real stems embedded (e.g., po-deive). More interestingly, however, the effect was more pronounced when the embedded stems were free (e.g., re-call) than when they were bound (e.g., po-ceive). Wurm concluded that free stems have more semantic connectivity and usability in new combinations than bound stems and therefore were stronger candidates for recognition. This distinction between bound and free stems is crucial for the current study.

To summarize, models of morphological processing extend from full parsing decomposition-based accounts to full listing continuous accounts. Hybrid dual-route models, on the other hand, provide a middle ground. However, empirical evidence for morphemic decomposition, as reviewed below, either within single full parsing models or dual route models is compelling. Therefore, the aim of the current research is not to examine morphological decomposition per se but rather to test if decomposition takes place in the same manner across all types of morphologically complex words. In general terms, we want to investigate the constraints governing morphological decomposition and whether different properties of morphologically complex words can impact the mechanism underlying decomposition.

1.2. How Does Decomposition Operate?

If decomposition is the primary mechanism for recognizing morphologically complex words it is crucial to understand how it operates. Various theories have been proposed. The affix-stripping model[5], suggests that affixes are stripped from complex words at an early pre-lexical stage, leading to the identification of the stem (e.g., (re+build+s). The speed and accuracy of processing the stem depends largely on its frequency. More recent research suggests that affix-stripping process is meaning-independent, allowing for the decomposition of both true complex words (e.g., *keeper*) and pseudo-complex ones (e.g., *corner*)[17]. Rastel et al. conducted masked priming experiments comparing semantically and morphologically related primes and targets (e.g., *cleaner*-CLEAN), semantically unrelated but morphologically related primes and targets (e.g., *corner*-CORN), and both semantically and morphologically unrelated primes and targets (e.g., *brothel*-BROTH). They found significant priming effects in the first two conditions, supporting the idea that decomposition operates mainly on morphological basis and is not influenced by semantic relationships. In a similar vein, Taft et al.[18] manipulated stems and affixes in auditory and visual lexical decision tasks using real and unreal affix+stem combinations. They found that rejecting unreal affix+real stem combinations was faster than real affix+real stem ones, indicating that affix stripping did not occur in the former, leading to faster rejection due to whole-word processing. Overall, these findings contribute to our understanding of how decomposition functions in the processing of morphologically complex words

In another decomposition account, the affix plays a secondary role in the decomposition process. Unlike the affix-stripping model, the edge-aligned embedded word activation account postulates that the mechanism of decomposition is initiated by extracting the edge-aligned embedded stem rather than stripping the affix[19]. That is, stem extraction and activation is the primary process of decomposition. Affix stripping, on the other hand, can be resorted to only when "embedded word activation is hindered" ([19], p. 285). Although this account was originally postulated to account for decomposition in visual word recognition, evidence for this account was also observed in spoken word recognition. For example, Zhang and Samuel[20] used multiple auditory-auditory priming experiments to investigate the different conditions that govern the activation of embedded words in initial position (e.g., ham in hamster) or final position (e.g., bone in trombone). Their findings supported the activation of embedded words. However, activation was modulated by a number of factors including the size of the embedded word relative to the carrier word, the position of the embedded word in the carrier word, and listening conditions.

The two decomposition accounts discussed above can directly accommodate priming effects of regular forms that include overt affixes (e.g., *instructed*-INSTRUCT). However, priming effects of irregular forms (e.g., *taught*-

TEACH) require processing at a more abstract level. This abstract level of processing and decomposition is captured by the single-route full decomposition account [21]. In this account, decomposition does not only take place when there are overtly linearly combined stems and affixes (e.g., instructed), but also when complex forms do not contain these overt constituents. A word such as *taught* will be decomposed into the stem *teach* and an abstract past tense morpheme (ibid).

1.3. Frequency Effects in Decomposition

Frequency has been utilized to examine the validity of decomposition versus full-listing models of complex word processing. Specifically, researchers have investigated the effects of two types of frequencies: surface frequency (i.e., the frequency of the entire word itself, such as 'builder') and base frequency (i.e., the overall frequency of all words containing the stem 'build'). The impact of surface frequency has been considered as supporting evidence for full-listing models [8], while the influence of stem frequency has been viewed as supporting decomposition-based models [6, 7]. In dual-route models, however, both the entire word and its constituent morphemes are represented, thus both types of frequencies are expected to affect the lexical processing of complex words.

Ample cross-linguistic evidence suggests that decomposition initiates the recognition of various types of morphologically complex words. A seminal study by Taft and Forster [5] was the first to provide evidence for morphological decomposition in lexical processing. Taft and Forster utilized multiple lexical decision tasks to investigate the factors influencing response latency and accuracy rates in rejecting nonwords. Their findings revealed that participants were slower and less accurate in rejecting prefixed nonwords containing bound stems (e.g., dejuvenate as juvenate appears in the real word rejuvenate) compared to nonwords without bound stems (e.g., depertoire). Additionally, nonwords that were bound stems of existing prefixed words (e.g., juvenate) were slower and less accurate to reject than nonwords that were not stems of prefixed words (e.g., luvenate). In a subsequent study, Taft [6] demonstrated that stem frequency (e.g., the frequency of the stem 'build' in 'rebuilds') influenced response latency. The effect of stem frequency in processing morphologically complex words was interpreted as evidence supporting an early pre-lexical morphological decomposition of such words into stems and affixes. Similarly, effects of both surface frequency and stem frequency were demonstrated in the spoken word recognition of suffixed words. Meunier and Segui [22] found that the speed of lexical decision to auditorily presented suffixed words was influenced by both surface and stem frequencies. These findings indicated that suffixed words in French can be processed through both a decompositional route and a whole-word route, thus supporting a dual-route model of auditory word recognition for suffixed words.

However, recent studies have shown a lack of stem frequency effect in the lexical processing of certain morphologically complex words [1]. Instead, the impact of surface frequency was evident, indicating that the whole word surface frequency of a complex word like 'rebuilds' was more significant than the stem frequency of 'build'. These results were interpreted as evidence against obligatory decomposition, suggesting that complex words are initially processed in terms of their full form [11]. The absence of a stem frequency effect was seen as supporting the existence of dual processing routes, where simultaneous activation of the whole word and its constituent morphemes occurs [12, 13, 23].

Nevertheless, Taft [7] argued against the assumption that the lack of base frequency effect supports a single whole-word or parallel processing route. He rather maintains that obligatory decomposition will always occur at the early pre-lexical stage. However, influences at the later stage of recombining the stem and affix, where surface frequency emerges, can obscure the base frequency effect that emerged in the early obligatory decomposition stage. That is, the more difficult the recombination stage, the more obscured the base frequency effect. Therefore, since a high base frequency word such as 'moon' rarely combines with the affix *–s,* the advantage of having a high base frequency will be counterbalanced by the more difficult combinability of these two morphemes at the recombination stage. Thus, the processing time of the word 'moons' will be comparable to that of a low base frequency word such as 'fangs', but one that has a relatively easier combinability of its morphological constituents.

Apparently, different models of polymorphemic word recognition differ in their interpretations of the lack of base frequency effect. On the one hand, it was taken as evidence for the activation of whole-word representations either solely or in parallel with the representations of morphemic constituents. On the other, the obligatory decomposition model interprets this as a counterbalancing effect at the recombination stage. Despite different interpretations, the findings collectively support a dual route model in which the recognition of a morphologically complex word can be achieved via the access of its whole-word representation, the representations of its constituent morphemes, or both in parallel [24]. Recent evidence suggests that one of the factors that will determine which route will be used is the productivity of the affix. Words with more productive affixes will be decomposed rather than processed holistically [25].

1.4. Decomposition of Morphologically Complex Words in Arabic

The majority of the studies discussed above investigating lexical processing have traditionally focused on languages with concatenative (i.e., linear) morphology. In concatenative morphology languages such as English, morphologically simple words consisting of only one morpheme (i.e., a stem; e.g., call) are common. Complex words, on the other hand, are formed by linearly attaching a bound morpheme (i.e., affix) to either a bound stem (e.g., re+juvenate) or a free stem (e.g., re+call). This process can be utilized in inflections (e.g., call+s) or derivations (e.g., caller). Therefore, the impact of stem frequency on the processing of morphologically complex words has traditionally been interpreted as supporting morphological decomposition.

However, non-concatenative (non-linear) morphology languages such as Arabic provide an interesting case for the examination of models of complex word processing. In Arabic, virtually all words are intrinsically complex [26]. This is because even simple (i.e., non-affixed) words are structured by nonlinearly interweaving two morphemes: a consonantal root and a vowel pattern. For example, the word /qaTʕ/ 'cutting' in Arabic is derived by mapping the root consonants qTʕ into the vowel pattern faʕl, where the three consonants f, ʕ, and l in the pattern represent placeholders for root consonants. However, three different instantiations of the root and pattern model were developed to account for the derivation of a more complex form such as the *place noun* /maqTaʕ/ 'section'. One view that acknowledges prefixation as a method of complex word derivation in Arabic is prosodic in nature [27]. In this view, a complex form such as /maqTaʕ/ can be broken into the prefix [ma], the root qTʕ, a vocalic melody *a*, and a CV skeleton.

Although there are other instantiations of the root and pattern model that do not involve affixation as a method of derivation in Arabic (see Cohen [28]), in the present study, we follow the perspectives of McCarthy [27] and Holes [26] and assert that more complex forms in Arabic, such as /maqTaʕ/, are derived through a process of prefixation. Therefore, Arabic encompasses both concatenative and non-concatenative morphological forms. We thus hypothesize that the recognition of these complex words in Arabic involves not only non-concatenative decomposition to access the root morpheme, but also a process of concatenative decomposition into a prefix and a stem. An obligatory non-concatenative decomposition model has been proposed for Arabic [29], suggesting that lexical processing in Arabic entails an early mandatory parsing route where all morphologically complex forms are decomposed into root and pattern morphemes. This model has been empirically supported in Arabic through various paradigms, including priming (e.g., [30–32]), silence replacement (e.g., [33]) and magnetoencephalography [34].

Nevertheless, other studies suggest that under some conditions words in Arabic can also follow a whole-word route of processing. For example, Wray [35] manipulated root and pattern frequencies in a number of lexical decision experiments. She found out that whereas verbs embedded in productive patterns were influenced by root frequency indicating decomposition, verbs embedded in less productive patterns were influenced by surface frequency indicating whole word access. These findings, similar to those discussed above showing an affixal productivity effect, demonstrate that both routes of processing can be used in Arabic, with the productivity of the pattern imposing a constraint on the decomposition route (see also Al-Omari [36] for evidence of both whole-word and constituent morphemes activation in spoken word recognition in Arabic).

More recently, Alamri [37] contrasted the processing of prefixed words in Arabic with those formed only by mapping roots into patterns. He utilized the visual word paradigm with eye-tracking in which both fixation location and duration are measured. Alamri aimed to examine root effects independent of phonological and semantic influences by manipulating the phonological, morphological, and semantic relatedness of the competing pictures to the spoken word. Two types of words were used: non-prefixed target words (e.g., /farʃah/ 'rug') and prefixed target words (e.g., /ma-sbaħ/ 'swimming pool'). Alamri discovered that root effects were more prominent in the context of prefixed words, suggesting decomposition. Non-prefixed words, on the other hand, were processed more rapidly through the whole-word route.

Taken together, the studies discussed above suggest that a single obligatory decomposition route in Arabic cannot be taken for granted to account for differences in processing of all types of words. Rather, more recent evidence suggests that Arabic spoken word recognition can proceed via dual routes: a whole-word route and a morphological (i.e., root and pattern) decomposition route. Several factors seem to promote decomposition over whole-word processing. These factors include the productivity of the pattern and the morphological complexity of the words (i.e., prefixation).

2. The Current Study

As discussed above, prefixed morphologically more complex words in Arabic provide a unique test case for examining the constraints governing the selection of access routes in spoken word recognition. This is because prefixed words in Arabic encompass both concatenative and non-concatenative morphological forms. For instance, consider the verb /taqaTTaʕ/ 'be cut' (intransitive and reflexive). On one hand, it features the concatenative prefix ta- attached linearly to the free stem /qaTTaʕ/ 'cut' (transitive and intensive). On the other hand, the free stem /qaTTaʕ/ is formed non-linearly by mapping the root qTʕ into the pattern faʕʕal. However, when forming the noun, a modification of the stem occurs. Specifically, the last vowel /a/ is replaced with /u/, resulting in the bound stem /qaTTuʕ/. Thus, while linear affix-stripping in Arabic of the verb /taqaTTaʕ/ would retain a free stem (i.e., /qaTTaʕ/ is an existing word in Arabic), affix stripping the noun /taqaTTuʕ/ would leave a bound stem (i.e., /qaTTuʕ/ is not a word in Arabic).

The aim of the current paper is to investigate whether the lexicality of the stem determines the processing route in Arabic. We specifically ask if processing prefixed words in Arabic would always follow a root-based decomposition route or whether this is contingent on the nature of the stem. Does the difference between prefixed nouns and verbs in terms of the lexicality of the stem lead to different routes of lexical processing in Arabic? This question is both empirically and theoretically motivated. Recall that Wurm[15] proposed a constraint on the morphemic route in their dual-route model, where only free stems (e.g., take in retake) are considered after affix-stripping, not bound stems (i.e., stems that are not existing words in their own right) (e.g., juvenate in rejuvenate). This constraint was empirically supported in English. Using an auditory lexical decision task, Wurm[16] found that embedding real English stems in auditorily presented nonwords had a more pronounced effect when the embedded stem was a free stem rather than a bound stem. Wurm concluded that free stems have more semantic connectivity and usability in new combinations than bound stems, making them stronger candidates for recognition. Whether the lexical processing route of a spoken prefixed word in Arabic depends on the lexicality of the stem remains an open question.

Here, we hypothesized that if the root-based non-concatenative decomposition is an obligatory processing route in spoken word recognition in Arabic, then root frequency effects should not be largely affected by the contrast in the lexicality of the stem between prefixed nouns and prefixed verbs. A lexicality effect, on the other hand, would provide evidence that highlights some conditions in which morphological processing can follow a different route (i.e., a whole word or stem-based route) for some types of words in Arabic. To this effect, we compared lexical decision times of auditorily presented prefixed nouns and verbs in Arabic. In these words, root type frequency was manipulated, and stem and surface frequencies were held constant. An obligatory root-based non-concatenative decomposition account will be supported if root type frequency affects the speed of recognition equally in both types of words. However, a dual-route account will be reinforced if root frequency affects recognition time in nouns only, but not in verbs. Here are our research questions:

Research Question 1. *Is there an effect of Arabic root type frequency on the speed of processing prefixed nouns that is independent of surface (Whole Word) frequency?*

Hypothesis 1. *Prefixed nouns in Arabic are obligatorily decomposed into roots and patterns in spoken word recognition. Therefore, we expect to find an effect of root type frequency on processing.*

Research Question 2. *Is there an effect of Arabic root type frequency on the speed of processing prefixed verbs that is independent of both stem and surface frequencies?*

Hypothesis 2. *Prefixed verbs in Arabic contain a free stem based on which a lexical decision can be made prior to root-based decomposition. Therefore, we do not expect to find an effect of root type frequency on processing.*

2.1. Method

An auditory lexical decision (LD) task was utilized in the present study to examine the impact of root type frequency on the recognition of prefixed nouns and verbs in Arabic. During the auditory LD task, participants were presented with spoken stimuli and required to indicate promptly whether each stimulus was a real Arabic word or a nonword by pressing a corresponding button. The choice of an LD task in this study was advantageous as it is known to be sensitive to frequency effects in both auditory (e.g.,[38]) and the visual domains (e.g.,[39]). Furthermore, using the LD task enabled the investigation of type frequency effects of the same roots in nouns and verbs, thereby mitigating potential confounds that could arise from testing different roots across word types.

2.2. Participants

Twenty-nine native Arabic speakers took part voluntarily in the experiment. All participants were male college students with no reported history of speech or hearing problems. Their ages ranged from 18 to 23 years, with a mean age of 21 years old.

2.3. Materials

Aralex[31] was utilized for the selection and frequency calculations of our stimulus items. Aralex is an online Arabic database that relies on a corpus of 40 million words. It provides access to surface frequencies, as well as type and token frequencies of stems, roots, and patterns for Arabic words. Token frequencies of words are determined by their occurrence rate per one million words in the corpus. For example, a surface frequency of 0.1 indicates that the specific word has been observed 4 times in the 40-million-word corpus.

A total of 40 Arabic quadriliteral roots (e.g., dħrdʒ) were selected. Half of the target roots (N = 20) had high root type frequency (SD = 1.79, range = 5–10, mean = 5.65), while the other half had low root type frequency (SD = 1.01, range = 1–4, mean = 2.4). These roots were chosen specifically because, after being mapped into patterns, they allowed for the manipulation of root type frequency while keeping both stem and surface frequencies constant for verbs and surface frequency for nouns. Root type frequency was used instead of root token frequency in creating our stimuli, as it has consistently been shown to impact the decomposition of surface forms into their constituent morphemes in Arabic (e.g.,[32, 40]).

To create the 40 prefixed verbs, the roots (e.g., dħrdʒ) were initially mapped into the verb pattern CaCCaC. To get the augmented (i.e., prefixed) form, the prefix ta- was then added to the pattern to produce the pattern taCaCCaC. The prefix ta- causes the meaning of the pattern to become reflexive, so the verb /daħradʒ/ 'roll' (transitive and causative) becomes /tadaħradʒ/ 'roll' (intransitive and reflexive)[26]. On the other hand, the 40 prefixed nouns were created by a simple modification to the prefixed verb pattern. The last vowel (i.e., /a/) in the verb /tadaħradʒ/ was replaced with the vowel /u/ to produce the prefixed (verbal) noun /tadaħrudʒ/ 'the act of rolling'. Similarly, the mapping of the root zħlq in these two patterns produced two words: the verb /tazaħlaq/ 'slid' (intransitive and reflexive) and the noun /tazaħluq/ "the act of sliding", respectively. It is important to note that while linear affix-stripping in Arabic of the verb /tazaħlaq/ would result in a free stem (i.e., /zaħlaq/ 'slid' (transitive, causative) is an existing word in Arabic), affix stripping the noun /tazaħluq/ would leave a bound stem (i.e., /zaħluq/ is not a word in Arabic). Therefore, verbs have both surface frequency (i.e., the whole word frequency of /tazaħlag/) and stem frequency of /zaħlaq/, whereas nouns only have surface frequency (i.e., tazaħluq).

These frequencies were matched between the two root type frequency groups. High root frequency verbs had an average surface frequency of 0.437 counts per million (SD = 0.575, range = 0.03–1.71 counts per million); low root frequency verbs had an average surface frequency of 0.167 counts per million (SD = 0.329, range = 0.03–1.55 counts per million). Additionally, high root frequency verbs had an average stem frequency of 0.555 counts per million (SD =

0.703, range = 0.00–2.24 counts per million); whereas low root frequency verbs had an average stem frequency of 0.484 counts per million (SD = 0.764, range = 0.00–2.6 counts per million). The difference between these frequencies of the two verb root frequency groups was not statistically significant ($p > 0.05$). Likewise, high root frequency nouns had an average surface frequency of 0.238 counts per million (SD = 0.462, range = 0.00–1.74 counts per million); low root frequency nouns had an average surface frequency of 0.166 counts per million (SD = 0.617, range = 0.00–2.73 counts per million). The difference between these frequencies of the two noun root frequency groups was not statistically significant ($p > 0.05$).

Importantly, this process of creation allowed for matching target words between root frequency conditions on several variables, including length in terms of number of phonemes and syllables, and initial phoneme, which influences the word's cohort activation [41]. Additionally, the 80 target words were matched in terms of the word uniqueness point (UP) (i.e., the phoneme at which only one word becomes a candidate for recognition) [42] and the root uniqueness point (i.e., the phoneme at which only one root becomes a candidate for recognition) [15]. The whole word UP was at phoneme number seven (e.g., the last /a/ in /tadaħradʒ/) and the root uniqueness point was at phoneme number six (e.g., the last /r/ in /tadaħradʒ/) across all items. Both of these points have been shown to impact response latency in spoken word recognition (e.g., [15, 38]), making it crucial to control for them.

The final list of stimuli consisted of 160 items, including 80 real words and 80 nonword fillers. The nonword fillers were generated by mapping pseudo roots in the same verb and noun patterns as the real words. Each stimulus item was individually spoken and recorded by a male native Arabic speaker using a high-quality microphone onto digital-audio-tape at a sampling rate of 44.1 kHz. Subsequently, the recordings were stored as digital 16-bit files on a computer disk. The initial silence duration was standardized to 50ms across all stimulus files.

2.4. Procedure

The current auditory LD task was run, including presentation and data collection, by E-prime [43]. Participants were assessed individually, with each one tested separately. They were seated in front of a computer running E-Prime and wore Beyerdynamic DT-100 headphones. Before the experiment began, instructions were displayed on the screen in Arabic. Participants were informed that they would hear a mix of stimuli, including actual Arabic words and nonwords, and they were instructed to identify which items were real words and which were not by pressing the corresponding key on the keyboard. All questions from the participants were addressed before the experiment started.

Before the experimental trials, each participant completed 10 practice trials to familiarize themselves with the task. These included five real words and five nonwords, and the results from these trials were excluded from the final analysis. Participants then listened to a randomly selected list of stimuli at a comfortable volume through the headphones. The "P" key was designated for real word responses, while the "W" key was for nonword responses. Participants were asked to respond as quickly and accurately as possible by pressing the appropriate button. After each response, there was a pause of 1500 ms before the next stimulus was presented. RT was recorded from the start of the stimulus to the moment the response was made.

3. Results

Three participants were excluded from the analysis due to a high (above 50%) percentage of errors. Therefore, the reported results are based on data collected from 26 participants. Results of prefixed nouns and verbs will be presented separately.

3.1. Root Frequency Effects on Prefixed Nouns

For the sake of convenience, we reiterate the pertinent hypothesis here:

Hypothesis 1. *Prefixed nouns in Arabic are obligatorily decomposed into roots and patterns in spoken word recognition. Therefore, we expect to find an effect of root type frequency on processing.*

To test this hypothesis, we employed ANCOVA (Analysis of Covariance). ANCOVA is used to evaluate whether there is a significant effect of root type frequency on response latency for prefixed nouns, while controlling for the effect of whole word surface frequency.

The analysis entailed comparing the impact of root type frequency conditions (high vs. low) on reaction time for all 40 prefixed nouns. The balanced group sizes aided in avoiding biases that could result from unequal sample distributions, enabling the analysis to concentrate on the influence of root type frequency on reaction time while controlling for whole word frequency.

In **Table 1**, the mean reaction time for high type root frequency nouns indicates that prefixed nouns with high root type frequency are processed faster on average than those with low root type frequency. The relatively small standard deviations in both groups suggest a consistent pattern in reaction times within each group. However, the observed difference in means will be further analyzed using ANCOVA to determine whether it remains statistically significant after controlling for the effect of whole word frequency.

Table 1. Mean reaction time in milliseconds by root type frequency for prefixed nouns.

Dependent Variable: Reaction Time			
Root Type Frequency	**Mean**	**Std. Deviation**	**N**
High	1291.46994	97.790549	20
Low	1377.29446	94.794379	20
Total	1334.38220	104.524421	40

Levene's test in **Table 2** assesses the assumption of homogeneity of variances, which is essential for the validity of ANCOVA results. The test determines whether the variance of the dependent variable (reaction time) is consistent across the two root frequency groups. In this instance, the F-value is 0.399 with a significance value (Sig.) of 0.531, exceeding the conventional threshold of 0.05. Consequently, the assumption of homogeneity of variances is met, enabling a reliable ANCOVA analysis. This outcome enhances the reliability of subsequent inferential tests by confirming that differences in reaction times are not attributed to unequal variability between the groups.

Table 2. Levene's test of equality of error variances.

Dependent Variable: Reaction Time			
F	**df1**	**df2**	**Sig.**
0.399	1	38	0.531

Table 3 presents the results of the ANCOVA examining the effect of root type frequency on reaction time, while controlling for whole word frequency (WW frequency).

- **Corrected Model**: The overall model, which includes the intercept, root type frequency, and whole word frequency, is significant (F = 4.098, p = 0.025). This suggests that the model explains a significant portion of the variance in reaction times. The partial eta squared value of 0.181 indicates that 18.1% of the variance in reaction time is explained by the model.
- **WW Frequency**: The effect of whole word frequency on reaction time is not significant (F = 0.383, p = 0.540), indicating that it does not significantly influence the processing speed of prefixed nouns. The partial eta squared value is very small (0.010), confirming a minimal effect.
- **Root type frequency**: The root type frequency (high vs. low) has a significant effect on reaction time (F = 7.546, p = 0.009). The partial eta squared value (0.169) suggests that root type frequency accounts for 16.9% of the variance in reaction times, independently of whole-word frequency. This supports the hypothesis that root type frequency significantly affects the speed of processing prefixed nouns.

In summary, this analysis demonstrates that root type frequency significantly affects reaction times for prefixed nouns, even when controlling for whole-word frequency. The ANCOVA results show a significant impact of root type frequency on the reaction time of prefixed nouns (F = 7.546, p = 0.009), indicating its substantial influence on the processing speed of these nouns, regardless of whole-word frequency. The Partial Eta Squared value of 0.169 suggests a moderate effect size, highlighting the meaningful contribution of root type frequency to the variance in reaction time. This finding supports the hypothesis that root type frequency plays a crucial role in the processing of prefixed nouns, as expected in the decomposition of these nouns into their roots and patterns during recognition.

3.2. Root Frequency Effects on Prefixed Verbs

For the sake of convenience, we restate the relevant hypothesis here:

Hypothesis 2. *Prefixed verbs in Arabic contain a free stem based on which a lexical decision can be made prior to root-*

Table 3. ANCOVA of reaction time by root type frequency for prefixed nouns.

Dependent Variable: Reaction Time						
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Corrected Model	77267.693[a]	2	38633.846	4.098	0.025	0.181
Intercept	62576136.750	1	62576136.750	6637.548	0.000	0.994
WW frequency	3609.212	1	3609.212	0.383	0.540	0.010
root type frequency	71140.852	1	71140.852	7.546	0.009	0.169
Error	348821.137	37	9427.598			
Total	71649123.270	40				
Corrected Total	426088.829	39				
R Squared = 0.181 (Adjusted R Squared = 0.137)						

based decomposition. Therefore, we do not expect to find an effect of root type frequency on processing.

To test this hypothesis, ANCOVA was used to assess whether there are significant differences in reaction time, shown in **Table 4** below, due to the root type frequency, while controlling for potential confounding variables such as Whole-Word frequency and Stem frequency. This helps in understanding whether root type frequency independently impacts the speed of processing beyond the effect of other variables.

Table 4. Mean reaction time in milliseconds by root type frequency for prefixed verbs.

Dependent Variable: Reaction Time			
Root Type Frequency	**Mean**	**Std. Deviation**	**N**
High	1326.0775	132.77650	20
Low	1387.0970	120.73204	20
Total	1356.5873	129.01446	40

Levene's Test was performed to assess the assumption of homogeneity of variance, a prerequisite for ANCOVA. This test evaluates whether the error variances of the dependent variable (reaction time) are equal across the levels of the independent variable (root type frequency). In this instance, the **p-value (Sig.)** is 0.380, exceeding the typical significance threshold of 0.05. This outcome suggests that there is no significant difference in the error variances between the "High" and "Low" root type frequency groups, meaning the assumption of homogeneity of variance is satisfied. Therefore, the ANCOVA analysis, shown in **Table 5**, can proceed with confidence that the variances are approximately equal across groups.

Table 5 provides insights into the impact of various factors on reaction time of prefixed verbs:

- **Corrected Model**: The model as a whole has an F-value of 1.851 with a p-value of 0.155. This suggests that the model, including all predictors, is not statistically significant in explaining the variance in reaction time, as the p-value exceeds the common significance level of 0.05. The partial eta squared value of 0.134 indicates a small effect size.
- **Intercept**: The intercept is highly significant ($F = 2484.030$, $p < 0.001$) and explains a substantial portion of the variance in reaction time, as indicated by the partial eta squared value of 0.986.
- **WW frequency**: Whole word frequency demonstrates an F-value of 2.096 with a p-value of 0.156, indicating non-significance. The partial eta squared value of 0.055 implies a small effect size.
- **Stem frequency**: Stem frequency similarly does not have a significant impact on reaction time ($F = 1.086$, $p = 0.304$), with a partial eta squared value of 0.029, suggesting a minimal effect size.
- **Root type frequency**: The effect of root type frequency on reaction time is not statistically significant ($F = 0.838$, $p = 0.366$). The partial eta squared value of 0.023 indicates a very small effect size, suggesting that root type frequency does not have a meaningful impact on reaction time when controlling for other variables.

Overall, the **R Squared** value of .134 (with an adjusted R Squared of 0.061) indicates that the model explains only a small portion of the variance in reaction time, suggesting that other factors not included in the model may be influencing the reaction times.

In summary, ANCOVA analysis revealed that root type

Table 5. ANCOVA of reaction time by root type frequency for prefixed verbs.

Dependent Variable: Reaction Time						
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Corrected Model	86762.464[a]	3	28920.821	1.851	0.155	0.134
Intercept	38804828.250	1	38804828.250	2484.030	0.000	0.986
ww frequency	32743.032	1	32743.032	2.096	0.156	0.055
Stem frequency	16959.545	1	16959.545	1.086	0.304	0.029
root type frequency	13096.598	1	13096.598	0.838	0.366	0.023
Error	562382.026	36	15621.723			
Total	74262303.160	40				
Corrected Total	649144.490	39				
R Squared = 0.134 (Adjusted R Squared = 0.061)						

frequency did not significantly affect the reaction time for prefixed verbs ($F = 0.838$, $p = 0.366$). The Partial Eta Squared value of 0.023 indicates a very small effect size, suggesting that root type frequency does not explain much of the variance in reaction time for verbs. This result confirms the hypothesis that root type frequency would not affect processing speed in prefixed verbs, highlighting that the processing of prefixed verbs may not be reliant on root type frequency as observed in nouns. This implies that the lexical decision for prefixed verbs could be more influenced by other factors such as the stem or whole word frequencies which were controlled for across conditions.

4. Discussion

The current study investigated a primary research question: is the root-based decomposition route a precursor of lexical access for all spoken words in Arabic [29], or can the recognition of certain words be achieved through a whole-word or stem-based route? The findings from this study provided evidence that root-based access may not be the most efficient mechanism for lexical processing in some Arabic words. By manipulating root type frequency and keeping whole-word and stem frequencies constant, it was discovered that root type frequency significantly impacts the processing speed of prefixed nouns but not prefixed verbs. High root type frequency prefixed nouns were recognized more quickly than low root type frequency prefixed nouns. However, the results indicated no significant differences in response latency based on root type frequency in prefixed verbs.

The significant effect of root type frequency on processing prefixed nouns was hardly surprising. It replicates root effects that have been consistently shown in studies using different paradigms to investigate word recognition in Arabic (e.g., [30, 33, 34, 44, 45]). The robust root type frequency effects in prefixed nouns clearly indicate that our subjects have utilized an obligatory root-based decomposition route. However, the lack of a root type frequency effect in prefixed verbs is striking. It suggests that different mechanisms are at play in the processing of prefixed verbs. The difference in root type frequency effects between prefixed nouns and prefixed verbs was true despite the fact that identical roots were used across the root type frequency conditions in both types of words. One plausible interpretation is that the lack of a root type frequency effect in prefixed verbs could be due to the structural differences in how prefixed nouns and prefixed verbs are formed in Arabic. Recall that linear affix-stripping in Arabic of a prefixed verb such as /tazaħlaq/ 'slid' (intransitive, reflexive) would keep a free stem (i.e., /zaħlaq/ 'slid' (transitive, causative) is an existing word in Arabic). Conversely, however, a bound stem would remain after affix stripping the prefixed noun /tazaħluq/ 'the act of sliding' (i.e., /zaħluq/ is not a word in Arabic). Therefore, whereas word recognition (or at least lexical decision) of prefixed nouns may require more detailed non-concatenative root-based analysis, root access is less efficient in the processing of prefixed verbs compared to prefixed nouns. In other words, recognition of prefixed verbs might rely more on surface-level information or concatenative stem-based processing.

Our findings are consistent with a dual route processing model of spoken word recognition, where both a morphological decomposition route and a whole-word route can be utilized, with the effectiveness of each route being influenced by various factors [15, 24]. Previous studies on concatenative morphology languages have shown that specific conditions can determine the processing route employed (e.g., [1, 12, 15, 16, 46, 47]). For instance, Wurm [15] proposed a constraint on the morphemic route, suggesting that only free stems (e.g., 'take' in 'retake'), and not bound stems (e.g., 'juvenate' in 'rejuvenate'), should be considered in affixed morphologically complex words. Wurm [16] demonstrated that the impact of stem frequency in auditory lexical decision tasks was more prominent when the embedded stems were free (e.g., 're-call') compared to when they were bound (e.g., 'po-ceive'). According to Wurm, free stems were more robust candidates for recognition due to their higher semantic connectivity and potential for use in new combinations than bound stems. It is noteworthy that only prefixed verbs in our study featured a free stem (e.g., /zaħlaq/ in /tazaħlaq/), which may have influenced our results by utilizing the free stem rather than the root in lexical access. Consequently, we observed no significant difference in response latency based on root type frequency in the context of prefixed verbs.

Other similar constraints limiting the root-based decomposition route were found in studies investigating spoken word recognition in Arabic. Alamri [37] contrasted the processing of prefixed words and non-prefixed words in Arabic spoken word recognition. He found that while non-prefixed words were more quickly processed by the whole-word route, root effects were more pronounced in the context of prefixed words, suggesting decomposition. Similarly, the productivity of the pattern seems to impose a constraint on the decomposition route in Arabic spoken word recognition. Wray [35] found that Arabic verbs embedded in productive patterns were influenced by root frequency, indicating decomposition, while verbs embedded in less productive patterns were influenced by surface frequency, indicating whole-word access.

The current study provides another constraint on the obligatory root-based decomposition route in spoken word recognition in Arabic. It shows that both processing routes can be utilized in Arabic, with the route chosen dependent on the lexicality of the stem in prefixed words. However, as both whole-word frequency and stem frequency were controlled in our stimuli, we are unable to definitively determine which access unit (whole word or the stem) influenced lexical decisions in prefixed verbs. Subsequent research could manipulate these two frequencies to better isolate their impact on spoken word recognition of prefixed verbs.

Nevertheless, recall that Taft [7] has argued against the assumption that the lack of base frequency effect in complex words is sufficient evidence that obligatory morphological decomposition has not occurred. He rather maintained that obligatory decomposition will always occur at the early prelexical stage. However, influences at the later stage of recombining the stem and affix, where surface frequency emerges, can obscure the base frequency effect in the early obligatory decomposition stage. That is, the more difficult the recombination stage the more obscured the base frequency effect. Therefore, since a high base frequency word such as 'moon' rarely combines with the affix -s the advantage of having a high base frequency will be counterbalanced by the easier combinability of a low base frequency word such as 'fangs'. At first glance, our results of prefixed verbs may appear to provide counterevidence for Taft's early decomposition model. However, a closer examination reveals that the present findings of prefixed verbs are consistent with an early concatenative decomposition model in which affixes of complex words are stripped and the stem is identified. It is exactly because of this process, rather than despite of it, only prefixed nouns, which did not reveal a free stem after affix stripping, were influenced by root type frequency. That is, both prefixed nouns and verbs may have been concatenatively decomposed into a prefix and a stem. However, whereas lexical access of a prefixed verb proceeded via the free stem, lexical access of a prefixed noun required a further process of non-concatenative decomposition and root identification.

Can the absence of a root type frequency effect in prefixed verbs be explained by the potentially more challenging combinability between the root and pattern in prefixed verbs compared to prefixed nouns? Has non-concatenative root-based decomposition and access occurred in prefixed verbs, with processing costs at the recombination stage potentially reversing its effect as proposed by Taft [7] and more recently supported by Hermena et al. [48]? Our results do not support this explanation. This is because the word types used in our experiment do not align with the conditions necessary for a reversal of the root frequency effect as suggested by Taft. We utilized identical roots across the root type frequency conditions for both word types and ensured whole-word and stem frequencies were matched across conditions to maintain recombination stage difficulty comparability. Despite these efforts, significant facilitation of high type frequency was only observed in prefixed nouns. This discrepancy may indicate that the nature of the stem not only influences the selection of the access route but also determines which route is exclusively utilized. Our current findings do not allow for further speculation on whether a deliberate manipulation of roots and patterns could reverse the root type frequency effect at the recombination stage in prefixed nouns. Future research could employ such manipulations to differentiate between the lack of a root frequency effect at the pre-lexical stage and a potential reversal effect at the recombination stage.

The novelty of our findings lies in the specific constraints identified on root-based decomposition in Arabic, particularly regarding prefixed verbs. Our study uniquely illustrates that the root effect is not uniform across all morphological forms, challenging the assumption of obligatory root-based processing for all spoken words in Arabic. This nuanced understanding aligns with dual-route models of morphological processing, which posit that both root-based and whole-word processing routes can coexist and are employed based on specific lexical characteristics. In this study, the differential effects of root type frequency on prefixed nouns versus prefixed verbs underscore the need for models that accommodate variable processing mechanisms contingent on the morphological structure of the word. The clear distinction between the processing of prefixed nouns and verbs offers new insights into how lexical access may vary depending on the inherent properties of the words involved. This finding diverges from earlier studies that examined the processing of complex words without adequately distinguishing between word types or controlling for competing frequency factors. Additionally, our exploration of the implications of free versus bound stems further extends the conversation around morphological processing in Arabic. The observation that prefixed verbs, which contain a free stem, did not exhibit a root type frequency effect suggests that the nature of the stem plays a crucial role in determining the processing route. This insight adds a new layer to the understanding of morphological processing, indicating that the lexical properties of individual words can significantly influence the mechanisms employed during word recognition. In conclusion, the current study provides important evidence that challenges existing theories of morphological processing in Arabic. By demonstrating the variability in processing routes based on word type and morphological structure, we underscore the necessity for models that are adaptable and reflective of the complexity inherent in language. Future research should continue to explore these dynamics, particularly through cross-linguistic comparisons and manipulations of morphological structures, to further elucidate the intricacies of lexical access and processing in morphologically diverse languages.

5. Conclusions

Apparently, the ultimate goal of word recognition in any language is the efficient and accurate processing of information. It seems that characteristics of the words in a given language determine the route in which this goal can be achieved. Whereas some spoken words (i.e., prefixed verbs) in the current LD experiment were sufficiently identified via surface-level information, others (i.e., prefixed nouns) entailed decomposition-based identification of the root. Although previous research provides ample evidence for obligatory root-based decomposition in Arabic (e.g., [30, 32, 45]), the current findings can be accommodated by dual-mechanism, rather than single-mechanism, approaches to morphological processing [1, 11–15]. Admittedly, the current study is not the first to provide evidence for the availability of dual routes in spoken word recognition in Arabic. Nonetheless, it sheds light on a novel constraint on the obligatory root-based decomposition route; namely, the lexicality of the stem in prefixed words. These results contribute to our understanding of morphological processing in Arabic asserting that there are multiple paths to lexical access.

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Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The data that support the findings of this study are available from the author upon reasonable request.

Conflicts of Interest

The author declares no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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