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Morphological Structure in the Arabic Mental Lexicon: Productivity and Priming Effects in
Nominal and Verbal Patterns

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by

Abeer Ali Abbas

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ABSTRACT OF THE DISSERTATION

Morphological Structure in the Arabic Mental Lexicon: Productivity and Priming Effects in

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Professor Megha Sundara, Chair

Semitic languages, including Arabic, are characterized by two types of discontinuous morphemes: roots and word patterns. However, the role of these morphemes in lexical access and representation remains debated. Roots have been found to exhibit robust priming effects across both nominal and verbal patterns. In contrast, word patterns have shown mixed results, with verbal patterns consistently demonstrating stronger priming effects than nominal patterns. While previous research, such as Deutsch et al. (1998), suggested that productivity might explain these differences, no study has directly investigated the role of productivity in the morphological priming of Arabic word patterns. This dissertation addresses this gap by examining whether documented differences between priming between nominal and verbal word patterns are due to

differences in productivity and whether morphological priming in word patterns can be distinguished from the effects of overlap in form and meaning. A total of 583 native Arabic speakers participated in five experiments, including cross-modal priming and masked visual priming tasks. Stimulus onset asynchronies (SOAs) of 32 ms, 42 ms, 48 ms, and 65 ms were varied to investigate the time course of lexical access in word patterns. Stimuli included high- and low-productivity nouns and verbs, compared with orthographic, semantic, and unrelated controls.

The results showed that productivity plays a critical role in explaining the differential priming effects of nominal and verbal patterns. High-productivity word patterns, both nominal and verbal, exhibited robust priming effects, while low-productivity patterns did not, offering new insights into the interaction between productivity and morphological decomposition in Arabic. These findings support the dual-route model of morphological processing, highlighting that high-productivity patterns are accessed via decomposition, while low-productivity patterns rely on whole-word storage. Additionally, the findings showed that word pattern priming effects were found only at longer SOAs (42 ms, 48 ms, and 65 ms) but not at 32 ms, emphasizing that of word patterns activate morphemic representations after roots. Furthermore, high-productivity patterns were distinguished from form and meaning overlap, providing clear evidence for their independent role in morphological decomposition.

The dissertation of Abeer Ali Abbas is approved.

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TABLE OF CONTENTS

1. Introduction.....	1
2. Literature review	2
2.1. Morphological priming and models of morphological representation	3
2.2. Morphological priming in Arabic and Hebrew.....	4
2.3. Distinguishing Morphological Priming from Form and Meaning Effects.....	10
2.4. Comparison of Verbal and Nominal Patterns in Arabic and Hebrew.....	11
2.5. The Effect of Productivity on Priming.....	12
3. The goal and significance of the research.....	14
4. Experiment 1: cross-model priming task	15
4.1 Methods.....	16
4.1.1. Participants.....	16
4.1.2. Materials and design	17
4.1.3. Stimulus validation	19
4.2. Procedure	20
4.3. Data Analysis	21
4.3.1. Statistical Models.....	21
4.3.2. Data Preparation.....	21
4.3.3. Accuracy analysis	22
4.3.4. Reaction Time Analysis.....	22
5. Experiment 2: Masked Visual Priming Task with a 48ms SOA	29
5.1.Methods.....	30
5.1.1.Participants.....	30
5.1.2.Materials and design	30
5.2.Procedure	30
5.3.Data Analysis	31
5.3.1.Statistical Models.....	31
5.3.2.Data preparation.....	32
5.3.4.Accuracy Analysis	32
5.3.5. Reaction Time Analysis.....	33
6. Experiment 3: Masked Visual Priming Task with a 65ms SOA	37
6.1.Methods.....	38
6.1.1.Participants.....	38
6.1.2.Materials, Design, and Procedure	38
6.2.Data analysis	39
6.2.1.Statistical Models.....	39

6.2.2.Data preparation.....	39
6.2.3.Accuracy analysis	39
6.2.4.Reaction Time Analysis.....	40
7. Experiment 4: Masked Visual Priming Task with 42ms SOA	45
7.1.Methods.....	45
7.2.1.Participants.....	46
7.2.2.Materials, design, and procedure	46
7.3. Data analysis	46
7.3.1.Statistical Models.....	46
7.3.2.Data preparation.....	46
7.3.3.Accuracy analysis	47
7.3.4.Reaction Time Analysis.....	47
8. Experiment 5: Masked Visual Priming Task with 32ms SOA	51
8.1. Methods.....	52
8.1.1.Participants.....	52
8.1.2.Materials, Design, and Procedure	52
8.2.Data analysis	52
8.2.1.Statistical Models.....	52
8.2.2.Data preparation.....	52
8.2.3.Accuracy analysis	53
8.2.4.Reaction Time Analysis.....	53
9. SOA Effects on Morphological Priming Across Word Classes and Productivity Levels	56
10. General discussion	59
11. Future Research Directions.....	72
12. Conclusion	73
APPENDIX A: High productive verbs with the template [ʔiC.Ca.CaC], type frequency: 580 ...	74
APPENDIX B: High productive verbs with the template [Ca.CaC], type frequency: 456	74
APPENDIX C: High productive verbs with the template [Caa.CaC], type frequency: 441	75
APPENDIX D: High productive verbs with the template [ta.Caa.CaC], type frequency: 382	75
APPENDIX E: Low productive verbs with the template [ʔiC.CaC.Ca], type frequency: 18.....	76
APPENDIX F: Low productive verbs with the template [is.CaC.CaC], type frequency: 31	76
APPENDIX G: Low productive verbs with the template [ʔiC.Ca.CaC], type frequency: 229	77
APPENDIX H: Low productive verbs with the template [CaC.CaC], type frequency: 296	77

APPENDIX I: High productive nouns with the template [taC.CiiC], type frequency: 632	78
APPENDIX J: High productive nouns with the template [maC.CuuC], type frequency: 469	78
APPENDIX K: High productive nouns with the template [CaC.CaaC], type frequency: 432.....	79
APPENDIX L: High productive nouns with the template [Cu.CuuC], type frequency: 390	79
APPENDIX M: Low productive nouns with the template [Caa.CuuC], type frequency: 88	80
APPENDIX N: Low productive nouns with the template [mu.Caa.CiC], type frequency: 159...	80
APPENDIX O: Low productive nouns with the template [maC.CaC], type frequency: 273.....	81
APPENDIX P: Low productive nouns with the template [Ca.CaaC], type frequency: 294.....	81
References	82

LIST OF FIGURES

Figure 1: Mean reaction times (RT) for high and low productivity nouns and verbs across test, orthographic, semantic, and unrelated control conditions in the cross-model priming task in Experiment 1	25
Figure 2: Mean reaction times (RT) for high and low productivity nouns and verbs across test, orthographic, semantic, and unrelated control conditions in the masked visual priming task with an SOA of 48ms in Experiment 2.....	37
Figure 3: Mean reaction times (RT) for high and low productivity nouns and verbs across test, orthographic, semantic, and unrelated control conditions in the masked visual priming task with an SOA of 65ms in Experiment 3.....	43
Figure 4: Mean reaction times (RT) for high and low productivity nouns and verbs across test, orthographic, semantic, and unrelated control conditions in the masked visual priming task with an SOA of 42ms in Experiment 4.....	51
Figure 5: Mean reaction times (RT) for high and low productivity nouns and verbs across test, orthographic, semantic, and unrelated control conditions in the masked visual priming task with an SOA of 32ms in Experiment 5.....	56
Figure 6: Reaction times across conditions for high- and low-productivity nouns and verbs at different SOAs.....	57
Figure 7: Reaction times across conditions at SOA32.....	58
Figure 8: Reaction times across conditions at SOA 42.....	58
Figure 9: Reaction times across conditions at SOA48.....	58
Figure 10: Reaction times across conditions at SOA 65.....	58

Figure 11: Type Frequency Distribution of Nouns and Verbs in the experiments in this dissertation compared to those in Boudelaa and Marslen-Wilson's (2005) Study.....	64
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LIST OF TABLES

Table 1: Nominal vs verbal patterns; average productivity, median productivity, range of productivity	18
Table 2: Sample set of the stimuli.....	20
Table 3: Accuracy rates (in percentages) for high and low productivity nouns, verbs, and control conditions across all conditions in the cross-modal priming task in Experiment 1	22
Table 4: Mean reaction times (ms) and standard deviations for high and low productivity nouns, verbs, and control conditions across all conditions in the cross-modal priming task in Experiment 1.....	24
Table 5: Accuracy rates (in percentages) for high and low productivity nouns, verbs, and control conditions across all conditions in masked visual priming task with an SOA of 48ms in Experiment 2	32
Table 6: Mean reaction times (ms) with standard deviations in parentheses for high and low productivity nouns, verbs, and control conditions across all conditions in masked visual priming task with an SOA of 48ms in Experiment 2	35
Table 7: Accuracy rates (in percentages) for high and low productivity nouns, verbs, and control conditions across all conditions in the masked visual priming task with an SOA of 65ms in Experiment 3	40
Table 8: Mean reaction times (ms) with standard deviations in parentheses for high and low productivity nouns, verbs, and control conditions across all conditions in the masked visual priming task with an SOA of 65ms in Experiment 3.....	41

Table 9: Accuracy rates (in percentages) for high and low productivity nouns, verbs, and control conditions across all conditions in the masked visual priming task with an SOA of 42ms in Experiment 4.....	47
Table 10: Mean reaction times (ms) with standard deviations in parentheses for high and low productivity nouns, verbs, and control conditions across all conditions in the masked visual priming task with an SOA of 42ms in Experiment 4.....	49
Table 11: Accuracy rates (in percentages) for high- and low- productivity nouns, verbs, and control conditions across all conditions in the masked visual priming task with an SOA of 32ms in Experiment 5.....	53
Table 12: Mean reaction times (ms) with standard deviations in parentheses for high and low productivity nouns, verbs, and control conditions across all conditions in the masked visual priming task with an SOA of 32ms in Experiment 5.....	54
Table 13: Summary of Morphological Priming Effects Across Experiments	62

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1. Introduction

Arabic, like other Semitic languages, features non-concatenative morphology with two abstract morphemes: roots and word patterns (Wright, 1995; Versteegh, 1997; Boudelaa & Marslen-Wilson, 2001; Saiegh-Haddad & Henkin-Roitfarb, 2014). Roots are sequences of consonants (usually three) that carry core semantic meaning, while word patterns consist mostly of vowels and sometimes consonants (Wright, 1995). Word patterns define word category and morphosyntactic information. For instance, the root /k-t-b/ ("relating to writing") combines with the pattern /Ca-Ca-Ca/ to form /kataba/ ("He wrote"). This combination is non-concatenative since morphemes are discontinuous on the surface. In contrast, English morphology is typically concatenative, with morphemes combining linearly (e.g., *un-* + *happy* = *unhappy*).

Research on Semitic morphology highlights the importance of morphological structure in lexical processing and representation (Boudelaa & Marslen-Wilson, 2005, 2011; Deutsch et al., 1998; Frost et al., 2000). The most common technique for examining morphology's role in word recognition is priming, where a target word's recognition is analyzed when it follows morphologically related and unrelated primes at different stimulus onset asynchronies (SOAs) or lags. Previous experiments in Semitic languages have shown that morphological priming occurs for some words but not for others (e.g., Frost et al., 1997; Shalhoub-Awwad 2020; Boudelaa & Marslen-Wilson 2005). For instance, Arabic and Hebrew verbal patterns exhibit robust priming effects, as documented by Boudelaa & Marslen-Wilson (2005, 2011, 2013) and Deutsch et al. (1998). Conversely, nominal patterns have shown weaker priming effects in both languages, as demonstrated by Frost et al. (1997) and Shalhoub-Awwad (2020). In this dissertation, I investigated the causes of these priming differences across word classes, specifically focusing on nominal and verbal patterns in Arabic.

A key difference between verbal and nominal patterns, which may explain their priming differences, is productivity. Verbal patterns are generally more productive than nominal patterns (Deutsch et al., 1998). For example, Arabic has fewer than a dozen highly productive verbal patterns, while hundreds of nominal patterns vary in productivity. Similar differences in productivity are observed in Hebrew. Hebrew has seven verbal patterns (three active, three passive, and one reflexive), all used for verb conjugation and highly productive. In contrast, Hebrew nominal patterns include over a hundred distinct forms with varied productivity levels (Ben-Asher, 1971). However, most morphological priming experiments in both Arabic and Hebrew have not distinguished between high and low productivity in word patterns. In two experiments, I examined the influence of productivity on the priming of nominal and verbal patterns in Arabic and investigated whether the observed differences in priming effects between nominal and verbal patterns are driven by productivity effects or word class differences.

This dissertation begins with a review of models of morphological representation, followed by a summary of priming effects in Arabic and Hebrew, focusing on the roles of roots and word patterns in word recognition. Then, I document differences in priming for nominal and verbal patterns in Arabic word recognition and discuss findings from a meta-analysis of morphological priming in Semitic languages and examine the role of productivity (or family size) in word recognition across languages. This review highlights the existing gap in the literature on morphological processing in Arabic, ending with the research questions, experimental design, and methodology. The dissertation concludes with the results and their theoretical implications.

2. Literature review

2.1. Morphological priming and models of morphological representation

Morphological priming is the phenomenon where the recognition of a word (the target) is facilitated by the prior presentation of a morphologically related word (the prime).

Morphological priming has been studied in many languages to determine how exposure to various aspects of the morphological structure of a word influences recognition speed and accuracy. These studies shed light on the structure of the mental lexicon and the mechanisms of lexical access (e.g., Boudelaa & Marslen-Wilson, 2015; Frost et al., 2000; Shalhoub-Awwad & Leikin, 2016; Amenta & Crepaldi, 2012).

There are five main proposals on how morphologically complex words are represented in the mental lexicon. In the **fully decomposed model**, complex words are represented as morphemes that are stored in the mental lexicon and actively influence lexical access (e.g., Smolka et al., 2014; Stockall & Marantz, 2006; Taft & Kougious, 2004; Taft & Forster, 1975). In contrast, the **whole-word model** proposes that each complex word is stored as a single unit, without decomposition (e.g., Blevins, 2016; Lukatela et al., 1980; Milin et al., 2017; Seidenberg & Gonnerman, 2000). In this model, while morphemes are not stored in the lexicon, morphological relatedness emerges because morphologically related words typically share meaning and form.

A third model, referred to as the **dual representation with dual access model**, introduced by Schreuder and Baayen (1995), proposes that each word in the mental lexicon has both whole-word and decomposed representations. Lexical access involves competition between the two access routes, with the dominant route determined by factors such as productivity. High-productivity items are more likely to be accessed through decomposition, while low-productivity items are accessed via whole-word retrieval (Schreuder & Baayen, 1995; Berent & Pinker, 2007;

Clahsen et al., 1992). For instance, Albright & Hayes (2003) and Nieder et al. (2021) propose that regular and productive processes facilitate word formation through morpheme-based decomposition, while irregular and unproductive processes favor whole-word retrieval. While the distinction between productive and unproductive morphological processes is not categorical (see Albright & Hayes, 2003; Nieder et al., 2021), morphemic representation is often associated with productive, transparent, and regular processes (Xu et al., 2023)

In addition, the **bifurcated representation model** posits that words are represented in one of two forms: whole-word representations or decomposed representations (Berent & Pinker, 2007; Clahsen et al., 1992). The choice of representation depends on characteristics such as productivity, with low-productivity words stored as whole forms and high-productivity words stored in decomposed forms.

Lastly, the **single representation, dual access model** proposes that words are stored in the lexicon with a single representation (either whole-word or decomposed) but can be accessed through two distinct routes: whole-word retrieval or decomposition. Norris (1994) and Grainger & Jacobs (1996) propose that the choice of access route depends on factors such as productivity. Whole-word retrieval is faster for low-productivity items, whereas decomposition dominates for high-productivity items. In this dissertation, I evaluate theoretical evidence regarding the effect of productivity on the representation of nominal and verbal pattern morphemes in Arabic.

2.2. Morphological priming in Arabic and Hebrew

Evidence from morphological priming demonstrates how morphological structures influence word recognition and therefore has been used to provide evidence for the organization of the mental lexicon (e.g., Boudelaa & Marslen-Wilson, 2015; Frost et al., 2000; Shalhoub-Awwad & Leikin, 2016). Research on Semitic languages, such as Arabic and Hebrew, shows that when

processing a complex word, speakers automatically decompose it into its morphemic constituents, roots and word patterns. These morphemes then activate the word's meaning in the mental lexicon (e.g., Caramazza, 1997; Deutsch & Frost, 2003). However, while the root shows consistent priming effects, the word pattern has a weaker priming effect in both Arabic and Hebrew.

For instance, we know that root priming effects are robust because root priming in Arabic occurs even when the prime and target belong to different syntactic categories either both sharing a root within nouns or both sharing a root within verbs (Boudelaa & Marslen-Wilson, 2005, 2011, 2015). In two masked priming experiments, Boudelaa and Marslen-Wilson (2005) examined root priming in nominal and verbal patterns. In Experiment 1, which focused on nouns as primes, they found that Arabic readers recognized nouns faster when these prime words shared a root morpheme with the target compared to unrelated primes (primes with no morphological or semantic connection), orthographic controls (word pairs sharing two to three consonants without sharing a root), and semantic controls (pairs related in meaning but without shared roots or word patterns). In Experiment 2, which focused on verbs as primes, they found that Arabic readers recognized verbs faster when these prime words shared a root morpheme with the target compared to unrelated controls, orthographic controls, and semantic controls. These results showed that root priming is observed in Arabic even when the prime and target, sharing the same root, belong to different syntactic categories, such as both being verbs or nouns. Similarly, robust root priming effects have been observed in Hebrew, where primes and targets from different syntactic categories also show strong facilitation (e.g., Deutsch et al., 1998; Frost et al., 1997).

In contrast, word pattern priming shows more variation in Arabic and Hebrew. Verbal patterns show a robust priming effect in both Arabic (Boudelaa & Marslen-Wilson, 2005, 2011, 2015) and Hebrew (Deutsch et al., 1998; Frost et al., 2000). Boudelaa & Marslen-Wilson (2015) found significant priming for Arabic verbal patterns using cross-modal priming. For example, Boudelaa and Marslen-Wilson (2015) found that the target *[farraqa]* ("scatter") was recognized faster when primed by *[ħatʕʕama]* ("demolish") compared to when it was preceded by an orthographic control (primes sharing two consonants but no morphological or semantic relationship) or an unrelated prime. Researchers use these controls to ensure that priming effects are due to morphological relationships rather than orthographic, or semantic similarities. Similar to Arabic verbs, Hebrew verbs also exhibit strong morphological priming effects. For example, in masked visual priming experiments, the target *[hug.dar]* ('was defined') was recognized faster when primed by *[huk.lat]* ('was recorded'), compared to orthographic control primes. These orthographic controls shared the same number of letters with the target but were derived from a different verbal pattern (Deutsch et al., 1998).

However, the results for nominal patterns are mixed: some studies have found priming effects, while others have not. In their cross-modal experiments, Boudelaa and Marslen-Wilson (2015) observed significant priming for Arabic nominal patterns, such as faster recognition of *[ħuduuθun]* "happening" when primed by *[suʕuunun]* "prisons" compared to orthographic controls or unrelated controls. In contrast, Shalhoub-Awwad (2020) found no priming for nominal patterns, as in the case of *[ruku]* "riding" failing to facilitate *[duku]* "entrance" beyond that observed in the case of orthographic overlap, such as *[duxa:n]* "smoke" and *[duxu:l]* ("entrance"). Similarly, Frost et al. (1997) reported no priming for Hebrew nominal patterns, highlighting the inconsistency in nominal word pattern priming.

A meta-analysis by Xu et al. (2023) of 229 morphological priming experiments involving 4710 Semitic speakers confirmed differences in the robustness of priming between roots and word patterns. Root priming effects were consistent for both nouns and verbs in Arabic and Hebrew, with no differences across word class. Word pattern priming, while present, was smaller in magnitude than for roots. Further, it varied by word class, with stronger effects in verbs than nouns, in both Arabic and Hebrew. Word pattern and root priming differ in their sensitivity to SOA as well, as shown by Boudelaa & Marslen-Wilson (2005), who studied priming effects in Arabic. In their masked priming experiment the time interval between the prime and target (SOA) was varied in four conditions (32 ms, 48 ms, 64 ms, and 80 ms). They found root priming at all SOAs. However, word pattern priming was not observed at all SOAs. Verbal and nominal word patterns did not show priming at the shortest SOA (32 ms). At SOA of 48 ms, significant priming by word patterns was observed, but the effect was transient. Verbal patterns showed no priming at 64 ms or 80 ms, while nominal patterns showed priming at 64 ms but not at 80 ms. These results provide evidence that the identification of the root occurs earlier and is more robust than the identification of the word pattern morpheme. In addition, the authors argue that the result of word pattern priming emerging later than root priming (at 48 rather than 32 ms SOAs) is consistent with a processing dependency between the identification of the root and the word pattern. They argue that at the shortest SOA, the prime may not be decomposed quickly enough for the identification of the word pattern to influence parallel identification processes in the target. However, roots appear to be processed more quickly in both the prime and target, allowing root-priming effects to be observed even at the earliest SOA. As a result, the word pattern priming effect in Arabic is highly sensitive to the relative timing of different access processes.

Xu et al. (2023) confirmed in a meta-analysis that only word pattern priming, not root priming, is sensitive to SOA. Word pattern priming effects were significant in masked priming experiments only when SOAs ranged between 40–50 ms. This dissertation builds on these findings by systematically examining the role of SOA in morphological priming through masked priming experiments at 32 ms, 42 ms, 48 ms, and 65 ms. These experiments investigate whether the effects of high- and low-productivity patterns in verbal and nominal forms are consistent across SOAs, focusing on the sensitivity of word pattern priming to varying stimulus asynchronies. These experiments provide a detailed understanding of the timing and robustness of word pattern priming effects in Arabic.

One could argue that the differences between root and word pattern priming, specifically in Arabic, are not evidence for their separability as influential cognitive entities but are instead based on differences in how they are represented in orthography. Roots are represented only by consonants, while word patterns are primarily carried by vowels (though they also include consonants in some cases). The root in Arabic is always fully specified in the orthographic form, whereas word patterns are only partially specified, especially when they include a consonant or a long vowel represented as a full grapheme in the orthography, rather than as a diacritic. Given that this study focuses on the priming effect of word patterns in Arabic, I first evaluate priming in Experiment 1 using a cross-modal priming paradigm where the prime is auditory, ensuring that the word patterns are fully specified. In a cross-modal priming paradigm, primes are presented auditorily therefore, the lack of priming (if detected) cannot be attributed to the partial transcription of word patterns.

Additional evidence showing the robustness of the root is that words sharing a root prime each other effectively regardless of whether their semantic relationship is transparent or

opaque. For instance, Boudelaa and Marslen-Wilson (2000, 2001) demonstrated that words sharing a root prime each other effectively, even when the semantic relationship is opaque. For example, the word /*kataba*/ (“He wrote”) primes /*kitaabatun*/ (“writing”), which shares a transparent relationship with the root k-t-b (“writing”). Similarly, /*kataba*/ primes /*maktab*/ (“office”), despite the opaque relationship between the prime and target. These findings suggest that roots, rather than semantic relationships, primarily drive morphological priming in Arabic, supporting the full decomposition model.

In contrast, in concatenative languages, such as English, the priming of complex words is influenced by semantic transparency. For instance, “happy” primes “unhappy” (transparent), but “depart” does not prime “department” (opaque) (Schreuder & Baayen, 1994, 1995). This difference suggests that English complex words are represented and processed based on shared semantics rather than obligatory morphological decomposition, supporting a whole-word representation model for English.

Finally, root and pattern priming effects may also differ based on differences in productivity (family size). For example, Boudelaa & Marslen-Wilson (2011) demonstrated that root priming is stronger than word pattern priming in Arabic using both masked and cross-modal priming tasks. Using a 2x2 design, they showed significant priming when primes and targets shared a highly productive root, but no priming even when word patterns were highly productive. Productive word patterns facilitated priming only when paired with productive roots. When the root was less productive, word pattern priming was absent regardless of word pattern productivity. This indicates that root productivity, not word pattern productivity, drives decomposition in Arabic morphological processing. Boudelaa & Marslen-Wilson argue that the root's productivity determines priming effects, while word patterns are decomposed only in the

context of productive roots. These findings highlight the root's dominant role in Arabic word recognition and morphological decomposition.

2.3. Distinguishing Morphological Priming from Form and Meaning Effects

To make a convincing case for the independent representation of roots and patterns, it is necessary to evaluate whether priming resulting from shared roots or patterns is different from the priming effects due to overlap in form and meaning. The existing evidence for this dissociation remains mixed. Some studies show that morphological priming effects (both roots and word patterns) can be distinguished from the effects of overlap in both orthography and semantics. For instance, Boudelaa & Marslen-Wilson (2001) examined the effects of morphological structure (word patterns and roots) of Arabic complex words during visual processing. They compared morphological priming to priming observed in orthographic and semantic control conditions. They found that morphological priming effects (in both roots and word patterns) are more robust than form and meaning priming, which supports the non-linear and abstract nature of Arabic morphemic units. Similarly, Frost et al. (2000) found that in Hebrew, the priming effects of roots and word patterns cannot be reduced to orthographic overlap, and they occur even when primes and targets are not semantically related. However, aggregating across experiments in a meta-analysis, Xu et al. (2023) show that only root priming effects can be distinguished from the effects of overlap in both form and meaning. In contrast, although word pattern priming was distinct from the effects of form overlap, more studies are needed to determine if word pattern priming effects can be distinguished from overlap in both form and morphosyntactic function. However, as Xu et al., point out, the extent to which orthographic overlap is controlled in experiments varies, and is often involves less segmental form overlap than is observed in either root or pattern priming. Whether morphological,

specifically pattern priming is distinct from the effects of form and meaning overlap also investigated in this dissertation.

2.4. Comparison of Verbal and Nominal Patterns in Arabic and Hebrew

Research has shown that even within word patterns, verbal patterns have a more robust priming effect than nominal patterns in both Arabic and Hebrew (Deutsch et al., 1998; Boudelaa & Marslen-Wilson (2005, 2011). For example, Boudelaa & Marslen-Wilson (2015) demonstrated robust priming for Arabic verbal patterns in a cross-modal priming experiment. Words like [kaððaba] 'belie,' sharing the CaCCaCa pattern with the target [farraqa] 'scatter,' showed faster recognition, while phonological controls like [maraqun] 'broth' and unrelated primes like [laʕibun] 'playing' did not prime the target. Similar findings in Hebrew revealed strong priming effects for verbs like [huklat] 'was recorded' and [hugdar] 'was defined' in both masked visual and cross-modal paradigms (Deutsch et al., 1998; Frost et al., 2000). Frost et al. (2000) further showed that Hebrew verbal pattern priming is distinct from semantic and phonological priming, emphasizing the importance of morphological structures.

Nominal pattern priming, however, is less consistent. Using a cross-modal priming paradigm, Shalhoub-Awwad (2020) found that while nominal pattern primes improved lexical decision accuracy in Arabic, they had no significant impact on reaction times. Abu-Rabia and Shalhoub-Awwad (2004) also reported no facilitation in lexical decision or naming tasks for Arabic nominal patterns using masked priming techniques. Finally, Boudelaa and Marslen-Wilson (2001) also reported that the priming effect of nominal patterns in Arabic is weaker than that shown by verbal patterns.

In Hebrew, studies similarly showed weak or no priming for nominal patterns (Frost et al., 1997; Deutsch et al., 2005). Frost et al. (1997) reported that while roots facilitated both

lexical decision and naming, nominal patterns did not. These results underscore the central role of roots in lexical access, with nominal patterns exerting a weaker influence. A challenge to these earlier findings comes from Deutsch, Velan, and Michaly (2018) who argue that methodological limitations may have reduced priming by Hebrew nominal patterns. Using a fast-priming paradigm with a delayed-letters procedure, they found facilitatory effects for nominal pattern primes versus orthographic controls at SOAs of 33 and 42 ms based on eye-fixation latency. This suggests that nominal patterns may play a role in lexical organization and access under specific conditions.

One proposal for the differences between priming of verbal and nominal patterns in Semitic languages appeals to differences in productivity. Verbal patterns are generally more productive than nominal patterns, as noted by Deutsch et al. (1998) and Boudelaa and Marslen-Wilson (2001). The main goal of the experiments in this dissertation is to investigate the role of productivity in verbal and nominal word pattern priming to determine whether the observed priming effects between these patterns are primarily driven by productivity or word class differences.

2.5. The Effect of Productivity on Priming

We know from research on European languages like Dutch that productivity significantly affects lexical processing. Baayen et al. (1997) demonstrated that Dutch noun stems with large family sizes elicited faster response times in visual lexical decision tasks compared to those with smaller family sizes. Similarly, Dutch complex words with more productive stems are processed more rapidly and accurately than those with less productive stems, even when they share the same inflectional suffix (Bertram et al., 2000; De Jong et al., 2000). Comparable findings have been

reported for other concatenative languages like English. For instance, Ford et al. (2003) found that family size influences lexical access in English.

Although affix productivity has received less attention, Marslen-Wilson et al. (2019) found that highly productive prefixes and suffixes in English (e.g., *-ness* or *re-*) showed stronger priming effects than less productive ones (e.g., *en-* as in *enslave* or *-th* as in *depth*), and these effects were independent of phonological overlap. Similarly, in Italian, Laudanna, Burani, and Cermele (1994) found that the number of word types containing a given prefix (such as *ri-* or *co-*) affected how quickly and accurately nonwords, formed by combining a prefix and a real word, were processed. These studies emphasize that morphemic productivity impacts lexical access across languages.

In Semitic languages, productivity is a key factor distinguishing nouns from verbs. Verbal patterns are generally more productive than nominal patterns (Deutsch et al., 1998). However, the role of productivity in lexical processing has not been systematically explored in priming studies in Arabic and other Semitic languages. One exception is Boudelaa and Marslen-Wilson (2011), who investigated the impact of productivity (family size) on root and word pattern priming in Arabic. As summarized earlier, they found that highly productive word patterns failed to prime when combined with unproductive roots, suggesting that word pattern priming depends on root productivity rather than the pattern itself.

Although Boudelaa and Marslen-Wilson's (2011) work explored productivity effects in roots and word patterns, they did not examine the effects of productivity differences on priming within nominal and verbal patterns. My dissertation addresses this gap by analyzing whether productivity explains the differences in priming between nominal and verbal patterns in Arabic. Unlike previous studies, I compare the priming effects of high- and low-productivity patterns

within verbs and nouns separately. This approach will allow me to determine whether the observed differences in priming across word classes result from inherent differences in productivity of nominal and verbal patterns.

3. The goal and significance of the research

The goal of this study is to investigate the influence of productivity on the priming of nominal and verbal patterns in Arabic and to examine whether the observed differences in priming effects between nominal and verbal patterns are driven by productivity or word class differences. In a series of experiments in this dissertation, I investigate how productivity, measured by type frequency, influences priming of verbal and nominal patterns in Arabic across two paradigms: cross-modal priming (Experiment 1) and masked visual priming (Experiment 2). I also test whether morphological priming effects for verbal and nominal patterns differ from orthographic and semantics controls.

Additionally, by varying the SOA in masked priming experiments to examine the consequences on word pattern priming across productivity levels and word classes. I used masked visual priming experiments with SOAs of 32 ms, 42 ms, 48 ms, and 65 ms to explore timing effects on word pattern priming in Arabic's morphological structure (Experiments 2–5). Previous research (Boudelaa & Marslen-Wilson, 2005; Xu et al., 2023) suggests shorter SOAs may reduce or eliminate word pattern priming effects.

The hypotheses for this study are as follows: If productivity affects priming for verbal and nominal patterns, then high-productivity verbal and nominal patterns will exhibit priming compared to their low-productivity counterparts. Additionally, if word type (verb or noun) is more influential, verbal patterns, regardless of their productivity level, will show priming rather than nominal patterns. Furthermore, varying SOA durations may influence the strength or

presence of these priming effects, with shorter SOAs potentially weakening priming across conditions. Together, the findings will expand on the role of word patterns in processing as well as their representation in existing morphological processing models, contributing to a better understanding of Arabic and other languages with non-concatenative morphology. These findings will also show whether the differences between verbal and nominal patterns are driven by productivity or word class distinctions.

4. Experiment 1: cross-modal priming task

Experiment 1 used a cross-modal priming task, based on Boudelaa and Marslen-Wilson (2011), to examine whether differences in word pattern priming effects for nominal and verbal patterns, observed in visual paradigms, extend across modalities. Cross-modal priming was chosen due to the nature of Arabic orthography, where consonants are fully represented in writing, but vowels often appear as diacritics. As noted by Boudelaa and Marslen-Wilson (2011), roots are fully specified orthographically, while word patterns may only be partially specified unless they contain long vowels represented as full graphemes. Unlike subsequent experiments, where both the prime and target are presented visually, in this task, the prime was presented auditorily, and the target was presented visually (orthographically). This cross-modal auditory-visual design ensured full specification of verbal and nominal patterns in the prime, eliminating ambiguity in recognition. In the written targets, participants may struggle to fully recognize patterns, especially when they lack long vowels. To address this, word patterns with long vowels were used to ensure full specification, while ambiguous templates were avoided. The only ambiguous template included in the data was [Ca.CaC], commonly found in high-productivity verbs. To prevent misinterpretation, diacritics were added for clarity. Without diacritics, participants might

perceive the word as /ka.tab/ (كَتَبَ ‘he wrote’), following the [Ca.CaC] template, or as /ku.tib/ (كُتِبَ ‘it was written’), following the [Cu.Cil] template.

In addition, based on Xu et al.’s (2023) findings, larger priming effects were expected in cross-modal priming compared to masked visual priming. Boudelaa and Marslen-Wilson (2011) also used cross-modal priming to examine the impact of productivity (family size) on root and word pattern priming in Arabic nouns. This study builds on their Experiment, extending the analysis to verbal and nominal patterns and investigating the independence of morphological priming from orthographic and semantic effects. In masked visual priming, brief prime presentation minimizes semantic processing (Frost et al., 1997; Perea et al., 1995). Cross-modal priming, with auditory primes, allows semantic processing, providing a comparison point.

This experiment primarily examined the effect of productivity on verbal and nominal patterns by comparing high- and low-productivity verbal and nominal patterns (as measured by family size). By varying productivity, this study aimed to investigate whether priming effects for verbal and nominal word patterns are more strongly influenced by productivity or word class differences. Additionally, it examined the independence of morphological priming from orthographic and semantic effects.

4.1 Methods

4.1.1. Participants

A total of 130 participants (75 females, 57 males) aged 20 to 45 years (average age 34) participated in the experiment. All were native Arabic speakers born and raised in Saudi Arabia, fluent in Modern Standard Arabic (MSA) due to early exposure, and with formal education starting at age six. They were recruited via online platforms, mainly Snapchat, and the experiment was administered online, but on a computer to ensure consistency.

4.1.2. Materials and design

In this study, productivity, measured by type frequency, refers to how many different word forms a morpheme (like a root or pattern) can generate. For example, the pattern /CaC.CaC/ generates forms like /dar.ras/ "taught," /waz.zaʕ/ "divided," and /nað.ðam/ "organized," reflecting productivity. Similarly, plural patterns also illustrate productivity. The pattern /ma.Caa.CiC/ generates forms like /ma.kaa.tib/ "desks" and /ma.naa.fiʕ/ "benefits," while the pattern /ʔaC.CaaC/ produces forms such as /ʔam.laak/ "properties" and /ʔas.raar/ "secrets." These examples demonstrate how productivity is reflected in the variety of word forms created by specific patterns.

Following Boudelaa and Marslen-Wilson (2011), this study adopts type frequency as a measure of productivity, as it captures the diversity of word forms a morpheme can generate rather than its overall frequency of occurrence. Their findings suggest that priming effects are primarily driven by root productivity rather than word pattern productivity, reinforcing the idea that morphological decomposition is more likely to occur when a morpheme is highly productive.

I used the Aralex database (Boudelaa & Marslen-Wilson, 2010), based on a 40-million-word corpus, to measure productivity (type frequency) in this study. This differs from token frequency, which measures how often a morpheme or word appears in a corpus. The values presented in Table 1 represent the type frequency of each word pattern, as derived from the Aralex database (Boudelaa & Marslen-Wilson, 2010). Type frequency refers to the number of distinct word types that share a given word pattern within the 40-million-word corpus of Aralex. For example, the high-productivity verb pattern CaCCaC has an average type frequency of 464.75, meaning that, on average, word patterns of this category appear in combination with approximately 465 distinct roots within the corpus. This measure captures the productivity of a pattern by indicating how many different word forms it generates, rather than how frequently individual

words occur (token frequency). Similarly, the low-productivity verb pattern isCaCCaC has an average type frequency of 143.5, meaning that patterns in this category occur in approximately 144 distinct roots. This difference in type frequency reflects the extent to which a pattern is actively used in Arabic word formation. The median productivity and range of productivity values provide additional distributional details, illustrating how the productivity levels of different word patterns vary within the dataset. By using type frequency as a measure of productivity, this study aligns with previous research (e.g., Baayen, 1993; Marslen-Wilson et al., 2019), where higher type frequencies indicate greater morphological productivity, influencing lexical access and representation.

Table 1: *Nominal vs verbal patterns; average productivity, median productivity, range of productivity*

Conditions	Average Productivity	Median Productivity	Range
High productive verbs	464.75	448.5	382-580
Low productive verbs	143.5	130	18-296
High productive nouns	481.25	450.5	392-632
Low productive nouns	151.25	147.5	37-273

To control for root frequency effects, only roots with type frequencies between 20 and 25 were selected, representing the median productivity of roots in the Aralex database. This was done to avoid interference from highly frequent or infrequent roots (Boudelaa & Marslen-Wilson, 2011). The experiment included 128 target items divided into four conditions based on productivity and word class: High-Productive Verb, Low-Productive Verb, High-Productive Noun, and Low-Productive Noun. Four templates were paired with eight roots, resulting in 32 items per condition. Additionally, 128 non-words were created using real word patterns paired with pseudo-roots, following the method outlined by Abu-Rabia and Awwad (2004).

Each target item was paired with four prime types: (1) the test prime, which matched the target's productivity and word class; (2) a semantic control, which was meaning-related but neither orthographically nor morphologically similar; (3) an orthographic control, which was

orthographically similar (with a three-segment overlap paralleling the extent of form overlap in the word pattern) but unrelated morphologically and semantically. The orthographic control, following Xu et al. (2023), shared three segments with the target but lacked semantic or morphological overlap. These controls were morphologically unrelated forms, whereas test primes shared morphological patterns (verbs or nouns); and (4) an unrelated control, which had no orthographic, morphological, or semantic relationship to the target. Stimuli were distributed across four counterbalanced lists, ensuring that participants did not see the same prime or target more than once. Each list included a mix of real words and non-words. The full list of stimulus items used in Experiments 1-5, including the Arabic script, IPA transcription, and English gloss for high and low productivity nouns, verbs, and control conditions, is provided in Appendix A-P.

Primes were recorded by a native Arabic speaker in a sound-attenuated booth at the UCLA Phonetics Lab using a Yeti USB condenser microphone. Audio files were digitized at 44 kHz and down-sampled to 22 kHz for consistency. The recordings were processed using Praat (Boersma & Weenink, 2020) to prepare the audio file for each prime. Labvanced software was used to present the auditory primes and visual targets and to measure reaction times and accuracy.

4.1.3. Stimulus validation

To ensure familiarity with the test items, 10 native Arabic speakers rated the words on a scale from 1 (not familiar) to 7 (very familiar); all items were presented using Labvanced. All stimulus items used in the experiments received an average familiarity rating of 5 or higher. Additionally, another group of 10 native Arabic speakers rated the semantic relatedness of each prime-target pair on a scale from 1 (semantically unrelated) to 7 (highly related). Prime-target pairs used in the semantic control condition had a semantic similarity rating of 5 or higher, while unrelated control pairs had a semantic similarity rating below 3. Orthographically- and morphologically

related pairs also had a semantic similarity rating below 3. A sample set of stimuli is presented in Table 2.

Table 2: *Sample set of the stimuli*

Conditions	Word pattern	Type frequency	Target	Test prime	Unrelated control prime	Orthographic control	Semantics control
High productive verb pattern	[Caa.Cal]	441	[ʃaa.wan] 'He helped.'	[sʔaa.daq] 'He approved'	[ruuh] 'soul'	[ʃum.maal] 'workers'	[ta.dʔaa.mun] 'helping'
Low productive verb pattern	[is.CaC.CaC]	31	[ʔis.taʔ.bal] 'He received.'	[ʔis.taʃ.mal] 'utilize'	[ʒi.daar] 'wall'	[qa.mar] 'moon'	[taw.sʔiil] 'delivery'
High productive noun pattern	[CaC.CaaC]	432	[ʔʌb.baax] 'a cook'	[ħaf.faar] 'a digger'	[ʔʌ.riiq] 'road'	[ba.ħar] 'sea'	[waʒ.bah] 'meal'
Low productive noun pattern	[ma.Caa.CiC]	37	[ma.ʔaa.sil] 'laundries'	[ma.sʔaa.dir] 'sources'	[rih.lah] 'trip'	[ʔa.dʔab] 'anger'	[sʔaa.buun] 'soap'

4.2. Procedure

The cross-modal priming experiment was conducted online. Labvanced software was used for stimulus presentation and data collection. Participants were asked to complete the experiment on computers in quiet rooms to ensure the accuracy of the collected data. Prime words were presented auditorily, and visual targets were displayed using Labvanced software to measure reaction times and accuracy rates.

Before beginning the experiment, participants provided informed consent and received a detailed explanation of the study, including its purpose, their rights, confidentiality of responses, time commitment, and the option to withdraw at any time. The task involved making lexical decisions about visual targets. Participants were instructed to listen to the auditory primes and decide as quickly and accurately as possible whether the visual target was an Arabic word. Each trial began with a forward-fixation cross (+) displayed at the center of the screen for 1,000 ms, followed by the auditory prime. The visual target appeared immediately after the prime with a 0 ms SOA (no delay). The target remained on the screen until participants responded or 2,000 ms

elapsed. Participants pressed the green button labeled "نعم" (Yes)for Arabic words and the red button labeled "لا")No) for pseudowords.

The experiment began with 10 practice trials (5 words and 5 pseudowords). After the practice session, participants could take a break before starting the main experiment, which consisted of 256 experimental trials: 128 words and 128 non-words. The entire session lasted approximately 20 to 25 minutes per participant.

4.3. Data Analysis

4.3.1. Statistical Models

Reaction times (RTs) were analyzed using linear mixed- effects models (LME) with the lme4 package (Bates et al., 2016) in R (R Core Team, 2020). Fixed effects included category (test prime, semantic control, orthographic control, and unrelated control), with unrelated control as the baseline reference. Additional fixed effects included productivity (high vs. low) and part of speech (verb vs. noun), along with their interactions. Random intercepts for subjects and items were included. Estimated marginal means (EMMs) were computed for significant interactions using the emmeans package (Lenth, 2025). To ensure robustness, the analysis was also conducted on log-transformed reaction times as a secondary verification of the results. For accuracy data, a generalized linear mixed-effects model (GLMM) with a binomial distribution (correct/incorrect) used the same fixed and random effects as the RT analysis to confirm that participants were equally accurate across conditions, productivity levels, and word classes.

4.3.2. Data Preparation

Out of the 130 participants, six were excluded for accuracy rates below 80%, leaving 124 participants. Missing responses accounted for 4.60% of trials, which were also excluded. For RT analysis, only correct responses to words were retained, excluding 1.37% of data due to errors.

One item, with an accuracy rate below 80% was also excluded. Finally, outliers, defined as trials on which RTs were either below 200 ms or more than two standard deviations from the condition mean, were removed, excluding an additional 4.41% of data. These exclusionary criteria followed the methodology of Boudelaa and Marslen-Wilson (2005).

4.3.3. Accuracy analysis

Results showed no significant accuracy differences across conditions, productivity levels, or word classes (all p -values > 0.05), with participants maintaining consistently high accuracy (approximately from 95–97%). These findings indicate that task manipulations did not affect accuracy. The accuracy rates for each condition, including high- and low-productivity nouns and verbs across all control and test conditions, are shown in Table 3.

4.3.4. Reaction Time Analysis

RTs in morphological, orthographic, and semantic priming conditions were compared to the unrelated condition to evaluate priming, focusing on differences between high- and low-productivity nouns and verbs. The goal was to determine if morphological priming was distinct from orthographic and semantic priming and to explore interactions between productivity and word class. The results are reported to address three key questions: (1) Is there morphological priming? (2) Do priming effects interact with productivity levels and word class? (3) Is morphological priming different from orthographic and semantic effects?

Table 3: *Accuracy rates (in percentages) for high and low productivity nouns, verbs, and control conditions across all conditions in the cross-modal priming task in Experiment 1*

Condition	Test prime	Baseline (Unrelated control)	Orthographic control	Semantics control
High productive nouns	96.68%	95.92%	96.81%	96.18%
High productive verbs	97.52%	96.75%	96.61%	96.35%
Low productive nouns	96.97%	97.19%	96.84%	96.90%
Low productive verbs	96.79%	95.59%	96.85%	96.61%

4.3.4.1. Is there (morphological) priming?

The reaction time (RT) data are summarized in Table 4 and Figure 1, and the analysis provided clear evidence of morphological priming. Both the linear mixed-effects model (LME) and the log-transformed analysis showed significantly faster RTs compared in the test prime condition compared to the unrelated control condition ($\beta = -63.186$, $SE = 12.441$, $t = -5.079$, $p < 0.001$), indicating faster responses to morphologically related primes. High-productivity nouns and verbs demonstrated stronger priming effects than low-productivity items. For high-productivity nouns, test prime condition had a mean RT of 1058.01 ms, significantly faster than the unrelated control RT of 1122.83 ms ($\beta = 64.82$, $SE = 12.5$, $z = 5.1$, $p < .0001$). High-productivity verbs showed similar results, with a mean RT of 1036.77 ms in the test prime condition compared to 1106.75 ms in the unrelated control condition ($\beta = 71.86$, $SE = 12.6$, $z = 5.751$, $p < 0.001$).

In contrast, low-productivity nouns and verbs showed no priming effects. Low-productivity nouns in the test prime condition had a mean RT of 1112.57 ms, not significantly different from the unrelated control RT of 1136.94 ms ($\beta = 25.31$, $SE = 12.5$, $z = 2.023$, $p = 0.1796$). Low-productivity verbs also showed no significant effect, with mean RTs of 1122.59 ms in the test prime condition and 1147.06 ms in the unrelated control condition ($\beta = 26.24$, $SE = 12.6$, $z = 2.086$, $p = 0.1577$). These results confirm that morphological priming is observed only for high-productivity items.

I also found evidence for semantic priming, as expected in a cross-modal priming task. The semantic control condition significantly reduced RTs compared to the unrelated control ($\beta = 64.697$, $SE = 12.572$, $t = -5.146$, $p < 0.001$), indicating faster responses due to semantic priming. Estimated marginal means (EMMs) revealed significant semantic priming for high-productivity nouns ($\beta = 64.70$, $SE = 12.6$, $z = 5.146$, $p < 0.001$) and for low-productivity nouns ($\beta = 63.55$, SE

= 12.5, $z = 5.082$, $p < 0.001$) and low-productivity verbs ($\beta = 80.50$, $SE = 12.5$, $z = 6.433$, $p < 0.001$). However, no semantic priming effect was observed for high-productivity verbs ($\beta = 23.72$, $SE = 12.4$, $z = 1.906$, $p = 0.2254$). These results suggest that semantic priming occurred in high-productivity nouns and low-productivity items but not in high-productivity verbs, where priming effects were exclusively morphological.

Table 4: Mean reaction times (ms) and standard deviations for high and low productivity nouns, verbs, and control conditions across all conditions in the cross-modal priming task in Experiment 1

Condition	Test prime	Baseline (Unrelated control)	Orthographic control	Semantics control
High productive nouns	1058.01 (254.01)	1122.83 (253.79)	1103.49 (247.54)	1056.20 (258.11)
High productive verbs	1036.77 (247.54)	1106.75 (252.15)	1091.50 (253.21)	1083.22 (256.81)
Low productive nouns	1112.57 (257.71)	1136.94 (273.29)	1111.02 (242.22)	1074.74 (253.74)
Low productive verbs	1122.59 (270.22)	1147.06 (259.49)	1124.68 (255.53)	1068.06 (248.25)

The orthographic control condition showed no significant priming effects across all categories ($\beta = -19.070$, $SE = 12.449$, $t = -1.532$, $p = 0.1262$). Specifically, no orthographic priming was observed for high-productivity nouns ($\beta = 19.07$, $SE = 12.4$, $z = 1.532$, $p = 0.4183$) or high-productivity verbs ($\beta = 14.42$, $SE = 12.4$, $z = 1.159$, $p = 0.6526$). Similarly, low-productivity nouns ($\beta = 27.21$, $SE = 12.5$, $z = 2.175$, $p = 0.1301$) and low-productivity verbs ($\beta = 26.38$, $SE = 12.6$, $z = 2.096$, $p = 0.1543$) also showed no significant orthographic priming effects. These findings confirm that orthographic overlap does not facilitate lexical decision performance for either high- or low-productivity items. The lack of priming in orthographic and semantic controls, specifically for high-productivity verbs, emphasizes that their morphological priming effects are distinct and not influenced by orthographic or semantic overlap. While high-productivity verbs exhibited distinct morphological priming, the effects observed in high-productivity nouns and low-productivity items were influenced by semantic overlap, indicating

that these effects may not be uniquely morphological. I investigate this in detail in section 4.3.4.3.

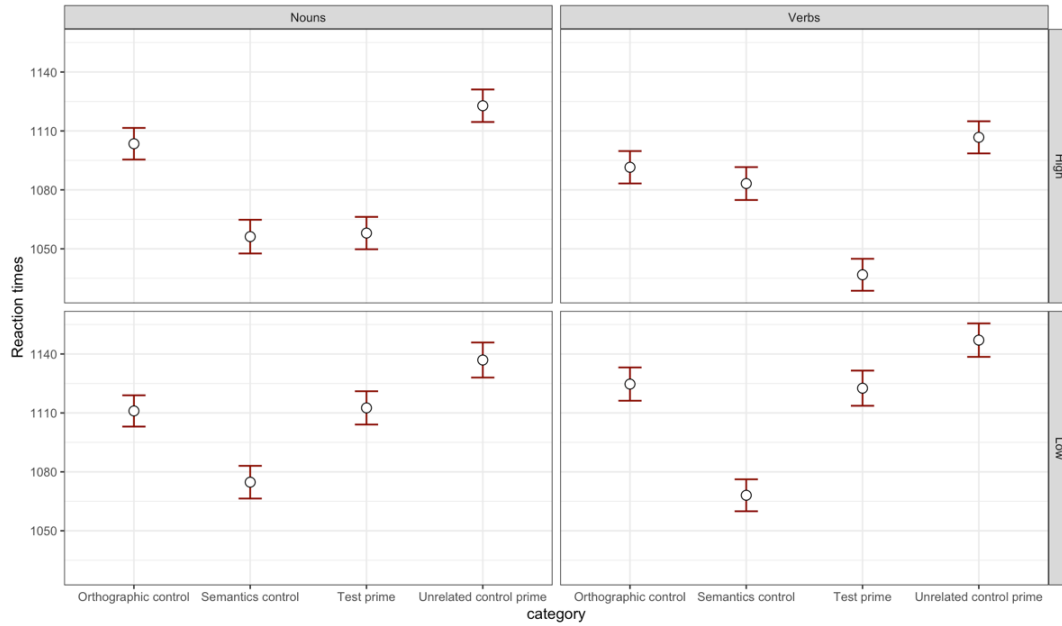


Figure 1: Mean reaction times (RT) for high- and low-productivity nouns and verbs across test, orthographic, semantic, and unrelated control conditions in the cross-modal priming task in Experiment 1

4.3.4.2. Is morphological priming related to productivity or word class?

The linear mixed-effects model (LME) analysis revealed a significant interaction between priming effect and productivity level but no significant interaction between priming effect and word class (noun vs. verb). A significant interaction between test prime and productivity ($\beta = 37.872$, $SE = 17.647$, $t = 2.146$, $p = 0.0324$) indicated that priming was stronger for high-productivity items compared to low-productivity ones. However, no significant interaction was found between test prime and word class ($\beta = -8.676$, $SE = 17.632$, $t = -0.492$, $p = 0.6229$), suggesting that morphological priming did not differ significantly between nouns and verbs. Further, there was no significant three-way interaction between test prime, word class, and productivity ($\beta = 7.751$, $SE = 25.013$, $t = 0.310$, $p = 0.7568$).

To examine these interactions further, an additional LME model analyzed reaction times (RTs) in the test prime and unrelated control conditions, excluding orthographic and semantic controls. The results showed a significant main effect of the test prime ($\beta = -64.003$, $SE = 11.992$, $t = -5.337$, $p < 0.001$), confirming strong morphological priming with faster RTs for related primes compared to unrelated controls. A significant interaction between test prime and productivity ($\beta = 39.024$, $SE = 17.016$, $t = 2.293$, $p = 0.0227$) reinforced that high-productivity items showed stronger priming effects than low-productivity items. No significant interaction between test prime and word class ($\beta = -7.787$, $SE = 17.001$, $t = -0.458$, $p = 0.6474$) further confirmed that priming effects did not differ significantly between nouns and verbs.

The reaction times (RTs) from the EMMs analysis, based on averages across the test prime and unrelated control conditions, also showed a clear productivity effect. High-productivity verbs had shorter reaction times (1070 ms) than low-productivity verbs (1135 ms), indicating a significant priming effect ($\beta = -64.4$, $SE = 8.55$, $z = -7.525$, $p < 0.0001$). Similarly, high-productivity nouns had shorter reaction times (1089 ms) compared to low-productivity nouns (1123 ms), showing a significant priming effect ($\beta = -33.9$, $SE = 8.51$, $z = -3.980$, $p = 0.0001$).

Regarding word class, the reaction times (RTs) from the EMMs analysis, based on averages across the test prime and unrelated control conditions, showed a difference between nouns and verbs within high-productivity conditions. High-productivity nouns had a mean reaction time (RT) of 1089 ms, while high-productivity verbs were faster, with a mean RT of 1070 ms ($\beta = 18.9$, $SE = 8.50$, $z = 2.225$, $p = 0.0261$). For low-productivity conditions, nouns (1123 ms) and verbs (1135 ms) showed no significant difference in mean RTs ($\beta = -11.6$, $SE = 8.56$, $z = -1.354$, $p = 0.1759$). Thus, the EMM analysis identified a difference between nouns and

verbs exclusively within high-productivity conditions based on averages across the test prime and unrelated control conditions.

4.3.4.3. Is morphological priming distinct from orthographic and semantic priming?

As reported in section 4.3.3.1, morphological priming was distinct from orthographic and semantic priming for high-productivity verbs. High-productivity verbs exhibited significant morphological priming, with no evidence of priming in orthographic or semantics control conditions. The reaction time (RT) in the semantic control condition for high-productivity verbs (1083.22 ms) was not significantly different from the unrelated control (1106.75 ms; $\beta = 23.72$, $SE = 12.4$, $z = 1.906$, $p = 0.2254$). Similarly, the orthographic control condition showed no significant difference (RT = 1091.50 ms; $\beta = 14.42$, $SE = 12.4$, $z = 1.159$, $p = 0.6526$). RTs in the orthographic control condition showed no significant difference from the unrelated control for all productivity levels, indicating neither facilitation nor inhibition. In contrast, high-productivity verbs in the test prime condition had significantly faster RTs (1036.77 ms, $\beta = 71.86$, $SE = 12.5$, $z = 5.751$, $p < .0001$), demonstrating significant priming. Since the test prime had a significant effect while orthographic controls had none, this confirms that priming was driven by morphological relationships rather than orthographic similarity.

High-productivity nouns, in contrast, exhibited both morphological and semantic priming but no orthographic priming. The orthographic control condition for high-productivity nouns had an RT of 1103.49 ms, which was not significantly different from the unrelated control (1122.83 ms; $\beta = 19.07$, $SE = 12.4$, $z = 1.532$, $p = 0.4183$). However, significant effects were observed in both the test prime and semantic control conditions. In the test prime condition, high-productivity nouns had a significantly faster RT (1058.01 ms, $\beta = 63.19$, $SE = 12.4$, $z = 5.079$, $p < 0.001$). Similarly, in the semantic control condition, they also showed significant priming

(1056.20 ms; $\beta = 64.70$, $SE = 12.6$, $z = 5.146$, $p < .0001$). The overlap of semantic and morphological effects in high-productivity nouns suggests that cross-modal priming in this category cannot be attributed solely to morphological structure.

For low-productivity items, semantic priming was observed, but there was no evidence of morphological or orthographic priming. Low-productivity nouns and verbs in the test prime condition showed no significant differences compared to unrelated controls (nouns: $\beta = 25.31$, $SE = 12.5$, $z = 2.023$, $p = 0.1796$; verbs: $\beta = 26.24$, $SE = 12.6$, $z = 2.086$, $p = 0.1577$). Similarly, orthographic control conditions showed no significant priming (nouns: $RT = 1111.02$ ms; $\beta = 27.21$, $SE = 12.5$, $z = 2.175$, $p = 0.1301$; verbs: $RT = 1124.68$ ms; $\beta = 26.38$, $SE = 12.6$, $z = 2.096$, $p = 0.1543$). However, significant semantic priming was observed. Low-productivity nouns in the semantic control condition showed significant priming effect ($\beta = 63.55$, $SE = 12.5$, $z = 5.082$, $p < .0001$), and low-productivity verbs showed similar results ($RT = 1068.08$ ms; $\beta = 80.50$, $SE = 12.5$, $z = 6.433$, $p < .0001$). These findings suggest that low-productivity items are influenced solely by semantic similarity, without any morphological or orthographic priming effects.

In summary, the results demonstrate that high-productivity verbs exhibit distinct morphological priming driven exclusively by morphological structure, with no influence from semantic or orthographic overlap. In contrast, high-productivity nouns show both morphological and semantic priming, making the priming effect of word pattern less distinct. Low-productivity items exhibit semantic priming only, with no evidence of morphological or orthographic priming. This distinction highlights that morphological priming is specific to high-productivity verbs, underscoring the importance of productivity, and to some extent word class, in determining the priming effects.

5. Experiment 2: Masked Visual Priming Task with a 48ms SOA

To eliminate semantic priming effects and investigate whether morphological priming for high-productive nouns found in Experiment 1 is independent of semantic priming, in Experiment 2, a masked visual priming task was used, based on the methods of Forster & Davis (1984) and Norris & Kinoshita (2008). Prime and target were presented visually in this experiment, unlike in Experiment 1, where the prime was auditory in the cross-modal priming task. Orthographic ambiguity in this prime-target pair was minimized by using word patterns fully specified with long vowels or diacritics where necessary to ensure consistent representation across all conditions. The only ambiguous template used was [Ca.CaC], a high-productivity verb template, for which diacritics were added to avoid misinterpretation.

This task has been widely employed in studies of morphological processing to examine the early stages of identifying morphologically complex words in languages like Arabic and Hebrew (e.g., Boudelaa & Marslen-Wilson, 2005; Frost et al., 1997; Longtin et al., 2003; Rastle et al., 2000). In masked visual priming, where primes are presented briefly, semantic processing is disrupted (Frost et al., 1997; Perea et al., 1995). This experiment builds on prior research by examining how morphological priming emerges under controlled visual conditions, where brief prime presentation minimizes semantic activation.

The selection of the SOA in masked priming paradigms was particularly important to ensure the morphological priming effects were accurately captured. I chose an SOA of 48 ms because Boudelaa & Marslen-Wilson (2005) identified it as the only SOA with significant priming effects for both verbal and nominal patterns. Additionally, this duration aligns with findings from Xu et al. (2023), who also reported robust priming effects at this SOA for both nominal and verbal patterns.

I expected to replicate the findings from Experiment 1 for High-productivity verbs: with test primes high productive verbs were expected to show faster reaction times (RTs) compared to unrelated controls. Low-productivity nouns and verbs were expected to exhibit minimal or no priming effects. Orthographic and semantic control conditions were predicted to show no significant priming for both nouns and verbs, consistent with previous findings (Boudelaa & Marslen-Wilson, 2005). Crucially, if productivity alone predicts morphological priming by word patterns, high-productivity nouns were also anticipated to exhibit significant priming effects, because masked visual priming does not allow for semantic priming effects.

5.1.Methods

5.1.1.Participants

A total of 132 participants aged 20 to 45 years (average age 34) took part in the study. All were native Arabic speakers, born and raised in Saudi Arabia, and fluent in Modern Standard Arabic (MSA) and with formal education. Recruitment was conducted via online platforms like Snapchat, following the same process as Experiment 1. The experiment was administered online, on a computer in a controlled environment.

5.1.2.Materials and design

The materials and design were adapted from Experiment 1 but adjusted for the visual nature of the primes. Unlike Experiment 1, no auditory recordings were used. Visual stimuli were presented using Labvanced software, which also recorded reaction times and accuracy rates.

5.2.Procedure

The experiment was conducted online using Labvanced software. Participants completed the task on laptops in quiet rooms. Before beginning, they provided informed consent and received

detailed instructions about the study's purpose, confidentiality, and their right to withdraw at any time without penalty.

Participants performed a lexical decision task, identifying as quickly and accurately as possible whether each string was a real Arabic word. Each trial began with a 500 ms forward mask of 28 vertical lines in a 30-point font, following Boudelaa & Marslen-Wilson (2011), who found this mask to be more effective than standard hash marks. The forward mask was followed by a visual prime displayed for a 48 ms SOA. The prime was immediately replaced by a target (word or nonword) displayed in a 34-point font. The target remained on the screen until participants responded or 2,000 ms elapsed.

The trials were randomized for each participant. Each session lasted approximately 15–20 minutes. Reaction times and accuracy were recorded and analyzed to evaluate morphological priming effects across productivity levels and word classes.

5.3.Data Analysis

5.3.1.Statistical Models

Like in Experiment 1, reaction times (RTs) were analyzed using linear mixed-effects models (LME) with the *lme4* package in R. Fixed effects included category (test prime, semantic control, orthographic control, and unrelated control), with unrelated control as the baseline. Additional fixed effects included productivity (high vs. low) and part of speech (verb vs. noun), along with their interactions. Random intercepts for participants and items accounted for individual and stimulus variability. For significant interactions, estimated marginal means (EMMs) were calculated using the *emmeans* package to perform follow-up comparisons, providing detailed insights into the interactions between productivity and word class. Accuracy was analyzed using

a generalized linear mixed-effects model (GLMM) with a binomial distribution, applying the same fixed and random effects as in the RT analysis to assess consistency across conditions.

5.3.2.Data preparation

Of the 132 participants initially recruited, three were excluded for having accuracy rates below 80%, leaving 129 participants for analysis. Missing responses accounted for 3.24% of trials, which were excluded. For RT analysis, only correct word responses were included, removing an additional 2.41% of trials due to errors. Following Farhy, Verissimo, and Clahsen (2018), all items were correctly identified with at least 80% accuracy, and so no items were excluded due to high error rates. Outliers were addressed by excluding RTs below 200 ms or more than two standard deviations from the condition mean, resulting in a further 4.45% exclusion.

5.3.4.Accuracy Analysis

Average accuracy was about 96–98% and showed no significant differences across conditions. These findings show that experimental manipulations affected reaction times rather than accuracy. The accuracy rates for each condition, including high- and low-productivity nouns and verbs across all control and test conditions, are presented in Table 5.

Table 5: *Accuracy rates (in percentages) for high and low productivity nouns, verbs, and control conditions across all conditions in masked visual priming task with an SOA of 48ms in Experiment 2*

Condition	Test prime	Baseline (Unrelated control)	Orthographic control	Semantics control
High productive nouns	98.06%	97.96%	98.17%	97.59%
High productive verbs	97.33%	96.61%	98.13%	98.39%
Low productive nouns	97.21%	97.64%	97.40%	97.43%
Low productive verbs	97.47%	97.04%	97.33%	97.44%

5.3.5. Reaction Time Analysis

As in Experiment 1, results from the 48 ms SOA visual masked priming experiment are presented to address three key questions: (1) Is there evidence of morphological priming? (2) Do priming effects interact with productivity levels and word class? (3) How does morphological priming differ from orthographic and semantic priming? The analysis highlights patterns in reaction times across conditions, illustrating the role of productivity, word class, and the distinctiveness of morphological priming relative to orthographic and semantic influences.

5.3.5.1. Is there (morphological) priming?

Reaction time (RT) data are presented in Table 6 and Figure 2; the analysis confirmed evidence of morphological priming. The linear mixed-effects model (LME) showed that the test prime condition significantly reduced RTs compared to the unrelated control condition ($\beta = -57.92$, $SE = 12.84$, $t = -4.51$, $p < 0.001$), indicating faster responses for morphologically related primes.

For high-productivity nouns, the test prime condition resulted in a mean RT of 985.86 ms, significantly faster than the 1045.04 ms observed in the unrelated control condition ($\beta = -57.92$, $SE = 12.8$, $z = 4.51$, $p < 0.0001$). Similarly, high-productivity verbs showed a mean RT of 994.11 ms, significantly faster than the unrelated control RT of 1037.03 ms ($\beta = -38.57$, $SE = 12.8$, $z = 3.00$, $p = 0.0142$). These results highlight robust morphological priming effects for high-productivity items.

In contrast, low-productivity nouns exhibited a mean RT of 1050.99 ms in the test prime condition, which was not significantly different from the 1064.77 ms in the unrelated control condition ($\beta = 14.53$, $SE = 12.8$, $z = 1.13$, $p = 0.6697$). Similarly, low-productivity verbs showed no significant priming effect, with a mean RT of 1032.27 ms in the test prime condition compared to 1054.55 ms in the unrelated control condition ($\beta = 26.19$, $SE = 12.9$, $z = 2.02$, $p =$

0.1796). These findings suggest that low-productivity items fail to produce significant morphological priming. Additionally, log-transformed RTs produced the same pattern of results, confirming the robustness of the findings.

In summary, the test prime condition demonstrated significant morphological priming effects for high-productivity nouns and verbs, confirming the role of morphological structure in facilitating target word recognition. The absence of significant priming in the orthographic and semantic control conditions across all productivity levels underscores that this effect is specific to morphological structure and not influenced by orthographic or semantic overlap.

5.3.5.2. Does Morphological Priming Interact with Productivity Level and Word Class?

Like in Experiment 1, the linear mixed-effects model (LME) revealed a significant interaction between priming and productivity level but no significant interaction between priming and word class (noun vs. verb). Specifically, the interaction between the test prime and productivity was significant ($\beta = 43.39$, $SE = 18.15$, $t = 2.39$, $p = 0.017$), indicating stronger priming effects for high-productivity items compared to low-productivity ones, as shown in Figure 2. However, the interaction between the test prime and word class was not significant ($\beta = 19.35$, $SE = 18.16$, $t = 1.07$, $p = 0.286$), suggesting that morphological priming effects did not differ between nouns and verbs. Further, like in Experiment 1, the three-way interaction between test prime, productivity, and word class across all conditions ($\beta = -31.0106$, $SE = 25.7295$, $t = -1.205$, $p = 0.2287$) was not significant.

To further explore these effects, a separate LME model analyzed RTs in the test prime and unrelated control conditions, excluding orthographic and semantic controls. This analysis confirmed robust morphological priming, with faster RTs for morphologically related primes compared to unrelated controls ($\beta = -60.96$, $SE = 12.49$, $t = -4.88$, $p < 0.001$). The interaction

between the test prime and productivity was again significant ($\beta = 44.84$, $SE = 17.65$, $t = 2.54$, $p = 0.0117$), showing stronger effects for high-productivity conditions. However, no significant interaction was observed between the test prime and part of speech ($\beta = 19.77$, $SE = 17.65$, $t = 1.12$, $p = 0.2639$), reinforcing the conclusion that priming effects did not vary by word class.

The reaction time (RT) analysis showed a significant productivity effect, as indicated by the estimated marginal means (EMMs). High-productivity nouns had a mean RT of 1019 ms, significantly faster than the 1059 ms observed for low-productivity nouns ($\beta = -40.6$ ms, $SE = 8.83$, $z = -4.599$, $p < 0.0001$). Similarly, high-productivity verbs had a mean RT of 1018 ms, significantly faster than the 1046 ms for low-productivity verbs ($\beta = -27.1$ ms, $SE = 8.87$, $z = -3.059$, $p = 0.0022$). These results confirm that high-productivity items were identified faster than low-productivity ones, regardless of word class.

Table 6: Mean reaction times (ms) with standard deviations in parentheses for high and low productivity nouns, verbs, and control conditions across all conditions in masked visual priming task with an SOA of 48ms in Experiment 2

Condition	Test prime	Baseline (Unrelated control)	Orthographic control	Semantics control
High productive nouns	985.86 (246.78)	1045.04 (267.91)	1029.50 (244.85)	1047.11 (264.24)
High productive verbs	994.11 (245.86)	1037.03 (268.47)	1016.04 (242.67)	1037.18 (266.58)
Low productive nouns	1050.99 (267.04)	1064.77 (270.42)	1041.54 (246.85)	1074.04 (275.76)
Low productive verbs	1032.27 (254.49)	1054.55 (271.95)	1050.02 (260.66)	1052.46 (265.21)

However, the EMMs analysis showed no significant difference in priming between nouns and verbs. High-productivity nouns had a mean RT of 1019 ms, and high-productivity verbs had a mean RT of 1018 ms, showing a non-significant difference of 0.233 ms ($SE = 8.83$, $z = 0.026$, $p = 0.9789$). In the low-productivity condition, nouns had a mean RT of 1059 ms, and verbs had 1046 ms, showing a non-significant difference of 13.709 ms ($SE = 8.87$, $z = 1.545$, $p = 0.1222$).

In sum, the results confirm that morphological priming interacts significantly with productivity, with high-productivity items showing stronger priming effects than low-productivity ones. However, no significant interaction was observed between priming and word class, indicating that productivity, rather than word class, drives the observed priming effects.

5.3.5.3. Is morphological priming distinct from orthographic and semantic priming?

Statistical analysis confirmed that morphological priming is distinct from both orthographic and semantic priming, for all high-productivity items. As expected in a masked visual priming task, no significant effects were observed for orthographic or semantic control conditions at any productivity level. For high-productivity nouns, the orthographic control condition had a mean RT of 1029.50 ms compared to 1045.04 ms in the unrelated control condition, showing no significant priming effect ($\beta = 18.26$, $SE = 12.79$, $t = 1.43$, $p = 0.154$). Similarly, high-productivity verbs in the orthographic control condition had a mean RT of 1016.04 ms compared to 1037.03 ms, with no significant difference ($\beta = 23.01$, $SE = 12.79$, $t = 1.80$, $p = 0.276$).

In the semantic control condition, high-productivity nouns had an RT of 1047.11 ms, which was nearly identical to the unrelated control RT of 1045.04 ms ($\beta = -0.73$, $SE = 12.81$, $t = 0.06$, $p = 0.954$). High-productivity verbs showed a similar pattern, with an RT of 1037.18 ms compared to 1037.03 ms in the unrelated control, also showing no significant effect ($\beta = -4.80$, $SE = 12.81$, $t = -0.38$, $p = 0.982$).

For low-productivity nouns, no significant priming effects were found in either orthographic ($\beta = 23.26$, $SE = 12.80$, $t = 1.82$, $p = 0.264$) or semantic control conditions ($\beta = -8.55$, $SE = 12.80$, $t = -0.67$, $p = 0.909$). Similarly, low-productivity verbs showed no significant effects in the orthographic control condition ($\beta = 6.35$, $SE = 12.90$, $t = 0.49$, $p = 0.961$) or the semantic control condition ($\beta = 5.02$, $SE = 12.90$, $t = 0.39$, $p = 0.980$).

In summary, no significant priming effects were observed in orthographic or semantic control conditions for either high- or low-productivity items, while significant effects were found in the morphological priming condition. These findings confirm that morphological priming in high-productivity verbs and nouns is driven solely by morphological structure and is distinct from orthographic or semantic similarity. High-productivity templates facilitated faster target recognition, whereas orthographic and semantic similarity did not contribute significantly to priming effects.

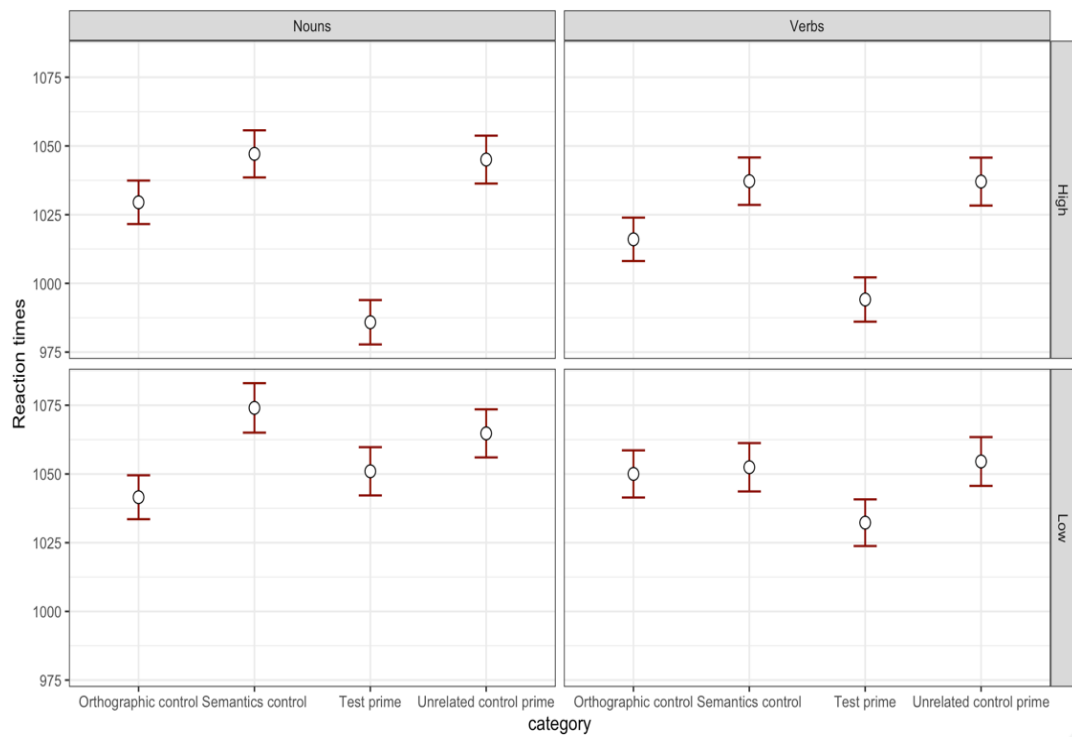


Figure 2: Mean reaction times (RT) for high- and low-productivity nouns and verbs across test, orthographic, semantic, and unrelated control conditions in the masked visual priming task with an SOA of 48 ms in Experiment 2.

6. Experiment 3: Masked Visual Priming Task with a 65ms SOA

In Experiments 1 and 2, we saw significant priming effects for high-productivity verbal and nominal patterns in Arabic, with minimal effects for low-productivity patterns. Orthographic controls showed no priming, and semantic priming appeared only in cross-modal priming

(Experiment 1). Experiment 3 builds on these findings by examining a masked visual priming task with a longer SOA of 65 ms. This SOA was chosen to test whether the productivity effects observed at 48 ms (Experiment 2) persist or reduce with a longer duration. Previous studies (e.g., Boudelaa & Marslen-Wilson, 2005; Xu et al., 2023) suggest that root priming effects in Semitic languages persist across SOAs, while word pattern priming may be more transient.

Again, because I used a masked visual priming task, no significant priming was expected in orthographic or semantic control conditions, consistent with Experiment 2. If the effect of word pattern priming is transient, no morphological priming effects are predicted at a 65ms SOA. However, if priming by high-productivity patterns is stable, we should continue to see significant priming effects for both nouns and verbs at 65 ms, while low-productivity patterns would exhibit weak or no priming.

6.1.Methods

6.1.1.Participants

Experiment 3 involved 108 participants aged 20 to 45. Participant recruitment and inclusion criteria were identical to that in Experiments 1 and 2.

6.1.2.Materials, Design, and Procedure

The materials, design, and procedure were identical to that of Experiment 2, with the only difference being the SOA, which was set to 65 ms in Experiment 3 instead of 48 ms. Labvanced software was used for visual stimulus presentation and data collection, ensuring consistent conditions for measuring reaction times and accuracy. Participants performed a lexical decision task where visual targets followed primes presented in a randomized order.

6.2.Data analysis

6.2.1.Statistical Models

As in previous experiments, reaction times (RTs) were analyzed using linear mixed-effects models (LME) in R, with fixed effects for condition (Test Prime, Unrelated Control, Orthographic Control, and Semantic Control), productivity (High vs. Low), and part of speech (Noun vs. Verb). The unrelated control served as the baseline reference. Random intercepts for participants and items were included to account for individual and item variability. Accuracy data were analyzed using a generalized linear mixed-effects model (GLMM) with a binomial distribution, maintaining the same structure as the RT analysis to ensure consistency across conditions. To confirm the reliability of the findings, an additional analysis was performed using log-transformed reaction times.

6.2.2.Data preparation

The experiment initially involved 108 participants, with nine excluded for accuracy rates below 80%, leaving 99 participants for analysis. Approximately 3.61% of trials were excluded due to missing responses. Only correct word responses were used for RT analysis, resulting in the exclusion of 2.63% of the data due to errors. Items with accuracy rates below 80% were excluded, resulting in the removal of three items. RTs below 200 ms or more than two standard deviations from the mean within each condition were excluded, removing an additional 4.13% of the data, following established methods (Boudelaa & Marslen-Wilson, 2005).

6.2.3.Accuracy analysis

Accuracy data were analyzed using a mixed-effects logistic regression model with condition, productivity, and part of speech as fixed effects and random intercepts for participants and items. As in previous experiments, no significant differences in accuracy were observed between

conditions, with participants maintaining high accuracy rates (94–97%). Statistical analyses revealed no significant effects of productivity or word class on accuracy (all p -values > 0.05). These results suggest that any observed effects are more likely attributable to differences in reaction times rather than accuracy. The accuracy rates for each condition, including high- and low-productivity nouns and verbs across all control and test conditions, are shown in Table 7.

6.2.4. Reaction Time Analysis

Results from the reaction time analyses from the masked priming experiment with a 65 ms SOA, are organized to address three key research questions: (1) Is there evidence of morphological priming? (2) Do priming effects interact with productivity levels and word class? (3) How does morphological priming differ from orthographic and semantic influences? Statistical analyses of RT data explore patterns across experimental conditions, shedding light on the mechanisms underlying morphological priming in Arabic.

Table 7: *Accuracy rates (in percentages) for high and low productivity nouns, verbs, and control conditions across all conditions in the masked visual priming task with an SOA of 65ms in Experiment 3*

Condition	Test prime	Baseline (Unrelated control)	Orthographic control	Semantics control
High productive nouns	95.73%	95.80%	96.18%	97.22%
High productive verbs	95.20%	96.37%	95.19%	96.66%
Low productive nouns	96.17%	95.57%	95.80%	96.58%
Low productive verbs	95.98%	95.22%	94.72%	95.95%

6.2.4.1. Is there (morphological) priming?

The reaction time (RT) analysis in Experiment 3 (SOA of 65 ms) demonstrated clear evidence of morphological priming. Using a linear mixed-effects model (LME), the findings mirrored patterns observed in the 48 ms SOA experiment (Experiment 2) and the cross-modal priming task (Experiment 1). The test prime condition significantly reduced RTs compared to the

unrelated control condition ($\beta = -56.84$, $SE = 12.01$, $t = -4.73$, $p < 0.001$), indicating faster responses for morphologically related primes.

As shown in Table 8 and Figure 3, priming effects were stronger for high-productivity nouns and verbs compared to low-productivity items. High-productivity nouns in the test prime condition had a mean RT of 839.29 ms, significantly faster than the unrelated control RT of 893.53 ms ($\beta = 56.85$, $SE = 12.0$, $z = 4.732$, $p < 0.0001$). Similarly, high-productivity verbs exhibited a mean RT of 842.83 ms, significantly faster than the unrelated control RT of 900.64 ms ($\beta = 61.95$, $SE = 12.0$, $z = 5.14$, $p < 0.0001$).

In contrast, low-productivity items displayed no priming effects. Low-productivity nouns had a mean RT of 922.33 ms in the test prime condition, with no significant difference from the unrelated control RT of 926.30 ms ($\beta = 9.52$, $SE = 12.1$, $z = 0.78$, $p = 0.85$). Low-productivity verbs similarly showed no significant priming effect, with mean RTs of 913.93 ms in the test prime condition versus 932.50 ms in the unrelated control ($\beta = 26.89$, $SE = 12.2$, $z = 2.21$, $p = 0.11$).

In conclusion, Experiment 3 confirmed significant morphological priming for high-productivity items, emphasizing the role of morphological structure in facilitating lexical access. The lack of significant priming in orthographic and semantic control conditions for both high- and low-productivity items highlights the specificity of morphological priming effects.

Table 8: *Mean reaction times (ms) with standard deviations in parentheses for high and low productivity nouns, verbs, and control conditions across all conditions in the masked visual priming task with an SOA of 65ms in Experiment 3*

Condition	Test prime	Baseline (Unrelated control)	Orthographic control	Semantics control
High productive nouns	839.29 (189.50)	893.53 (232.09)	888.62 (234.60)	900.81 (243.53)
High productive verbs	842.83 (206.30)	900.64 (229.36)	878.33 (225.09)	892.20 (236.09)
Low productive nouns	922.33 (239.40)	926.30 (242.38)	909.21 (240.57)	920.72 (245.72)
Low productive verbs	913.93 (245.15)	932.50 (259.38)	915.94 (254.95)	927.91 (253.84)

6.2.4.2. Does morphological priming interact with productivity and word class?

As in Experiments 1 and 2, the analysis using both the linear mixed-effects model (LME) and log-transformed RTs showed a significant interaction between priming and productivity level but no significant interaction between priming and word class (noun vs. verb). The test prime and productivity interaction ($\beta = 47.32$, $SE = 17.03$, $t = 2.779$, $p = 0.005$) indicated that priming effects were stronger for high-productivity items than for low-productivity ones (Figure 3). However, the test prime and word class interaction ($\beta = -5.10$, $SE = 17.01$, $t = -0.30$, $p = 0.76$) showed no significant difference, suggesting that morphological priming effects were consistent across nouns and verbs. As before, the three-way interaction between test prime, productivity, and word class ($\beta = -12.270$, $SE = 24.141$, $t = -0.508$, $p = 0.6115$) was not significant.

A separate LME model focusing on the test prime and unrelated control conditions further supported these findings. The test prime significantly reduced RTs compared to unrelated controls ($\beta = -56.32$, $SE = 12.31$, $t = -4.57$, $p < 0.001$), confirming robust morphological priming. Additionally, a significant interaction between test prime and productivity ($\beta = 47.17$, $SE = 17.46$, $t = 2.70$, $p = 0.007$) demonstrated stronger priming for high-productivity conditions. The interaction between test prime and word class remained non-significant ($\beta = -5.03$, $SE = 17.44$, $t = -0.28$, $p = 0.77$), indicating no difference in priming between nouns and verbs.

The reaction times (RTs) in the Estimated Marginal Means (EMMs) analysis, based on averages across the test prime and unrelated control conditions, highlighted a clear productivity effect. High-productivity nouns had a mean RT of 868 ms, significantly faster than low-productivity nouns, which had a mean RT of 926 ms ($\beta = -58.9$, $SE = 8.73$, $z = -6.75$, $p < .0001$). Similarly, high-productivity verbs had a mean RT of 876 ms, compared to 933 ms for low-productivity verbs, a significant difference ($\beta = -56.6$, $SE = 8.77$, $z = -6.455$, $p < .0001$).

In contrast, EMMs found no significant priming effect for word class. High-productivity nouns (868 ms) and high-productivity verbs (876 ms) showed no significant difference ($\beta = -8.43$, $SE = 8.72$, $z = -0.96$, $p = 0.3335$). Low-productivity nouns (926 ms) and verbs (933 ms) also showed no significant difference ($\beta = -6.11$, $SE = 8.78$, $z = -0.696$, $p = 0.4864$).

In sum, these results confirm that productivity significantly influences priming effects, with high-productivity items exhibiting priming. Additionally, word class (noun vs. verb) does not significantly impact priming, suggesting that productivity is the primary determiner of morphological priming effects.

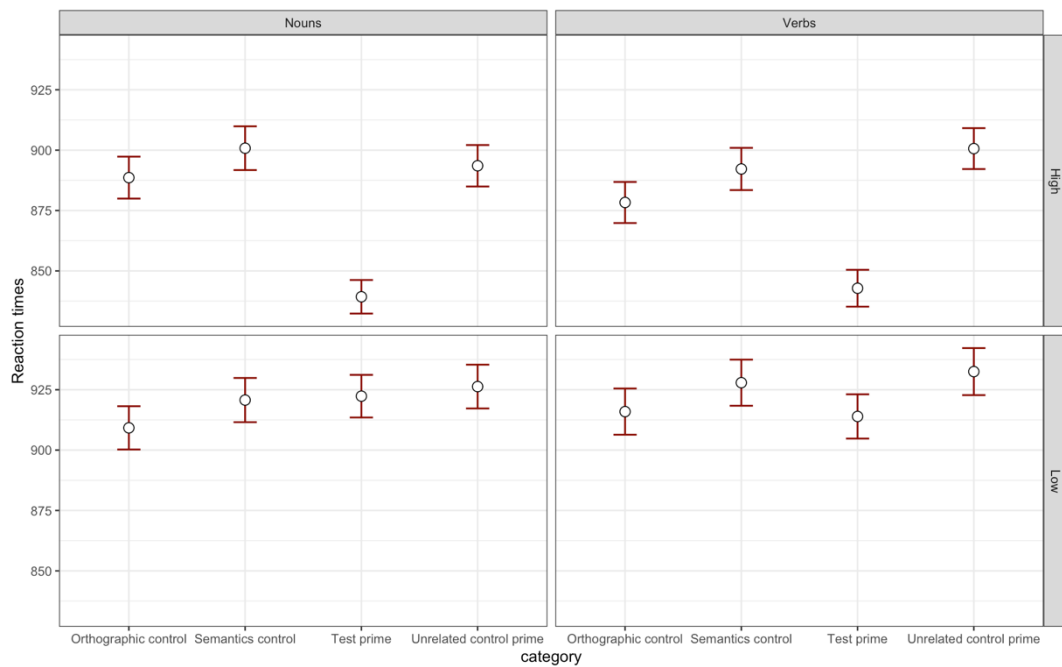


Figure 3: Mean reaction times (RT) for high- and low-productivity nouns and verbs across test, orthographic, semantic, and unrelated control conditions in the masked visual priming task with an SOA of 65ms in Experiment 3

6.2.4.3. Is morphological priming distinct from orthographic and semantic priming?

Statistical analysis confirmed that morphological priming was distinct from both orthographic and semantic priming, as neither orthographic nor semantic control conditions produced significant effects for high- or low-productivity items. As expected in a masked visual priming

task, the orthographic control condition showed no significant priming effect ($\beta = -2.38$, $SE = 12.058$, $t = -0.198$, $p = 0.843$), and the semantic control condition also showed no significant effect ($\beta = 9.66$, $SE = 12.07$, $t = 0.801$, $p = 0.423$). For example, high-productivity nouns in the orthographic control condition had a reaction time (RT) of 888.62 ms compared to 893.53 ms in the unrelated control, with no significant difference ($\beta = 2.38$, $SE = 12.1$, $z = 0.198$, $p = 0.99$). Similarly, high-productivity verbs in the orthographic control condition had an RT of 878.33 ms compared to 900.64 ms in the unrelated control, showing no significant effect ($\beta = 18.94$, $SE = 12.1$, $z = 1.560$, $p = 0.40$).

In the semantic control condition, high-productivity nouns had an RT of 900.81 ms compared to 893.53 ms in the unrelated control, with no significant priming effect ($\beta = -9.66$, $SE = 12.1$, $z = -0.80$, $p = 0.8541$). High-productivity verbs in the semantic control condition had an RT of 892.20 ms compared to 900.64 ms in the unrelated control, also showing no significant effect ($\beta = 10.57$, $SE = 12.1$, $z = 0.876$, $p = 0.81$). These findings indicate that the observed priming effects were specifically driven by morphological structure, not orthographic or semantic similarity.

For low-productivity items, the pattern was consistent. Low-productivity nouns showed no significant priming effects in either the orthographic control condition ($\beta = 18.38$, $SE = 12.1$, $z = 1.51$, $p = 0.4267$) or the semantic control condition ($\beta = 6.33$, $SE = 12.1$, $z = 0.523$, $p = 0.9536$). Similarly, low-productivity verbs showed no significant effects in the orthographic control condition ($\beta = 20.83$, $SE = 12.2$, $z = 1.712$, $p = 0.3172$) or the semantic control condition ($\beta = 7.92$, $SE = 12.2$, $z = 0.651$, $p = 0.9154$).

In summary, neither orthographic nor semantic control conditions showed significant priming effects across high- and low-productivity levels, whereas the morphological priming

condition demonstrated a significant effect for high productivity nouns and verbs. These results emphasize that the priming effect observed in this experiment is uniquely associated with morphological structure in high-productivity items, rather than orthographic or semantic similarity. High-productivity templates, both nouns and verbs, facilitated target recognition in the masked priming task even at an SOA of 65ms, while orthographic and semantic relationships did not contribute to priming effects. This underscores the distinct role of morphological structure, particularly in high-productivity verbs and nouns, in lexical access. Further, it demonstrates that for high productivity items, word pattern priming is not transient.

7. Experiment 4: Masked Visual Priming Task with 42ms SOA

Experiment 4 explored masked priming with a 42 ms SOA to examine how slight changes in prime duration impacted morphological processing in Arabic. This SOA fell between the 48 ms tested in Experiment 2 and the 32 ms used in Experiment 5, offering an opportunity to evaluate its effects on high- and low-productivity nouns and verbs. Previous studies, including Boudelaa & Marslen-Wilson (2005) and Xu et al. (2023), highlighted the sensitivity of template priming to timing, with certain SOAs better capturing transient effects. This experiment built on their findings by assessing whether the results at 48 ms could be reliably replicated at a slightly shorter SOA.

If priming for high productivity patterns is stable, I hypothesized that the 42 ms SOA would show results similar to those at 48 ms, with significant priming for high-productivity nouns and verbs and limited effects for low-productivity patterns. I also expected no priming in orthographic and semantic control conditions. This experiment aimed to clarify how timing adjustments influenced morphological priming in Arabic.

7.1.Methods

7.2.1.Participants

Experiment 4 involved 113 native Arabic speakers aged 20 to 45 years. Recruitment and inclusion criteria were identical to that in the previous experiments.

7.2.2.Materials, design, and procedure

The materials, design, and procedure were identical to those in Experiments 2 and 3. The primary difference was the Stimulus Onset Asynchrony (SOA), set to 42 ms in Experiment 4, compared to 48 ms in Experiment 2 and 65 ms in Experiment 3. Labvanced software was used for stimulus presentation and to collect reaction times and accuracy data. Participants completed a lexical decision task, where primes were immediately followed by visual targets in a randomized order.

7.3. Data analysis

7.3.1.Statistical Models

Reaction times (RTs) were analyzed using linear mixed-effects models (LME), with fixed effects for category, productivity, and part of speech. The unrelated control served as the baseline for comparisons. Random intercepts for subjects and items were included to account for individual variability. Accuracy was assessed using a generalized linear mixed-effects model (GLMM) with a binomial distribution, ensuring a comprehensive evaluation of accuracy stability across conditions. To confirm the reliability of the findings, an additional analysis was performed using log-transformed reaction times.

7.3.2.Data preparation

The experiment included 113 participants initially, but six were excluded for accuracy rates below 80%, leaving data from 107 participants. Missing responses accounted for 6.71% of excluded trials. Only correct word responses were used for RT analysis, leading to the removal

of 2.62% of the data due to errors. Three items with high error rates were excluded, ensuring all remaining items had accuracy rates above 80%. Outliers, RTs below 200 ms or more than two standard deviations from the mean within each condition, were excluded, removing an additional 6.07% of data.

7.3.3. Accuracy analysis

Accuracy rates averaged 96–98% across all conditions, with no statistically significant differences between high- and low-productivity items or between nouns and verbs (all p -values > 0.05). These results indicate that productivity and word class did not influence accuracy, with observed effects instead reflecting differences in RTs. The accuracy rates for each condition, including high- and low-productivity nouns and verbs across all control and test conditions, are shown in Table 9.

Table 9: *Accuracy rates (in percentages) for high and low productivity nouns, verbs, and control conditions across all conditions in the masked visual priming task with an SOA of 42ms in Experiment 4*

Condition	Test prime	Baseline (Unrelated control)	Orthographic control	Semantics control
High productive nouns	97.06%	97.18%	96.97%	96.57%
High productive verbs	96.84%	97.26%	97.75%	97.53%
Low productive nouns	96.17%	97.38%	98.16%	97.07%
Low productive verbs	98.37%	98.12%	96.82%	97.87 %

7.3.4. Reaction Time Analysis

Results from the masked priming experiment with a 42 ms SOA are organized to address three main questions: (1) Is there evidence of morphological priming? (2) Do priming effects interact with productivity levels and word class? (3) How does morphological priming differ from orthographic and semantic influences? The results provide a detailed examination of RT patterns,

highlighting differences across experimental conditions. The RT averages are presented in Table 10 and Figure 4.

7.3.4.1. Is there (morphological) priming?

The results of the linear mixed-effects model (LME) showed a significant priming effect, with the test prime condition illustrating faster response times for morphologically related words compared to the unrelated control condition ($\beta = -31.302$, $SE = 13.21$, $t = -2.369$, $p = 0.0182$). However, this priming effect was primarily restricted to high-productivity verbs. High-productivity verbs in the test prime condition had a mean reaction time (RT) of 758.44 ms, significantly faster than the unrelated control RT of 837.50 ms ($\beta = 79.12$, $SE = 13.0$, $z = 6.102$, $p < .0001$).

In contrast, high-productivity nouns did not show a significant priming effect. Their mean RT in the test prime condition was 801.74 ms, which was not significantly faster than the unrelated control RT of 833.89 ms ($\beta = 31.30$, $SE = 13.2$, $z = 2.369$, $p = 0.0831$). Similarly, low-productivity nouns and verbs showed no significant priming effects. For low-productivity nouns, the test prime condition produced a mean RT of 822.72 ms compared to 845.86 ms in the unrelated control condition, indicating no significant priming ($\beta = 18.47$, $SE = 13.0$, $z = 1.41$, $p = 0.4894$). Low-productivity verbs had a mean RT of 823.58 ms in the test prime condition compared to 854.73 ms in the unrelated control, also failing to demonstrate significant priming ($\beta = 30.53$, $SE = 13.0$, $z = 2.347$, $p = 0.0877$).

No significant priming effects were observed in the orthographic or semantic control conditions across all categories. These findings emphasize that the observed priming effect is specific to morphological structure and limited to high-productivity verbs. High-productivity nouns and all low-productivity items did not exhibit significant morphological priming.

Table 10: Mean reaction times (ms) with standard deviations in parentheses for high and low productivity nouns, verbs, and control conditions across all conditions in the masked visual priming task with an SOA of 42ms in Experiment 4

Condition	Test prime	Baseline (Unrelated control)	Orthographic control	Semantics control
High productive nouns	801.74 (285.31)	833.89 (267.30)	830.08 (232.62)	840.01 (233.88)
High productive verbs	758.44 (288.47)	837.50 (247.57)	817.98 (227.51)	832.26 (241.27)
Low productive nouns	822.72 (272.23)	845.86 (252.56)	837.19 (242.43)	846.87 (247.63)
Low productive verbs	823.58 (281.22)	854.73 (249.87)	841.40 (248.05)	853.60 (248.57)

7.3.4.2. Does morphological priming interact with productivity and word class?

At SOA 42ms, both the linear mixed-effects model (LME) and log-transformed RT showed no significant interaction between morphological priming and productivity ($\beta = 12.83$, $SE = 18.56$, $t = 0.691$, $p = 0.489$). However, the results indicated that priming was primarily observed in high-productivity verbs, while no significant priming occurred in high-productivity nouns and low-productivity items.

The three-way interaction between test prime, productivity, and word class ($\beta = 35.755$, $SE = 26.114$, $t = 1.369$, $p = 0.1715$) was not significant. However, the Estimated Marginal Means (EMMs), based on averages across the test prime and unrelated control conditions, revealed a significant priming effect based on word class. Among high-productivity items, verbs showed significantly faster RTs compared to nouns ($\beta = 20.91$, $SE = 9.53$, $z = 2.194$, $p = 0.0282$). In contrast, low-productivity items showed no significant differences between nouns and verbs ($\beta = -5.62$, $SE = 9.48$, $z = -0.593$, $p = 0.5530$).

As illustrated in Figure 3, pure morphological priming occurred only for high-productivity verbs, with faster RTs in the test prime condition compared to unrelated controls. The absence of priming for high-productivity nouns suggests their priming may depend to some extent on semantic overlap rather than morphology. For the first time in Experiment 4, the

EMMs analysis shows that morphological priming is significantly influenced by word class, with high-productivity verbs exhibiting stronger priming than high-productivity nouns. This suggests that word class plays a critical role in priming at a 42 ms SOA, particularly in high-productivity conditions.

7.3.4.2. Is morphological priming distinct from orthographic and semantic priming?

Statistical analysis confirmed that morphological priming in high-productivity verbs was distinct from orthographic and semantic priming. No significant priming effect was observed in the orthographic control condition ($\beta = -2.966$, $SE = 13.083$, $t = -0.227$, $p = 0.8208$) or the semantic control condition ($\beta = 6.742$, $SE = 13.004$, $t = 0.518$, $p = 0.6043$). For example, no significant orthographic priming was found for high-productivity nouns, with 830.08 ms compared to 833.89 ms in the unrelated control ($\beta = 2.97$, $SE = 13.1$, $z = 0.227$, $p = 0.9959$), or for high-productivity verbs, with 817.98 ms compared to 837.50 ms ($\beta = 19.21$, $SE = 12.8$, $z = 1.496$, $p = 0.4399$). Similarly, no semantic priming was observed for high-productivity nouns, with 840.01 ms compared to 833.89 ms ($\beta = -6.74$, $SE = 13.0$, $z = -0.518$, $p = 0.9547$), or for verbs, with 832.26 ms compared to 837.50 ms ($\beta = 6.56$, $SE = 12.9$, $z = 0.508$, $p = 0.9572$).

Low-productivity items also showed no significant orthographic or semantic priming. For low-productivity nouns, the orthographic control condition had 837.19 ms compared to 845.86 ms in the unrelated control ($\beta = 6.55$, $SE = 12.9$, $z = 0.506$, $p = 0.9576$), while the semantic control condition had 846.87 ms compared to 845.86 ms ($\beta = -3.14$, $SE = 12.9$, $z = -0.243$, $p = 0.9950$). For low-productivity verbs, the orthographic control condition had 841.40 ms compared to 854.73 ms ($\beta = 13.85$, $SE = 12.9$, $z = 1.072$, $p = 0.7068$), and the semantic control condition had 853.60 ms compared to 854.73 ms ($\beta = 3.37$, $SE = 12.9$, $z = 0.262$, $p = 0.9937$). These

results show that morphological priming is specific to high-productivity verbs and is not influenced by orthographic or semantic similarity.

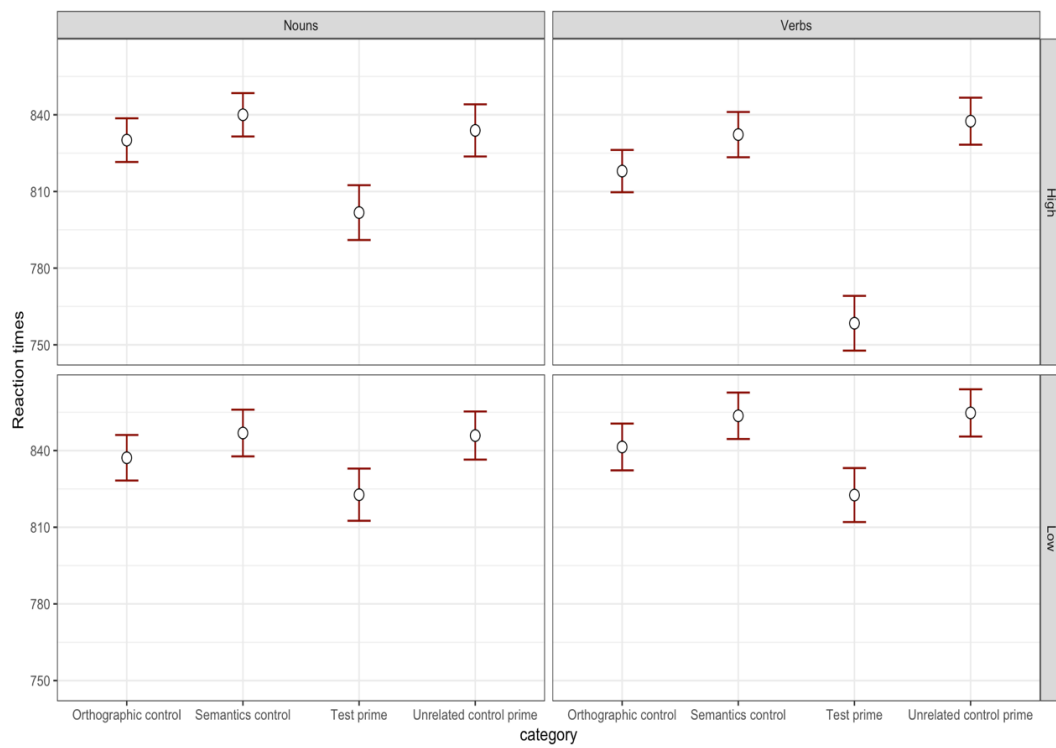


Figure 4: Mean reaction times (RT) for high- and low-productivity nouns and verbs across test, orthographic, semantic, and unrelated control conditions in the masked visual priming task with an SOA of 42ms in Experiment 4

8. Experiment 5: Masked Visual Priming Task with 32ms SOA

Experiment 5 investigates the shortest SOA (32 ms) used in this dissertation to examine morphological priming. Previous studies, including Boudelaa and Marslen-Wilson (2005), suggest that template priming is weaker or absent at short SOAs. Similarly, Xu et al. (2023) found that priming effects in Semitic languages reduce significantly at 32 ms. This experiment examined whether the priming effects observed for high productivity verbs at longer SOAs could still be found at 32ms. Based on prior findings, I hypothesized that no significant priming effects would be shown at 32 ms, as this duration may be too short for reliable morphological priming by word patterns.

8.1. Methods

8.1.1. Participants

A total of 100 native Arabic speakers aged 20 to 45 years participated. Recruitment and inclusion criteria were identical to all previous experiments.

8.1.2. Materials, Design, and Procedure

The materials, design, and procedure were identical to that in Experiments 2, 3, and 4. The key difference was the use of a 32 ms SOA, compared to 48 ms in Experiment 2, 65 ms in Experiment 3, and 42 ms in Experiment 4. Labvanced software was used to present visual stimuli and record reaction times and accuracy rates. Participants completed a lexical decision task, with visual targets presented immediately after primes in a randomized sequence.

8.2. Data analysis

8.2.1. Statistical Models

As in the previous experiments, reaction times (RTs) were analyzed using linear mixed-effects models with fixed effects for category, productivity, and part of speech, using the unrelated control as the baseline. Random intercepts accounted for variability across subjects and items. To confirm the reliability of the findings, an additional analysis was performed using log-transformed reaction times. Accuracy was assessed using a generalized linear mixed-effects model to identify differences across conditions, productivity levels, and word classes.

8.2.2. Data preparation

The experiment included 100 participants. Three participants with accuracy rates below 80% were excluded, leaving 97 participants for analysis. Approximately 4.28% of trials were excluded due to missing responses. Only correct word responses were used in the RT analysis, leading to the exclusion of 2.73% of the data due to errors. Two items with accuracy rates below

80% were removed. All remaining items had accuracy rates above 80%. Reaction times below 200 ms or exceeding two standard deviations from the mean within each condition were excluded as outliers, removing an additional 6.40% of trials.

8.2.3. Accuracy analysis

No significant differences in accuracy were found across conditions, with accuracy rates remaining high at approximately 95–97%. Comparisons between high- and low-productivity items, as well as between nouns and verbs, showed no significant differences ($p > 0.05$). These results indicate that productivity level and word class did not affect accuracy, and observed effects are only on reaction times. The accuracy rates for each condition, including high- and low-productivity nouns and verbs across all control and test conditions, are presented in Table 11.

Table 11: *Accuracy rates (in percentages) for high- and low- productivity nouns, verbs, and control conditions across all conditions in the masked visual priming task with an SOA of 32ms in Experiment 5*

Condition	Test prime	Baseline (Unrelated control)	Orthographic control	Semantics control
High productive nouns	97.62%	97.30%	97.42%	97.26%
High productive verbs	97.64%	97.49%	96.33%	95.82%
Low productive nouns	97.40%	95.51%	97.37%	97.94%
Low productive verbs	96.93%	97.77%	97.35%	97.98%

8.2.4. Reaction Time Analysis

Results from the reaction time analyses for the 32 ms SOA experiment are presented to address three main research questions: (1) Is there evidence of morphological priming? (2) Does morphological priming interact with productivity and word class? (3) Is morphological priming distinct from orthographic and semantic priming? Statistical analyses examined how this shorter prime duration affected priming and contributed to a deeper understanding of morphological processing in Arabic. Reaction times are summarized in Table 12 and Figure 5.

8.2.4.1. Is there (morphological) priming?

For the first time, both the linear mixed-effects model (LME) and log-transformed RT analysis indicated no evidence of morphological priming in this experiment. Reaction times (RTs) in the test prime condition were not significantly faster than those in the unrelated control condition ($\beta = 2.707$, $SE = 12.943$, $t = 0.209$, $p = 0.834$). Morphologically related primes did not facilitate faster responses at an SOA of 32ms.

For high-productivity nouns, the mean RT in the test prime condition was 786.77 ms, similar to the unrelated control RT of 785.01 ms ($\beta = -2.707$, $SE = 12.9$, $z = -0.209$, $p = 0.9968$). High-productivity verbs also showed no effect, with a mean RT of 782.13 ms in the test prime condition and 784.03 ms in the unrelated control ($\beta = 6.396$, $SE = 13.1$, $z = 0.487$, $p = 0.9620$). Low-productivity items similarly showed no priming effects. Low-productivity nouns had a mean RT of 790.79 ms in the test prime condition, comparable to 791.89 ms in the unrelated control ($\beta = 2.211$, $SE = 13.0$, $z = 0.170$, $p = 0.9983$). Low-productivity verbs had a mean RT of 796.13 ms in the test prime condition versus 801.35 ms in the unrelated control ($\beta = 3.639$, $SE = 13.0$, $z = 0.279$, $p = 0.9924$).

In conclusion, the test prime condition did not produce significant morphological priming effects for any category. At an SOA of 32 ms, morphological structure signaled by word patterns does not facilitate target word recognition in this masked visual priming task.

Table 12: Mean reaction times (ms) with standard deviations in parentheses for high and low productivity nouns, verbs, and control conditions across all conditions in the masked visual priming task with an SOA of 32ms in Experiment 5

Condition	Test prime	Baseline (Unrelated control)	Orthographic control	Semantics control
High productive nouns	786.77 (207.46)	785.01 (217.67)	792.19 (200.99)	782.83 (224.61)
High productive verbs	782.13 (250.81)	784.03 (213.04)	778.46 (206.92)	775.58 (208.85)
Low productive nouns	790.79 (248.82)	791.89 (218.88)	786.57 (235.65)	787.24 (213.16)
Low productive verbs	796.13 (235.03)	801.35 (228.86)	791.71 (212.89)	781.69 (233.45)

The 32 ms SOA experiment showed no significant priming effects for orthographic, or semantic conditions either. The linear mixed-effects model (LME) confirmed no significant orthographic priming ($\beta = 6.953$, $SE = 12.932$, $t = 0.538$, $p = 0.591$) or semantic priming ($\beta = -2.353$, $SE = 12.903$, $t = -0.182$, $p = 0.855$) for high- or low-productivity items. High-productivity nouns in the orthographic control condition had an RT of 792.19 ms compared to 785.01 ms in the unrelated control ($\beta = -6.953$, $SE = 12.9$, $z = -0.538$, $p = 0.9498$). High-productivity verbs had an RT of 778.46 ms compared to 784.03 ms in the unrelated control ($\beta = 6.081$, $SE = 13.0$, $z = 0.469$, $p = 0.9659$). In the semantic control, high-productivity nouns showed no priming effect, with an RT of 782.83 ms compared to 785.01 ms in the unrelated control ($\beta = 2.353$, $SE = 12.9$, $z = 0.182$, $p = 0.9978$). High-productivity verbs showed no significant effect, with an RT of 775.58 ms compared to 784.03 ms in the unrelated control ($\beta = 10.969$, $SE = 12.9$, $z = 0.848$, $p = 0.8315$).

Low-productivity items showed similar results. Low-productivity nouns in the orthographic control condition had an RT of 786.57 ms compared to 791.89 ms in the unrelated control ($\beta = 6.360$, $SE = 13.1$, $z = 0.487$, $p = 0.9620$). In the semantic control, low-productivity nouns had an RT of 787.24 ms compared to 791.89 ms in the unrelated control ($\beta = 6.086$, $SE = 13.0$, $z = 0.470$, $p = 0.9657$). Low-productivity verbs in the orthographic control had an RT of 791.71 ms compared to 801.35 ms in the unrelated control ($\beta = 10.248$, $SE = 13.0$, $z = 0.787$, $p = 0.8606$). In the semantic control, low-productivity verbs had an RT of 781.69 ms compared to 801.35 ms in the unrelated control ($\beta = 18.966$, $SE = 13.0$, $z = 1.460$, $p = 0.4620$).

Thus, no significant effects were found for any priming type across conditions. Reaction times for both high- and low-productivity items were similar between control and unrelated conditions, showing no distinct priming effects.

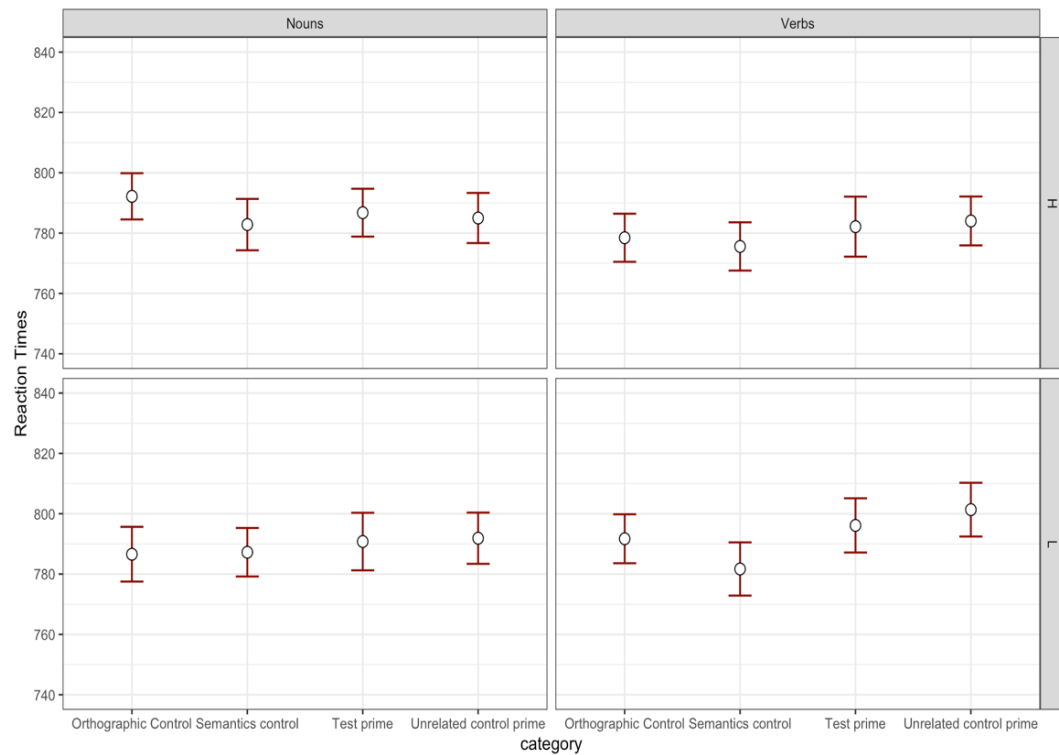


Figure 5: Mean reaction times (RT) for high- and low-productivity nouns and verbs across test, orthographic, semantic, and unrelated control conditions in the masked visual priming task with an SOA of 32ms in Experiment 5

9. SOA Effects on Morphological Priming Across Word Classes and Productivity Levels

To evaluate the effect on SOA on priming, in this section I analyzed the data from all visual masked priming experiments together. Reaction times (RT) for high- and low-productivity nouns and verbs across test, orthographic, semantic, and unrelated control conditions in the masked visual priming task at all SOAs are presented in Figures 7–10 for ease of comparison.

The linear mixed-effects model (LME) analysis showed a significant main effect of stimulus onset asynchrony (SOA) on reaction times. SOA was coded as a categorical variable, with SOA 32 as the baseline, allowing comparisons of RTs across SOAs. Effects for SOA 42, SOA 48, and SOA 65 were interpreted relative to SOA 32. As expected, people were slower at

longer SOAs. Compared to SOA 32 (baseline), RTs were significantly longer at SOA 42 ($\beta = 8.31$, $SE = 2.24$, $t = 3.71$, $p = 0.00022$), SOA 48 ($\beta = 2.63$, $SE = 2.132$, $t = 12.369$, $p < 0.005$), and SOA 65 ($\beta = 9.10$, $SE = 2.26$, $t = 4.0$, $p < 0.005$), confirming the impact of SOA on response latencies.

Figure 6 provides an overall comparison of reaction times across all SOAs for high- and low-productivity nouns and verbs. Different SOAs are indicated with distinct colors and markers, allowing for a clear visual representation of how reaction times vary across conditions. This figure enables direct comparisons of priming effects based on productivity and word class, providing an initial overview of the patterns observed in the data. By examining these broad trends, we can better contextualize the SOA-specific differences that are presented in the subsequent figures.

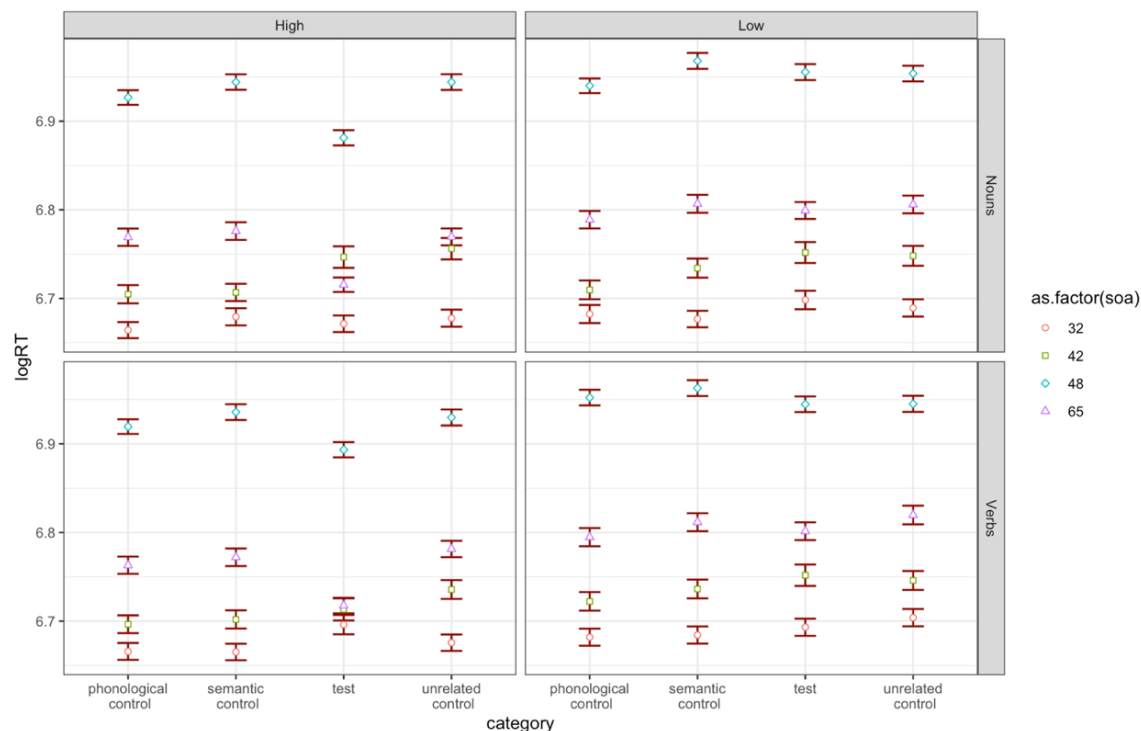


Figure 6: Reaction times across conditions for high- and low-productivity nouns and verbs at different SOAs

Examining the interaction between SOA and the test prime category, SOA 48 ($\beta = -5.182$, $SE = 1.673$, $t = -3.097$, $p = 0.00196$) and SOA 65 ($\beta = -5.217$, $SE = 1.769$, $t = -2.948$, $p = 0.00320$) had significant negative estimates, indicating that morphological priming in these conditions was greater than the extent of morphological priming at SOA 32. However, at SOA 42 ($\beta = -4.737$, $SE = 1.800$, $t = -0.263$, $p = 0.79241$) the extent of morphological priming was similar to that observed at an SOA of 32.

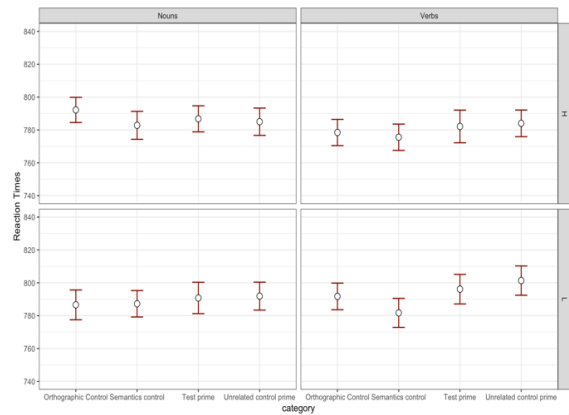


Figure 7: Reaction times across conditions at SOA 32

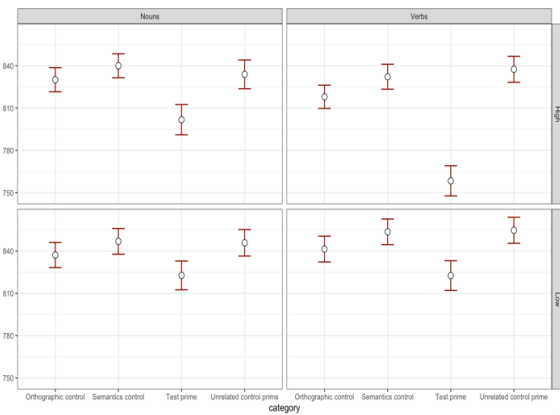


Figure 8: Reaction times conditions at SOA 42

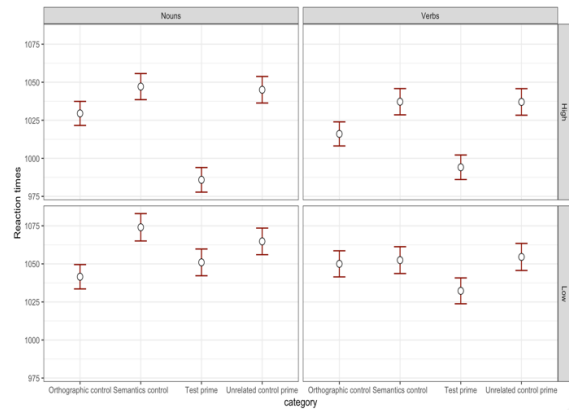


Figure 9: Reaction times across conditions at SOA 48

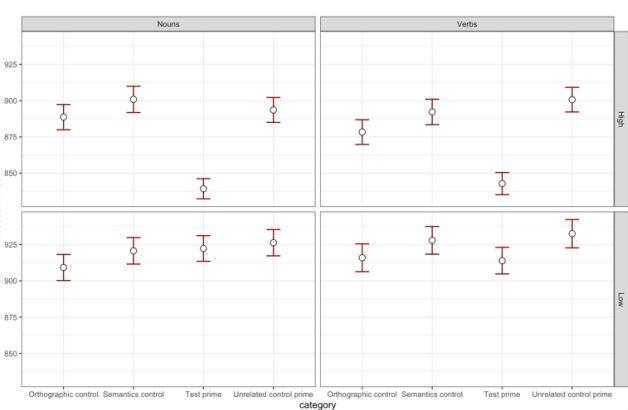


Figure 10: Reaction times across conditions at SOA 65

The interaction between SOA, test prime, and productivity did not result in significant priming at SOA 42 ($\beta = 8.433$, $SE = 2.546$, $t = 0.331$, $p = 0.7404$). A marginal effect was observed at SOA 48 ($\beta = 4.574$, $SE = 2.382$, $t = 1.920$, $p = 0.0548$), and a trend at SOA 65 ($\beta =$

3.380, SE = 2.523, $t = 1.340$, $p = 0.18032$). These results suggest that productivity likely influences priming at SOAs of 48 and 65, but even with about 100 subject per condition, there was not enough power to detect it.

In contrast, the interaction between SOA, test prime category, and word class did not produce significant effects across any SOA conditions. At SOA 42, the estimate was negative ($\beta = -3.025$, SE = 2.571, $t = -1.176$, $p = 0.23949$) and not significant. Similarly, at SOA 48, the estimate was positive ($\beta = 6.268$, SE = 2.392, $t = 0.262$, $p = 0.79327$) but remained non-significant. At SOA 65, the estimate was negative ($\beta = -2.812$, SE = 2.529, $t = -1.112$, $p = 0.26622$) and also non-significant. These findings indicate that SOA does not significantly affect priming based on word class. Instead, productivity appears to play a more prominent role in modulating priming effects across different SOA conditions. No other higher-level interactions were significant.

10. General discussion

In a series of experiments, I examined morphological priming by Arabic word patterns to evaluate the effect of productivity, measured by type frequency, on the priming of nominal and verbal patterns in Arabic. My goal was to determine whether previously reported differences in priming between nominal and verbal patterns can be attributed to differences in productivity alone. To do this, I examined morphological priming effects in high- versus low-productive nouns and verbs and tested whether morphological priming is distinct from semantic and orthographic priming. In experiment 1, I used cross-modal priming, where the prime was auditory, to eliminate orthographic effects and ensure that verbal and nominal patterns were fully specified. In the remaining experiments, I used masked visual priming, with both the prime and target presented visually, at varying SOAs (32 ms, 42 ms, 48 ms, and 65 ms).

In the cross-modal priming experiment, I found morphological priming for both high-productive verbs and high-productive nouns, but no priming effects for low-productive nouns or verbs. No orthographic priming was observed in any condition. However, although high-productive verbs exhibited purely morphological priming, for high-productive nouns, the extent of morphological priming was not different from the extent of semantic priming.

In the masked visual priming experiments, I aimed to determine whether removing the semantic priming effect, which is typically absent due to the brief prime duration, would show similar results. At an SOA of 32 ms, no priming effects were found for morphological, orthographic, or semantic priming.

At an SOA of 42 ms, I observed pure morphological priming only in high-productive verbs, with no priming effects for high-productive nouns or low-productive nouns or verbs. This contrasts with the cross-modal priming results, where high-productive nouns exhibited both morphological and semantic priming. The absence of priming for high-productive nouns at SOA 42 ms suggests that their priming in cross-modal experiments may be driven by semantics rather than morphology. In cross-modal priming, high-productive nouns showed both morphological and semantic effects, but when semantics was eliminated in the masked visual priming paradigm, no effects were observed for high-productive nouns, indicating that their priming may be primarily driven by semantics. Note however, that the priming at an SOA of 42 was not significantly different compared to the morphological priming at an SOA of 32 (where no priming effects were detected) so these results should be interpreted with caution.

At an SOA of 48 and 65 ms, the results show a clear productivity effect for both high-productive nouns and verbs. This was also confirmed in the statistical analysis with SOA as a variable; relative to SOA of 32, significant priming effects were detected at SOA 48 and SOA

65, indicating that increased SOA facilitates morphological priming effects, particularly for high-productive items. Both high-productive verbs and high-productive nouns exhibited robust morphological priming, with no orthographic or semantic effects observed across conditions. Low-productive items showed no priming at these SOAs. These findings argue against priming by high-productive nouns being driven by semantic overlap alone, given that no semantic effects were found in the masked visual priming experiments. Instead, high-productive nouns consistently demonstrated pure morphological priming at both SOA 48 ms and SOA 65 ms.

However, even though high-productive nouns showed pure morphological priming at both SOA 48 ms and SOA 65 ms, they still differed from high-productive verbs. High-productive verbs exhibited pure morphological priming not only at SOA 48 ms and SOA 65 ms but also in cross-modal priming and at SOA 42 ms, where high-productive nouns did not exhibit any priming. This difference suggests that while high-productive nouns exhibit morphological priming, their behavior is distinct from that of high-productive verbs, particularly in terms of the robustness and consistency of the priming effects.

The results of this dissertation suggest that the primary driver of morphological priming by Arabic word patterns is productivity, rather than word class distinctions. Across all experiments, high-productive items consistently exhibited morphological priming, while low-productive items, whether nouns or verbs, did not show any priming effects. This clear distinction based on productivity highlights its central role in word pattern priming. In addition, the lack of significant three-way interactions between test prime, word class, and productivity, as mentioned earlier in the results sections, across all experiments further supports the conclusion that productivity, rather than word class, explains the observed results. The statistical analyses consistently indicate that productivity is the main factor across both cross-modal and visual

masked priming experiments. Even in the analysis with SOA as a variable, where there was no interaction with word class, there was a trend towards an interaction with productivity, particularly at the longer SOAs consistently with the claim that SOA effects were primarily influenced by productivity rather than word class distinctions.

Table 13: *Summary of Morphological Priming Effects Across Experiments*

Experiment	Prime Type	SOA	Morphological Priming	Nouns vs Verbs	Productivity Effects	Effect of Phonological Control	Effect of Semantic Control
Exp 1	Auditory	0 ms (cross-modal)	Yes	No priming differences between nouns and verbs	Main effect of high-productivity (HP); no effect for low-productivity (LP) items	None	HP nouns showed an effect
Exp 2	Visual	48 ms	Yes	No priming differences between nouns and verbs	Main effect of HP; priming observed for HP nouns and verbs, but not LP items	None	None
Exp 3	Visual	65 ms	Yes	No priming differences between nouns and verbs	Main effect of HP; priming observed for HP nouns and verbs, but not LP items	None	None
Exp 4	Visual	42 ms	Yes	High-productivity verbs show effects, but weaker trends for nouns	Stronger priming effect for HP verbs than HP nouns; LP items do not show effects	None	None
Exp 5	Visual	32 ms	No	No priming effect	No observable effect for either HP or LP items	None	None

To summarize the key findings across all experiments, Table 13 provides an overview of morphological priming effects for high- and low-productivity nouns and verbs across different

SOAs and priming paradigms. This summary highlights the consistent priming effects for high-productivity items and the absence of priming for low-productivity items, reinforcing the role of productivity in morphological decomposition. The table also demonstrates how priming effects evolved across SOAs, with stronger effects emerging at longer SOAs.

In comparing my findings with those of Boudelaa and Marslen-Wilson (2005), who also investigated the morphological priming of verbal and nominal patterns in masked priming across different SOAs, I observed both similarities and differences. In the present study as well as Boudelaa and Marslen-Wilson, at an SOA of 32 ms, there was no priming effect across any conditions, including morphological, orthographic, or semantic priming. This suggests that the brief prime duration at this SOA may be insufficient to activate word pattern representations.

Boudelaa and Marslen-Wilson (2005) did not investigate an SOA of 42 ms, which was included in my study. At an SOA of 48 ms, Boudelaa and Marslen-Wilson reported word pattern priming for both nouns and verbs, whereas my results showed morphological priming only for high-productive nouns and verbs. Because Boudelaa and Marslen-Wilson did not systematically control for productivity, it is possible that the differences between the two findings are reflective of differences in productivity of word patterns across the studies. To confirm if this was the case, I calculated the type frequency of all items (verbs and nouns) used by Boudelaa and Marslen-Wilson (2005). These are presented in Figure 11, alongside the productivity of the items (verbs and nouns) used in my experiments. In Figure 11, we can see that all noun items in their study had high-productive word patterns, whereas their verbs included both high- and low-productive patterns. This difference in the distribution of productivity in their stimuli likely explains the larger priming effects observed in their study in nouns, but not verbs. In my experiments, low-

productive verbs and nouns showed no priming, emphasizing the role of productivity in driving morphological priming.

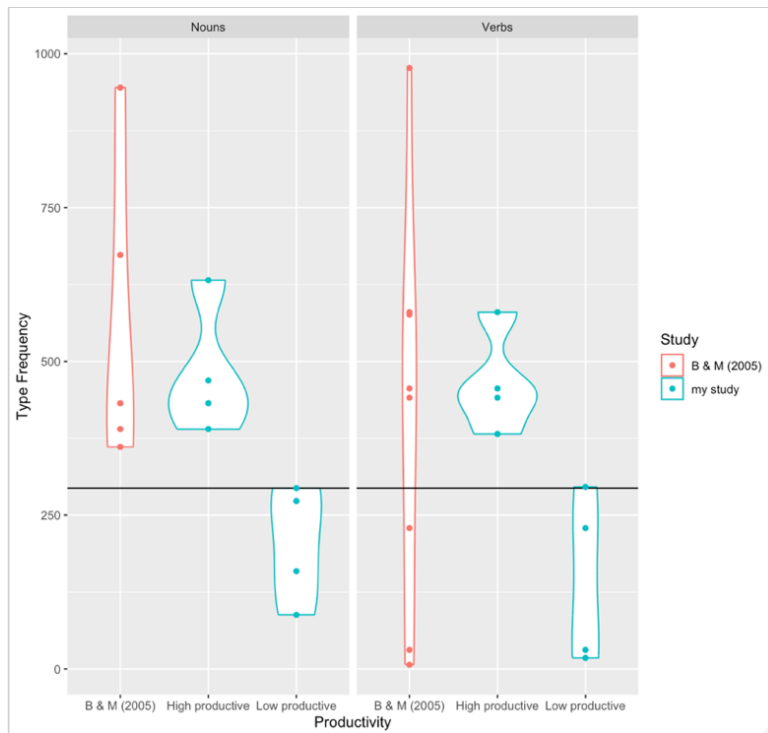


Figure 11: *Type Frequency Distribution of Nouns and Verbs in the experiments in this dissertation compared to those in Boudelaa and Marslen-Wilson's (2005) Study*

At an SOA of 65 ms as well, Boudelaa and Marslen-Wilson found priming only for nouns, with no priming for verbs. In contrast, my results demonstrated robust morphological priming for both high-productive nouns and verbs at this SOA. This difference can also be attributed to differences in stimulus productivity discussed above. In their study, all noun items had high-productive patterns, whereas their verb items showed greater variability in productivity. This variability likely weakened the overall priming effects for verbs in their study. The comparison with Boudelaa and Marslen-Wilson (2005) further strengthens the argument for a crucial role for productivity. The differences between their findings and my findings, specifically their results showing priming for nouns but not for verbs at SOA 65 ms, can also be attributed to

the productivity of their stimuli. When stimuli are carefully controlled for the productivity of word patterns as in the experiments in my studies, consistent priming effects were observed only for high-productive nouns and verbs. Overall, the comparison highlights the importance of controlling for productivity when investigating morphological priming.

However, recall that there were also some differences between high-productive nouns and verbs indicate that word class distinctions may also play a (limited) role in specific contexts. For example, in the cross-modal priming experiment, high-productive nouns exhibited both morphological and semantic priming, whereas high-productive verbs showed only pure morphological priming. This suggests that high-productive nouns may rely on semantic processing in addition to morphological structure. In contrast, in the masked visual priming experiments, where semantic effects are minimized, high-productive nouns demonstrated morphological priming only at SOAs of 48 ms and 65 ms, while high-productive verbs showed morphological priming even at SOA 42 ms. This difference points to an earlier and more consistent morphological effect for high-productive verbs compared to high-productive nouns, highlighting the interaction between productivity and word class distinctions under certain conditions.

In summary, while there are some conditions where word class might influence specific effects (e.g., semantics in cross-modal priming for high-productive nouns), the overall patterns across all experiments strongly support productivity as the main determiner of morphological priming in both nominal and verbal patterns in Arabic.

The finding that productivity plays a role in morphological priming in Arabic, a non-concatenative language, aligns with research on concatenative languages such as English, where affix productivity has been shown to influence lexical processing. For example, Marslen-Wilson

et al. (1996) found that high-productive prefixes and suffixes in English consistently elicited faster reaction times compared to low-productive ones, as discussed earlier in Section 2.5. The findings of this dissertation extend this observation to Arabic, demonstrating that productivity is a central factor in morphological priming across different morphological systems.

A consistent and robust priming effect for word patterns challenge the claims of Boudelaa and Marslen-Wilson (2011), who argued that morphological priming was determined entirely by the productivity of the root, with no priming observed for nominal patterns unless paired with productive roots. They show that even highly productive word patterns did not prime if they appeared in the context of a low-productive root, suggesting that the productivity of word patterns does not independently influence priming effects. Specifically, they observed that highly productive word patterns failed to produce priming when paired with unproductive roots, whereas productive roots consistently produced priming, regardless of the productivity of the word pattern.

It is possible that the absence of nominal word pattern priming in their study might be explained by the high productivity of the roots included in their experiments. However, after analyzing their data, I found that the root productivity (type frequency) in their study (range: 16–37) was not significantly different from the range of root productivity used in my research (range: 20–25). Therefore, differences in root productivity alone cannot account for the absence of priming effects for nominal word patterns in their experiments. Next, I compared the productivity of the nominal word patterns themselves between the two studies. The type frequency of high productive nominal word patterns used in Boudelaa and Marslen-Wilson’s study ranged from 200 to 434, whereas the type frequency of high productive of nominal word patterns in my study ranged higher, from 392 to 632. This higher type frequency of nominal

word patterns in my research may explain the robust priming effects observed for high-productive nominal patterns. Overall, the comparison illustrates that the higher productive word patterns give rise to robust priming effects. These results emphasize the independent role of word pattern productivity in morphological priming, demonstrating that both nominal and verbal word patterns can independently produce priming effects when the productivity of word patterns is sufficiently high.

This dissertation evaluates five models of lexical representation by focusing on the role of productivity in Arabic morphology, particularly in verbal and nominal patterns. **The fully decompositional model** posits that all morphologically complex words are represented as decomposed morphemes in the mental lexicon (Taft & Forster, 1975; Taft, 1988). According to this model, lexical access involves retrieving individual morphemes (root and pattern), regardless of productivity or word class. Any differences in processing arise due to timing or access mechanisms rather than differences in representation. Thus, this model predicts that all words, whether high or low productivity, should exhibit morphological priming if sufficient time is allowed for decomposition. This model aligns with the robust priming observed for high-productivity items at longer SOAs (48 ms and 65 ms), as these items are more easily decomposed under such conditions. However, the results for low-productivity verbs and nouns challenge this prediction. Low-productivity items, even at longer SOAs (e.g., 65 ms), consistently failed to exhibit morphological priming.

If all complex words were truly decomposed, priming should be observed for low-productivity items when sufficient time is provided. However, even at longer SOAs (e.g., 65 ms), no priming was observed for low-productivity verbs and nouns. While one might argue that 65 ms is insufficient for decomposition, high-productivity items are decomposed earlier, suggesting

that time alone is not the determining factor. If decomposition were purely a matter of time, some priming should emerge with increased SOA, even if weaker than that of high-productivity items. The complete absence of priming at 65 ms suggests that low-productivity words may not be decomposed automatically during lexical access, supporting the view that productivity, rather than just time, influences morphological decomposition. Previous research by Boudelaa and Marslen-Wilson (2005) tested longer SOAs and still found no priming effects in either nouns or verbs, indicating that the time window is not the issue. If a longer SOA did not produce priming, it is unlikely that 65 ms was insufficient. However, further research is needed to determine whether priming effects might emerge at even longer SOAs (e.g., 80 ms or 100 ms) or whether the lack of priming reflects a more fundamental difference in representation or processing.

The whole-word model proposes that all words, regardless of productivity, are stored and accessed as unanalyzed units in the mental lexicon (Seidenberg & Gonnerman, 2000). According to this model, morphological structure plays no role in lexical access, and words are retrieved as whole forms. This model effectively explains the lack of priming for low-productivity items, as these items are stored as whole words and lack morphological representations that could facilitate priming. In such models, morphological priming is explained by the joint effects of orthographic priming and semantic priming. However, recall that robust priming was observed for high-productivity verbs and nouns at longer SOAs, but there was no priming based on either orthographic overlap or meaning overlap. These effects cannot be fully explained by whole-word storage alone. Additionally, the marginal priming effects observed for low-productivity items at 42 ms further challenge this model. If all words are accessed as whole units, it is unclear why these marginal priming effects occur, even in the absence of orthographic

or semantic priming, raising questions about whether whole-word representations alone can explain the observed data results.

The bifurcated representation model suggests that each word is represented in one of two forms in the mental lexicon: either as a whole-word representation or as a decomposed representation (root + pattern). The form of representation is determined by factors such as familiarity and productivity. Low-productivity words are stored as whole units, while high-productivity words are stored in decomposed forms (Berent & Pinker, 2007; Clahsen et al., 1992). This model accounts for the robust priming observed for high-productivity items at longer SOAs, as decomposition facilitates priming through morphemes, and it correctly explains the lack of priming for low-productivity items at shorter SOAs (e.g., 32 ms). The results also show a marginal effect for low-productivity verbs at 42 ms ($p = 0.0877$), which does not reach statistical significance. The model correctly predicts the absence of significant priming for low-productivity verbs at 42 ms, given that this value is marginal. The observation of marginal effects, however, raises the possibility that certain low-productivity words might still exhibit weak morphological processing, even if this is not robust or reliable. This raises questions about whether whole-word representations alone can fully explain the observed priming patterns for these items.

Additionally, high-productivity items failed to show priming at shorter SOAs (e.g., 32 ms), despite being decomposed at longer SOAs. This finding challenges the assumption that high-productivity items are always decomposed. In Boudelaa and Marslen-Wilson (2005), an SOA of 32 ms was sufficient to elicit root priming, indicating that priming can occur at this short time window. However, in my results, word pattern priming was not observed at 32 ms. This

suggests that while root decomposition happens early, pattern decomposition might require more time.

The Dual Representation, Dual Access Model proposes that every word is represented in the lexicon in two forms: both as a whole-word and as a decomposed representation (root + pattern). Lexical access involves competition between these two access routes, with the dominant route determined by factors such as productivity. High-productivity items are more likely to be accessed through decomposition, while low-productivity items favor whole-word retrieval (Baayen et al., 1997). This model aligns with the robust morphological priming observed for high-productivity verbs and nouns at longer SOAs (48 ms and 65 ms), consistent with decomposition. The absence of priming at 32 ms for high-productivity items suggests that decomposition requires more time to dominate, highlighting the time-sensitive nature of this process. Low-productivity items consistently fail to exhibit morphological priming, supporting the dominance of whole-word retrieval. It is less clear how the marginal priming effects observed at 42 ms for low-productivity verbs can be accommodated. One possibility is that the productivity plays a more gradient, rather than categorical role and the low productive verbs used in this study were somewhat more productive than the low productive nouns. Future research is needed on the continuous effect of productivity on priming to test this hypothesis.

The single representation, dual access model assumes that words have a single representation (whole-word or decomposed) but can be accessed through two routes: whole-word retrieval or decomposition (Norris, 1994; Grainger & Jacobs, 1996). The choice of route depends on factors such as productivity. High-productivity items are expected to favor the decompositional access route, while low-productivity items rely on whole-word retrieval. This model supports some of the observed findings but struggles with others. It aligns with the robust

morphological priming for high-productivity items at longer SOAs (48 ms and 65 ms), as decomposition dominates when sufficient time is available. It also explains the lack of priming for low-productivity items at shorter SOAs (e.g., 32 ms), as these items are accessed through whole-word retrieval. Furthermore, the marginal priming effects for low-productivity items at 42 ms can be explained by the transition from whole-word to decomposed access as more time becomes available.

However, the model faces challenges in explaining why high-productivity items fail to show priming at shorter SOAs (e.g., 32 ms), where decomposition should still provide facilitation. One possible explanation is that 32 ms is simply too short a time window for decomposition to influence priming. Nevertheless, Boudelaa and Marslen-Wilson (2005) showed that 32 ms was sufficient to elicit root priming. This suggests that some level of morphological decomposition is possible at this SOA, but word pattern priming does not occur within this time frame. Furthermore, the results show that low-productivity items exhibit marginal priming at 42 ms, indicating that some level of morphological processing occurs at this SOA. This finding does not contradict the dual access model. Rather than assuming that items exclusively rely on either decomposition or whole-word access, the dual access model proposes a graded transition between the two, influenced by factors such as productivity and time constraints. The presence of priming at 42 ms for low-productivity items suggests that these items are not processed solely through whole-word access. Instead, it indicates that morphological decomposition can begin under certain conditions, even for less productive forms. This supports the model's flexibility in accommodating different processing mechanisms and reinforces the idea that decomposition is not strictly all-or-nothing, but rather dependent on the interaction of multiple factors.

11. Future Research Directions

Building on the findings of this study, several areas could be explored in future research. First, expanding the range of SOAs (e.g., 80 ms) in masked visual priming could help clarify the role of timing in morphological decomposition, as suggested by Xu et al. (2023) and Boudelaa and Marslen-Wilson (2005). Using different SOAs would provide a deeper understanding of the time course of the lexical access process. Specifically, it would allow us to determine the time window during which morphological templates (word patterns) are accessed and evaluate whether the influence of productivity remains consistent at longer SOAs. Furthermore, it would clarify whether word pattern priming continues to influence lexical processing at longer SOAs, contributing to a more comprehensive understanding of morphological decomposition in Arabic.

Second, further research should focus on examining intermediate productivity levels alongside high- and low-productivity levels. While this study primarily compared high and low levels, testing intermediate productivity would help determine whether priming effects increase progressively or emerge only after productivity reaches a specific level. Incorporating intermediate levels would provide deeper insights into how variations in productivity influence morphological priming and lexical access.

Additionally, examining the effects of productivity on both roots and word patterns would reinforce our understanding of the role productivity plays in morphological priming in Arabic, a non-concatenative language, particularly in both morphemes (roots and word patterns). Moreover, exploring the effects of productivity across dialectal variations, including informal Arabic, alongside other morphologically complex languages such as Hebrew and Maltese, could illustrate whether the productivity effects observed in this study extend beyond Modern Standard Arabic (MSA).

12. Conclusion

In this dissertation, I examined the role of productivity in morphological priming in Arabic, a language characterized by non-concatenative morphology, through a series of experiments that assessed priming effects for both verbal and nominal patterns. I asked whether the differences in priming between verbal and nominal patterns are driven by word class distinctions or productivity effects. These results emphasize the role of productivity as a primary determinant in priming for both verbal and nominal patterns. Robust morphological priming effects were found for high-productivity patterns in Arabic, whereas low-productivity patterns failed to produce reliable priming effects. Moreover, timing also influenced priming effects, as observed when SOAs were varied. High-productivity patterns showed priming effects at SOAs of 45 ms and 65 ms but not at 32 ms, suggesting that morphological decomposition requires a minimum time level to activate morphemic representations.

Overall, this dissertation provides clear evidence for the critical role of productivity in morphological priming and lexical processing. It underscores the psychological reality of non-concatenative morphemes in Arabic, particularly word patterns, and their independent contribution to morphological decomposition. These findings contribute to a broader understanding of the morphological structure in word recognition across different linguistic systems.

APPENDIX A: *High productive verbs with the template [ʔiC.Ca.CaC], type frequency: 580*

Target word	Test prime	Unrelated control prime	Orthographic control	Semantics control	Target nonword
اِفْتَرَقَ [ʔif.ta.raq] “Separated”	اِفْتَكَّرَ [ʔif.ta.kar] “Remembered”	عَافِيَةٌ [ʕaaf.jah] “health”	مَكَرَ [ma.kar] “Deceit”	رَحَلَ [ra.hal] “Departed”	اِفْنَطَسَ [ʔif.na.tʔas]
اِكْتَسَبَ [ʔik.ta.sab] “Gained”	اِفْتَهَمَ [ʔif.ta.ham] “Understood”	مَلْحَمَةٌ [mal.ha.mah] “Epic”	كَلَبَ [kalb] “Dog”	فَازَ [faaz] “Won”	اِكْتَرَقَ [ʔik.na.raq]
اِرْتَفَعَ [ʔir.ta.faʕ] “Rose”	اِفْتَرَسَ [ʔif.ta.ras] “Devoured”	مَرَحَلَةٌ [mar.ha.lah] “Stage”	فَرَمَ [fa.ram] “Minced”	عَالِي [ʕaa.li] “High”	اِرْطَكَّصَ [ʔir.tʔa.kasʕ]
اِحْتَمَلَ [ʔih.ta.mal] “Endured”	اِلْتَمَسَ [ʔil.ta.mas] “Excused”	مَغَادِرَةٌ [mu.yaa.da.rah] “Departure”	حَقَدَ [ha.qad] “hated”	مُمْكِنٌ [mum.kin] “Possible”	اِحْسَنَشَصَ [ʔih.sa.ʕasʕ]
اِقْتَرَبَ [ʔiq.ta.rab] “Approached”	اِخْتَطَفَ [ʔix.ta.tʔaf] “Kidnapped”	خُطْرَةٌ [xu.tʔuu.rah] “Danger”	سِرَبٌ [sirb] “Swarm”	مُتَّصِلٌ [mut.ta.sʕil] “Connected”	اِقْبَطَقَ [ʔiq.ba.tʔaq]
اِبْتَدَعَ [ʔib.ta.ʕad] “Moved away”	اِسْتَمَعَ [ʔis.ta.maʕ] “Approached”	كَهْفٌ [kahf] “Cave”	طَلَعَ [tʔa.laʕ] “Excited”	هَاجَرَ [haa.ʕar] “Migrated”	اِبْكَزَجَ [ʔib.ka.zaʕ]
اِسْتَلَمَ [ʔis.ta.lam] “Received”	اِقْتَنَعَ [ʔiq.ta.naʕ] “Convinced”	حَدِيقَةٌ [ha.dii.qah] “Garden”	فَهِمَ [fa.him] “Understood”	قَبِلَ [qa.bil] “Accepted”	اِسْمَفَسَ [ʔis.ma.fas]
اِفْتَخَرَ [ʔif.ta.xar] “Boasted”	اِلْتَزَمَ [ʔil.ta.zam] “Committed”	تَبَذَرَ [tab.ðir] “Wasting”	نَحَفَ [na.haf] “Slim”	نَجَحَ [na.ʕah] “Succeeded”	اِفْكَقَتَ [ʔif.ka.qat]

APPENDIX B: *High productive verbs with the template [Ca.CaC], type frequency: 456*

Target word	Test prime	Unrelated control prime	Orthographic control	Semantics control	Target Nonword
خَدَّمَ [xa.dam] “Served”	اِفْرَحَ [fa.rah] “Explain”	رَفِيقٌ [ra.fiiq] “Buddy”	اُنْقَدَ [ʔan.qad] “Rescued”	سَاعَدَ [saa.ʕad] “Helped”	خَقَقَ [xa.kaq]
حَلَمَ [ha.lam] “Dreamed”	جَبَرَ [ʕa.bar] “Fixed”	قَمَامَةٌ [qu.maa.mah] “Trash”	سَمَّاحٌ [sa.maah] “Permission”	نَوَّمَ [nawm] “Sleep”	حَخَّطَ [ha.ʕaʔʕ]
سَنَدَ [sa.nad] “Supported”	حَرَثَ [ha.raθ] “Plowed”	حَقِيْبَةٌ [ha.qii.bah] “Bag”	سَعِيدٌ [sa.ʕiid] “Happy”	تَعَاوَنَ [ta.ʕaa.wun] “Cooperation”	سَوَّشَ [sa.waʕ]
سَهَرَ [sa.har] “Stayed awake”	نَصَبَ [na.sʕab] “Cheated”	نَفَثَرَ [daf.tar] “Notebook”	سَارَقٌ [saa.riq] “Thief”	يَنَامَ [ja.naam] “He sleeps”	سَزَخَ [sa.zax]
رَصَدَ [ra.sʕad] “Observed”	جَلَسَ [ʕa.las] “Sat”	طَاوَلَةٌ [tʔaaw.lah] “Table”	صَافَحَ [sʕaa.fah] “Shook hands”	شَاهَدَ [ʕaa.had] “Watched”	رَفَجَ [ra.faz]
خَلَقَ [ha.laq] “Shaved”	نَصَرَ [na.sʕar] “Supported”	سَمَاعَةٌ [sam.maa.ʕah] “Headphone”	لَوْحَةٌ [law.hah] “Board”	نَظَّفَ [nadʕ.dʕaf] “Cleaned”	حَكَطَ [ha.katʕ]
طَلَبَ [tʔa.lab] “Requested”	حَدَثَ [ha.daθ] “Happened”	شَجَرَةٌ [ʕa.ʕa.rah] “Tree”	طَيِّبٌ [tʔaj.jib] “Kind”	اِسْتَفْسَرَ [ʔis.taf.sar] “Inquired”	طَشَعَ [tʔa.ʕaʕ]
خَصَلَ [ha.sʕal] “Occurred”	طَرَقَ [tʔa.raq] “Knocked”	صِدْيَلِيَّةٌ [sʕaj.da.lij.jah] “Pharmacy”	خَلِيبٌ [ha.liib] “Milk”	خَدُوْتُ [hu.duu.θ] “Happening”	خَجَقَ [ha.ʕaq]

APPENDIX C: High productive verbs with the template [Caa.CaC], type frequency: 441

Target Word	Test prime	Unrelated control prime	Orthographic control	Semantics control	Target nonword
صَارَحَ [sʰaa.raħ] “Declared”	ذَاكَرَ [ðaa.kar] “Studied”	صَنْدَلْ [sʰan.dal] “Sandal”	خَمِيرَ [ħa.miir] “Donkeys”	إِعْتَرَفَ [ʔiʕ.ta.raʔ] “Admitted”	صَاخَشَ [sʰaa.xaʃ] “Admitted”
بَارَكَ [baa.rak] “Blessed”	رَافَقَ [raa.ʔaq] “Joined”	خُبُوبَ [ħu.buub] “Pills”	بَقَرَ [ba.qar] “Cows”	رَحْمَةً [rah.mah] “Mercy”	بَاثَرُ [baa.θar] “Admitted”
عَاهَدَ [ʕaa.had] “Promised”	شَارَكَ [ʃaa.rak] “Participated”	أَقْلَامَ [ʔaq.laam] “Pens”	عَمَلَ [ʕa.mal] “Work”	إِلْتَزَمَ [ʔil.ta.zam] “Committed”	عَاخَكَ [ʕaa.hak] “Admitted”
بَادَرَ [baa.dar] “Initiated”	نَاطَرَ [naa.ðʕar] “Observed”	قَرْيَةً [qar.jah] “Village”	نَدِمَ [na.dam] “Regretted”	إِسْتَجَابَ [ʔis.ta.zaab] “Responded”	بَاخَصَ [baa.ʒasʕ] “Admitted”
رَاهَنَ [raa.han] “Wagered”	سَامَحَ [saa.maħ] “Forgave”	صَخُورَ [sʰu.xuur] “Rocks”	رَسَمَ [ra.sam] “Drew”	ضَمَانَ [dʕa.maan] “Guarantee”	رَاقَطَ [raa.qatʕ] “Admitted”
عَاوَنَ [ʕaa.wan] “Cooperated”	خَالَفَ [xaa.laf] “Disagreed”	تَفْنِيدَ [taf.niid] “Analysis”	عَمَلَ [ʕa.mal] “Worked”	تَكَافَأَ [ta.kaa.tuf] “Cooperation”	عَاخَصَ [ʕaa.ʒasʕ] “Admitted”
رَاقَبَ [raa.qab] “Observed”	جَادَلَ [ʒaa.dal] “Argued”	مَزْهَرِيَّةَ [maz.ha.rij.jah] “Vase”	قَعَدَ [qa.ʕad] “Sat”	أَضْطَلَعَ [ʔidʕ.tʕalaʕ] “Informed”	رَاخَصَ [raa.hasʕ] “Admitted”
لَاخَقَ [laa.haq] “Followed”	سَافَرَ [saa.far] “Traveled”	أَطْفَرَ [ʔa.dʕaa.fir] “Nails”	سَارَ [saar] “Walked”	جَرَى [ʒa.ra] “Ran”	جَاسَعَ [ʒaa.say] “Admitted”

APPENDIX D: High productive verbs with the template [ta.Caa.CaC], type frequency: 382

Target word	Test prime	Unrelated control prime	Orthographic control	Semantics control	Target nonword
تَسَاعَدَ [ta.saa.ʕad] “Helped”	تَشَابَهَ [ta.ʃaa.bah] “Resembled”	تُحْفَةً [tuħ.fah] “Masterpiece”	سَرَقَ [sa.raq] “Stole”	مُشَارَكَةً [mu.ʃaa.ra.kah] “Participation”	تَطَاوَرَ [ta.ðʕaa.mur] “Admitted”
تَقَارَبَ [ta.qaa.rab] “Approached”	تَعَادَلَ [ta.ʕaa.qad] “Contracted”	ضِفْدَعَ [dʕif.dʕaʕ] “Frog”	فَقَدَ [fa.qad] “Lost”	وَصُولَ [wu.sʕuul] “Arrival”	تَخَاخَصَ [ta.haa.xusʕ] “Admitted”
تَعَاوَنَ [ta.ʕaa.wan] “Cooperated”	تَقَاعَدَ [ta.qaa.ʕad] “Retired”	مَحَلَّ [ma.hal] “Store”	عَدَسَ [ʕa.das] “Lentils”	مُشَارَكَةً [mu.ʃaa.ra.kah] “Sharing”	تَعَاكَذَ [ta.yaa.kad] “Admitted”
تَسَابَقَ [ta.saa.baq] “Raced”	تَفَاهَمَ [ta.faa.ham] “Communicated”	صَحْرَاءَ [sʕah.raaʔ] “Dessert”	قَرِيبَ [qa.riib] “Closed”	تَحَدَّى [ta.had.di] “Challenge”	تَخَاتَعَ [ta.xaa.nay] “Admitted”
تَعَاقَبَ [ta.ʕaa.qab] “Alternated”	تَجَالَسَ [ta.ʒaa.las] “Sat together”	نَخْلَةً [nax.lah] “Palm tree”	عَقَلَ [ʕaql] “Mind”	مَحْكَمَةً [mah.ka.mah] “Court”	تَعَايَفَ [ta.ʕaa.baf] “Admitted”
تُعَالَجَ [ta.ʕaa.laʒ] “Was treated”	تَوَافَقَ [ta.waa.ʔaq] “Agreed”	كُرَّةَ [ku.raħ] “Ball”	جَمِيلَ [ʒa.miil] “Beautiful”	طَبِيبَ [tʕa.biib] “Doctor”	تَجَاوَلَ [ta.ʒaa.yal] “Admitted”
تَعَاهَدَ [ta.ʕaa.had] “Pledged”	تَهَاوَنَ [ta.haa.wan] “Was careless”	مَقْعَدَ [maq.ʕad] “Seat”	دَخَلَ [da.xal] “Entered”	إِثْقَاقَ [ʔit.ti.faaq] Agreement	تَجَاوَسَرَ [ta.ʒaa.sʕar] “Admitted”
تَقَاتَلَ [ta.qaa.tal] “Fought”	تَعَارَفَ [taʕaa.raʔ] “Got to know”	طَيَّارَةً [tʕaj.jaa.raħ] “Airplane”	مَعْقُولَ [maʕ.quul] “Reasonable”	جَرِيْمَةً [ʒa.rii.mah] “Crime”	تَكَاضَكَ [ta.kaa.dʕak] “Admitted”

APPENDIX E: Low productive verbs with the template [ʔiC.CaC.Ca], type frequency: 18

Target Word	Test prime	Unrelated control prime	Orthographic control	Semantics control	Target nonword
إِسْوَدَّ [ʔis.wad.da] “Became black”	إِعْتَزَّ [ʔiʕ.taz.za] “Became proud”	خَطَوْتُ [xu.tʔuutʔ] “Lines”	دَلَعْتُ [da.laʕ] “Spoiled”	ظَلَمْتُ [ðʔa.laam] “Darkness”	إِحْسَنْتُ [ʔih.saʕ.ʕa] “Became black”
إِبْيَضَ [ʔib.jadʕ.dʕa] “Became white”	إِصْحَبْتُ [ʔisʕ.hab.ba] “Accompanied”	نَجَّاحُ [na.ʒaah] “Success”	ضَرَبْتُ [dʕa.rab] “Hit”	تَلَجَّى [θalʒi] “Snowy”	إِقْكَنْتُ [ʔiq.kad.da] “Became white”
إِحْمَرَّ [ʔih.mar.ra] “Became red”	إِخْتَلَّ [ʔix.tal.la] “Disrupted”	خَاتَمْتُ [xaa.tam] “Ring”	حَلَى [ha.la] “Sweet”	دَمَّ [dam] “Blood”	إِحْشَنْتُ [ʔix.saθ.θa] “Became red”
إِعْوَجَّ [ʔiʕ.waʒ.ʒa] “Crooked”	إِشْفَرَّ [ʔiʕ.qar.ra] “Became Blond”	بُرْكَانُ [bur.kaan] “Volcano”	جَلَسَ [ʒa.las] “Sat”	مَائِلُ [maa.ʔil] “Inclined”	إِعْجَصَّ [ʔiʕ.ʒasʕ.sʕa] “Crooked”
إِضْطُرَّ [ʔidʕ.tʕar.ra] “Was forced”	إِزْرَقَّ [ʔiz.raq.qa] “Became blue”	سُوقُ [suuq] “Market”	رَمَى [ra.ma] “Threw”	مُجْبُورُ [maʒ.buur] “Forced”	إِجْزَكَ [ʔiz.zak.ka] “Was forced”
إِحْتَلَّ [ʔih.tal.la] “Occupied”	إِصْفَرَّ [ʔisʕ.far.ra] “Became yellow”	جِدَارُ [ʒi.daar] “Wall”	حَمَى [ha.ma] “Fever”	سَيِّطَرُ [saj.tʕa.rah] “Control”	إِخْكَغَّ [ʔix.kaʕ.ʕa] “Occupied”
إِعْتَزَّ [ʔiy.tar.ra] “Was proud”	إِرْمَدَّ [ʔir.mad.da] “Became gray”	مِصْبَاحُ [misʕ.baah] “Lamp”	غَسَلَ [ʕa.sal] “Washed”	زَهَى [za.haa] “Glowed”	إِعْكَثَّ [ʔiy.kaθ.θa] “Was proud”
إِنْحَلَّ [ʔin.hal.la] “Liberated”	إِخْضَرَّ [ʔix.dʕar.ra] “Became green”	عَسَلُ [ʕa.sal] “Honey”	نَسَى [na.sa] “Forgot”	مُنْطَلَقُ [mun.tʕa.liq] “Free”	إِنْحَخَّ [ʔin.hax.xa] “Liberated”

APPENDIX F: Low productive verbs with the template [is.CaC.CaC], type frequency: 31

Target word	Test prime	Unrelated control prime	Orthographic control	Semantics control	Target nonword
اسْتَدْرَجَ [ʔis.tad.raʒ] “Lured”	اسْتَحْسَنَ [ʔis.tah.san] “Welcomed”	نَافِذَةٌ [naa.fi.ðah] “Window”	جَلَسَ [ʒa.las] “Sat”	نَادَى [naa.da] “Called”	اسْتَحْكَجَ [ʔis.tax.kaʒ] “Lured”
اسْتَنْجَدَ [ʔis.tan.ʒad] “Sought help”	اسْتَنَقَلَ [ʔis.taθ.qal] “Resented”	صَاعِدُ [sʕaa.ʕid] “Rising”	أَخَذَ [ʔa.xad] “took”	مُسَاعَدَةٌ [mu.saa.ʕa.dah] “Help”	اسْتَكْشَشَ [ʔis.tax.taʃ] “Sought help”
اسْتَثْمَرَ [ʔis.taθ.mar] “Invested”	اسْتَبْغَدَ [ʔis.tab.ʕad] “Excluded”	مُفْرَدَةٌ [muf.ra.dah] “Singular”	شَعَرَ [ʕa.ʕar] “Felt”	رَبَحَ [ribh] “gain”	اسْتَقْخَرَ [ʔis.taʕ.xaz] “Invested”
اسْتَفْهَمَ [ʔis.taf.ham] “Inquired”	اسْتَعْجَلَ [ʔis.taʕ.ʒal] “Hurried”	مُؤَاخَذَةٌ [mu.ʔaa.xa.ðah] “Excuse”	هَرَبَ [ha.rab] “Escaped”	جَوَابُ [ʒa.waab] “Answer”	اسْتَقْطَلَتْ [ʔis.taʕ.tʕaθ] “Inquired”
اسْتَقْدَعَ [ʔis.taʕ.ʕad] “Nitpicked”	اسْتَلْهِمَ [ʔis.tal.ham] “Inspired”	تَحْدِيثُ [tah.diiθ] “Update”	عَجَبَ [ʕa.ʒab] “Liked”	تَمَسَّكَ [ta.mas.sak] “Held tightly”	اسْتَحْشَرَ [ʔi.tax.ʕaz] “Nitpicked”
اسْتَقْبَلَ [ʔis.taʕ.bal] “Welcomed”	اسْتَنْكَرَ [ʔis.tan.kar] “Criticized”	نُورُ [nuur] “Light”	قَمَرُ [qa.mar] “Moon”	نَوْصِيلُ [taw.sʔiil] “Delivery”	اسْتَكْطَلَجَ [ʔis.tak.tʕaʒ] “Welcomed”
اسْتَكْبَرَ [ʔis.tak.bar] “Arrogated”	اسْتَعْمَلَ [ʔis.taʕ.mal] “Used”	مُرَاجِعُ [ma.raa.ʒiʕ] “References”	كَرِيمُ [ka.riim] “Generous”	غُرُورُ [ʕu.ruur] “Arrogance”	اسْتَرْطَغَ [ʔis.taz.tʕay] “Arrogated”
اسْتَسْلَمَ [ʔis.tas.lam] “Gave up”	اسْتَخْدَمَ [ʔis.tax.dam] “Used”	قَطَعَ [qa.tʕaʕ] “Cut”	مَقَعَدُ [maq.ʕad] “Sat”	فَشَلَ [fa.ʕal] “Failure”	اسْتَصْشَمَ [ʔis.tasʕ.ʕam] “Gave up”

APPENDIX G: Low productive verbs with the template [ʔiC.Ca.CaC], type frequency: 229

Target word	Test prime	Unrelated control prime	Orthographic control	Semantics control	Target nonword
إِنْتَقَلَ [ʔin.ta.qal] “Transferred”	إِنْعَزَمَ [ʔin.ʕa.zam] “Was invited”	زَهْرَةٌ [zah.rah] “Flower”	غَسَلَ [ya.sal] “Cleaned”	حَرَكَتْ [ha.ra.kah] “Movement”	إِنْجَحَضَ [ʔin.ka.ʒadʕ] “Went down”
انْخَفَضَ [ʔin.xa.fadʕ] “Decreased”	إِنْدَمَرَ [ʔin.da.mar] “Destroyed”	سَمَكٌ [sa.mak] “Fish”	خَبَرَ [xa.bar] “News”	نَزَلَ [na.zal] “Went down”	إِنْبَجَقَ [ʔin.ba.ʒaq] “Went down”
إِنْسَحَبَ [ʔin.sa.hab] “Withdrew”	إِنْهَمَرَ [ʔin.ha.mar] “Was defeated”	وَادِي [waa.di] “Valley”	غَسَلَ [ʕa.sal] “Honey”	مُغَادَرَةٌ [mu.yaa.da.rah] “Departure”	إِنْطُجَ [ʔin.θa.tʕaʒ] “Went down”
إِنْتَظَرَ [ʔin.ta.ðʕar] “Waited”	إِنْخَدَعَ [ʔin.xa.daʕ] “Was betrayed”	رِيَّاحٌ [ri.jaah] “Winds”	تَمَرٌ [tamr] “Date”	تَمَهَّلَ [ta.mah.hal] “Delayed”	إِنْصَنَشَ [ʔin.sʕa.ʒaʃ] “Went down”
إِنْهَزَمَ [ʔin.ha.zam] “Was defeated”	إِنْبَسَطَ [ʔin.ba.satʕ] “Was happy”	دَرَجٌ [da.raʒ] “Stair”	قَلَمٌ [qa.lam] “Pen”	خَسَرَتْ [xa.saa.rah] “Lost”	إِنْسَنَعَ [ʔin.sa.ʃay] “Went down”
إِنْزَعَجَ [ʔin.za.ʕaʒ] “Was annoyed”	إِنْشَهَرَ [ʔin.ʃa.har] “Became famous”	كَوْكَبٌ [kaw.kab] “Planet”	عَمِيَ [ʕa.ma] “Blind”	تَضَنَّقَ [ta.dʕaa.ʒaq] “Was upset”	إِنْجَحَّخَ [ʔin.ʒa.qax] “Went down”
إِنْسَرَقَ [ʔin.sa.raq] “Was stolen”	إِنْقَلَبَ [ʔin.qa.lab] “Overturned”	جَبْرٌ [hibr] “Ink”	نَقَلَ [naql] “Transfer”	خَرَامِي [ha.raa.mi] “Thief”	إِنْعَجَجَ [ʔin.ya.jax] “Went down”
إِنْمَسَحَ [ʔin.ma.sah] “Was erased”	إِنزَلَقَ [ʔin.za.laq] “Slipped”	غَابَةٌ [yaa.bah] “Forest”	فَرَحَ [fa.rah] “Happiness”	مُخْتَفِيَ [mux.ta.fi] “Disappeared”	إِنْجَحَّقَ [ʔin..ka.ʒaq] “Went down”

APPENDIX H: Low productive verbs with the template [CaC.CaC], type frequency: 296

Target word	Test prime	Unrelated control prime	Orthographic control	Semantics control	Target nonword
طَمَأَنَ [tʕam.ʔan] “Reassured”	بَرَّقَعَ [bar.qaʕ] “Covered”	مِثْيَاءٌ [mi.naaʔ] “Port”	مَسَحَ [ma.sah] “Deleted”	ارْتَاخَ [ʔar.taah] “Relaxed”	كَفَعَطَ [kaq.ʕatʕ] “Went down”
بَثَّرَ [baʕ.θar] “Scattered”	جَرَّثَمَ [ʒar.θam] “Contaminated”	طَرِيقٌ [tʕa.riiq] “Road”	بَلَدٌ [ba.lad] “Country”	تَفَكَّكَ [ta.fak.kak] “Split”	بَثَّخَصَ [baθ.xasʕ] “Went down”
زَخَرَفَ [zax.raʃ] “Decorated”	بَرَّمَجَ [bar.maʒ] “Programmed”	جَزِيرَةٌ [ʒa.zii.rah] “Island”	فَلَكٌ [fa.lak] “Scope”	تَطْرِيزٌ [tatʕ.riiz] “Embroidery”	زَكَمَدَ [zak.sʕad] “Went down”
دَخَرَجَ [dah.raʒ] “Rolled”	جَمَّهَرَ [ʒam.har] “Gathered”	سَفِينَةٌ [sa.fii.nah] “Ship”	دَرْبٌ [darb] “Path”	سَقَطَ [sa.qatʕ] “Fell”	نَحَصَرَ [dah.sʕaz] “Went down”
تَرْجَمَ [tar.ʒam] “Translated”	فَرَّقَعَ [far.qaʕ] “Popped”	صَمُودٌ [sʕu.muud] “Strength”	سَعِيدٌ [sa.ʕiid] “Happy”	لُغَةٌ [lu.yah] “Language”	تَنَقَّكَ [tan.qak] “Went down”
فَشَّعَرَ [ʕaʃ.ʕar] “Shivered”	فَرَّمَلَ [far.mal] “Braked”	خَدِيدٌ [ha.diid] “Iron”	رَقَصَ [raqsʕ] “Dancing”	إِهْتَزَّازٌ [ʔih.ti.zaaz] “Vibration”	فَخَّعَنَ [qax.ʕan] “Went down”
سَيَّرَ [saj.tʕar] “Controlled”	غَرَّيَلَ [yar.bal] “Sifted”	مِهْنَةٌ [mih.nah] “Career”	رَكَبَ [rakab] “Rode”	تَحَكَّمَ [ta.hak.kam] “Controlled”	سَخَقَّتْ [sax.qaθ] “Went down”
أَنْكَرَ [ʔan.kar] “Denied”	سَقَلَبَ [ʃaq.lab] “Flipped”	عَالَمٌ [ʕaa.lam] “World”	كَسَلَ [ka.sal] “Laziness”	جَدَدَ [ʒa.had] “Denied”	أَجَقَضَ [ʔaʒ.qasʕ] “Went down”

APPENDIX I: High productive nouns with the template [taC.CiiC], type frequency: 632

Target word	Test prime	Unrelated control prime	Orthographic control	Semantics control	Target nonword
تَكْرِيم [tak.riim] “Honoring”	تَحْسِين [tah.siin] “Improvement”	تَمَار [da.maar] “Destruction”	كُرَّة [ku.rah] “Ball”	إِحْتِرَام [ʔih.ti.raam] “Respect”	تَشْصِيح [taʃ.sʕiiz] “Correction”
تَسْبِيح [tas.biih] “Worship”	تَصْفِير [tasʕ.fiir] “Whistling”	بَطَّة [batʕ.tʕah] “Duck”	كَسِير [ka.siir] “Broken”	صَلَاة [sʕa.laah] “Prayer”	تَخْكِيش [tax.kiiʃ] “Distraction”
تَعْلِيم [taʕ.liim] “Education”	تَحْدِيد [tah.diid] “Specification”	بِنَايَة [bi.naa.jah] “Building”	مِلْح [milh] “Salt”	مَدْرَسَة [mad.ra.sah] “School”	تَسْجِيخ [tas.ʒiix] “Recording”
تَكْبِير [tak.biiir] “Zoom in”	تَسْمِيع [tas.miiʕ] “Audition”	مُجْتَمَع [muʒ.ta.maʕ] “Society”	كُتْم [katm] “Mute”	صُورَة [sʕuu.rah] “Picture”	تَشْطَبِك [taʃ.ðʕiik] “Distraction”
تَعْدِيل [taʕ.diil] “Correction”	تَلْمِيح [tal.miih] “Hint”	مَطَار [ma.tʕaar] “Airport”	حَفِيد [ha.fiid] “Grandson”	صَحَّح [sʕah.hah] “Fixed”	تَكْفِيح [tak.qiiʒ] “Distraction”
تَرْقِيم [tar.qiim] “Numbering”	تَكْوِين [tak.wiin] Formation	حَيَوَان [ha.ja.waan] Animal	مَكْر [makr] Deceit	أَعْدَاد [ʔaʕ.daad] Numbers	تَطْشِيح [tatʕ.ʃiiz] “Distraction”
تَسْلِيم [tas.liim] Submission	تَوْفِير [taw.fiir] “Provision”	قُلُوب [qu.luub] “Hearts”	مَيْلَك [silk] “Wire”	إِعْطَاء [ʔiʕ.tʕaʔ] “Giving”	تَغْخِيح [tay.xiih] “Distraction”
تَقْطِيع [taʕ.tiih] “Lighten up”	تَقْلِيد [taq.liid] “Imitation”	دَوَائِر [da.waa.ʔir] “Circles”	حُفْرَة [huf.rah] “Hole”	أَبْيَض [ʔab.jadʕ] “White”	تَجْشِيح [taʒ.ʃiix] “Distraction”

APPENDIX J: High productive nouns with the template [maC.CuuC], type frequency: 469

Target word	Test prime	Unrelated control prime	Orthographic control	Semantics control	Target nonword
مَفْهُوم [maf.huum] “Understandable”	مَكْسُور [mak.suur] “Broken”	سَمَاء [sa.maaʔ] “Sky”	هَمْس [hams] “Whisper”	دِرَاسَة [di.raa.sah] “Study”	مَجْزُوط [maʒ.zuudʕ] “Distraction”
مَوْجُود [maw.ʒuud] “Present”	مَسْكُوب [mas.kuub] “Spilled”	صَخْرَاء [sʕah.raaʔ] “Desert”	دُرْج [durʒ] “Drawer”	حَاضِر [haa.dʕir] “Present”	مَقْكَوْط [maq.kuuðʕ] “Distraction”
مَدْفُون [mad.fuun] “Buried”	مُخْلُوط [mah.luul] “Solution”	جَرَح [ʒarh] “Wound”	خُلُوق [xa.luud] “Polite”	قَبْر [qabr] “Grave”	مَضْشُوق [madʕ.ʃuud] “Distraction”
مَغْلُوب [may.luub] “Loser”	مَحْمُول [mah.muul] “Carried”	حَيَاة [ha.jaah] “Life”	بَلَع [ba.laʕ] “Swallowed”	خَسَارَة [xa.saa.rah] “Loosing”	مَقْشُوع [maq.suuy] “Distraction”
مَعْرُوف [maʕ.ruuf] “Well known”	مَنْدُوب [man.duub] “Agent”	قَدَم [qa.dam] “Foot”	صَرْف [sʕarf] “Exchange”	شُهْرَة [ʃuh.rah] “Fame”	مَغْخُوط [may.xuutʕ] “Distraction”
مَفْقُود [maf.quud] “Lost”	مَشْرُوح [maʃ.ruuh] “Explained”	تِجَارَة [ti.ʒaa.rah] “Trade”	سَقْف [saqʕ] “roof”	ضَالِع [dʕaa.ʒiʕ] “Lost”	مَطْخُوص [matʕ.xuusʕ] “Distraction”
مَفْرُوض [maf.ruudʕ] “Obligatory”	مُتْكَوب [man.kuub] “Suffering”	حُرِّيَة [hur.ri.jah] “Freedom”	رَاضِي [raa.dʕi] “Pleased”	إِجْبَار [ʔiʒ.baar] “Compulsion”	مُتْخُوش [maθ.xuudʕ] “Distraction”
مَكْسُور [mak.suur] “Broken”	مَخْزُون [max.zuub] “Stored”	غُرْفَة [ʕur.fah] “Room”	سُور [suur] “Wall”	زُجَاج [zu.ʒaaʒ] “Glass”	مَكْغُوخ [mak.yuux] “Distraction”

APPENDIX K: High productive nouns with the template [CaC.CaaC], type frequency: 432

Target Word	Test prime	Unrelated control prime	Orthographic control	Semantics control	Target nonword
خَوَان [xaw.waan] “Cheater”	نَجَّار [naʒ.ʒaar] “Carpenter”	صندوق [sʰan.duuq] “Box”	خَبَز [xa.baz] “Baked”	مُنافِق [mu.naa.fiʒ] “Hypocrite”	خَكَّاف [xak.kaaf]
حَلَّاق [hal.laaq] “Barber”	خَوَّاف [xaw.waaf] “Scared”	مَلَابِيس [ma.laa.bis] “Clothes”	قَلْب [qalb] “Heart”	مَقَص [ma.qasʰ] “Scissor”	خَعَّات [haʃ.ʕaat]
خَدَام [xad.daam] “Servant”	مَنَّاع [man.naaʕ] “Inflexible”	لَيْل [lajl] “Night”	مَرَح [ma.rah] “Joy”	تَنْظِيف [tan.ðʰiif] “Cleaning”	خَشَّاص [xaʃ.ʃaadʰ]
سَبَّاح [sab.baak] “Plumber”	رَّحَّال [rah.haal] “Traveler”	تَبْذِير [tab.ðiir] “Squandering”	كَفَّن [ka.fan] “Covering”	عَامِل [ʕaa.mil] “Worker”	خَتَّاح [haθ.θaax]
طَبَّاح [tʰab.baax] “Chef”	حَفَّار [haf.faar] “Digger”	أَحْذِيَّة [ʔah.ði.jah] “Shoes”	بَحْر [ba.har] “Sea”	وَحْبَة [waʒ.bah] “Meal”	طَشَّار [tʰaʃ.ʃaaz]
كَنَّاس [kan.naas] “Sweeper”	جَوَّال [ʒaw.waal] “Cellphone”	مِصْبَاح [misʰ.baah] “Lamp”	نَسْر [nasr] “Eagle”	نَظِيف [na.ðiif] “Cleaned”	كَخَّات [kah.haat]
جَزَّار [ʒaz.ʒaar] “Butcher”	خَفَّاق [xaf.faaq] “Waving”	صَنْدَائِق [sa.naa.diiq] “Boxes”	زَّعَل [za.ʕal] “Upset”	لَحْم [la.ham] “Meat”	جَقَّاص [ʒaq.qaasʰ]
رَسَّام [ras.saam] “Painter”	كَذَّاب [kað.ðaab] “Lier”	كَنْز [kanz] “Treasure”	كَبَّر [ka.bar] “Grow up”	لَوْحَة [law.hah] “Painting”	رَثَّاط [raθ.θaatʰ]

APPENDIX L: High productive nouns with the template [Cu.CuuC], type frequency: 390

Target Word	Test prime	Unrelated control prime	Orthographic control	Semantics control	Target Nonword
طُمُوح [tʰu.muuh] “Ambition”	شُرُوع [ʃu.ruuʕ] “Starting”	قَهْوَة [qah.wah] “Coffee”	خَطْم [hatʰ.tʰam] “Broke”	شَغَف [ʃa.yaf] “Passion”	طُئُوك [tʰu.θuuk]
نُزُول [nu.zuul] “Coming down”	كُسُوف [ku.suuf] “Eclipse”	شَارِع [ʃaa.riʕ] “Street”	مَنْزِل [man.zil] “House”	سَقَط [sa.qatʰ] “Fell”	نُخُوج [nu.xuuzʒ]
وُضُوح [wu.dʰuuh] “Clarity”	صُمُود [sʰu.muud] “Resistance”	دَجَاجَة [da.ʒaa.ʒah] “Chicken”	خَوْض [hawdʰ] “Basin”	صَافِي [sʰaa.fi] “Clear”	وُخُوص [wu.xuusʰ]
سُلُوك [su.luuk] “Behavior”	شُرُوق [ʃu.ruuq] “Sunrise”	صَالَة [sʰaa.lah] “Living room”	كَسَل [ka.sal] “Laziness”	مَبَادِي [ma.baa.diʔ] “Principles”	سُبُوف [su.buuf]
هُرُوب [hu.ruub] “Escape”	بُلُوغ [bu.luuy] “Reaching”	أَسْنَان [ʔas.naan] “Teeth”	رَهَاب [ri.haab] “Phobia”	إِنْسَخَب [ʔin.sa.hab] “Withdrew”	هُشُوج [hu.ʃuuzʒ]
دُخُول [du.xuul] “Entry”	هُجُوم [hu.ʒuum] “Attack”	طَبَق [tʰa.baq] “Plate”	خَالِد [xaa.lid] “Endless”	وَصَلَ [wa.sʰal] “Arrived”	دُصُول [du.sʰuul]
غُرُوب [ʒu.ruub] “Sunset”	جُنُون [ʒu.nuun] “Madness”	سِحْر [ʃa.har] “Magic”	رَغْبَة [ray.bah] “Desire”	شَمْس [ʃams] “Sun”	غُكُوط [ʒu.kuutʰ]
سُقُوط [su.quutʰ] “Fall”	بُلُوغ [bu.luuy] “Reaching”	مَنَادِيل [ma.naa.diiil] “Napkins”	تَقْصِيط [taq.siitʰ] “Portion”	إِنْزِلَاق [ʔin.zi.laaq] “Slipping”	سُخُوش [su.xuufʃ]

APPENDIX M: Low productive nouns with the template [Caa.CuuC], type frequency: 88

Target Word	Test prime	Unrelated control prime	Orthographic control	Semantics control	Target Nonword
حاسوب [haa.suub] “Computer”	هاثور [haa.muur] “Grouper”	نخيل [na.xiil] “Palm trees”	سكر [suk.kar] “Sugar”	جهاز [zi.haaz] “Device”	خاكوغ [haa.kuuy]
صاروخ [sʰaa.ruux] “Rocket”	ناموس [naa.muus] “Insect”	بركة [ba.ra.kah] “Blessing”	خريص [ha.riisʰ] “Carful”	فضاء [fa.dʰaa] “Space”	صاجوش [sʰaa.ʒuuʃ]
ساطر [saa.tʰuur] “Cleaver”	ياقوت [jaa.quut] “Jewel”	ورقة [wa.ra.qah] “Leaf”	رطب [ra.tʰib] “Ripe”	تقطيع [taq.tʰiiʃ] “Cutting”	ساكوم [saa.kuum]
قانون [qaa.nuun] “Law”	كاثوس [kaa.buus] “Nightmare”	مساحة [ma.saa.hah] “Space”	ناقة [naa.qah] “Camel”	محكمة [mah.ka.mah] “Court”	قافوج [qaa.fuuʒ]
صابون [sʰaa.buun] “Soap”	جاسوس [ʒaa.suus] “Spy”	علم [ʃa.lam] “Flag”	صبر [sʰa.bar] “Patience”	نظافة [na.ðʰaa.fah] “Cleanliness”	صاشوح [sʰaa.fuuʰ]
قائوس [faa.nuus] “Light”	طابور [tʰaa.buur] “Line”	قطعة [qitʰ.tʰah] “Cat”	فارس [faa.ris] “Knight”	مصباح [misʰ.baah] “Lamp”	فاكوت [faa.kuut]
مناكوش [ʃaa.kuuʃ] “Hammer”	طاووس [tʰaa.wuus] “Peacock”	فستان [fus.taan] “Dress”	مكتوم [mak.tuum] “Hidden”	مسمار [mis.maar] “Nail”	شازوم [ʃaa.zuum]
قاموس [qaa.muus] “Dictionary”	تابوت [taa.buut] “Coffin”	ريشة [rii.ʃah] “Feather”	سرق [sa.raq] “Stole”	ترجمة [tar.ʒa.mah] “Translation”	قاجوع [qaa.ʒuuʃ]

APPENDIX N: Low productive nouns with the template [mu.Caa.CiC], type frequency: 159

Target word	Test prime	Unrelated control prime	Orthographic control	Semantics control	Target nonword
محابيب [mu.haa.sib] “Accountant”	مصارع [mu.sʰaa.riʃ] “Wrestler”	طبيعة [tʰa.bii.ʃah] “Nature”	حرب [harb] “War”	يبيع [ja.biiʃ] “Sell”	ميازف [mu.baa.zif]
محاضر [mu.haa.dʰir] “Lecturer”	مدافع [mu.daa.fiʃ] “Defender”	ليمون [laj.moon] “Lemon”	ضعيف [dʰa.ʃiif] “Weak”	جامعة [ʒaam.ʃah] “University”	مجاقت [mu.ʒaa.qit]
منايس [mu.naa.fis] “Competitor”	مغامر [mu.yaa.mir] “Adventurer”	جبل [ʒa.bal] “Mountain”	محيط [mu.hiitʰ] “Ocean”	تحدي [ta.had.di] “Challenge”	مخاشك [mu.xaa.ʃik]
مناميب [mu.naa.sib] “Suitable”	مغادر [mu.yaa.dir] “Departing”	قناة [qa.naah] “Channel”	سريع [sa.riiʃ] “Fast”	توافق [ta.waa.fuq] “Agreement”	مناعط [mu.naa.yitʰ]
مسافر [mu.saa.fir] “Traveler”	مقاتل [mu.qaa.til] “Fighter”	عنكبوت [ʃan.ka.buut] “Spider”	حافز [haa.fiz] “Motivator”	رحلة [rih.lah] “Trip”	مشاذح [mu.ʃaa.ðih]
مباشر [m.baa.fir] “Direct”	مخافط [mu.haa.fiðʰ] “Governor”	صباح [sʰa.baah] “Morning”	تراث [tu.raaθ] “Heritage”	تلفاز [tel.faaʒ] “Television”	معاثص [mu.ʃaa.θisʰ]
مسالم [mu.saa.lim] “Peaceful”	معاصر [mu.ʃaa.sʰir] “Contemporary”	بداية [bi.daa.jah] “Beginning”	سفير [sa.fiir] “Ambassador”	هادئ [haa.diʔ] “Quiet”	مفاسج [mu.faa.siʒ]
مشارك [mu.ʃaa.rik] “Participant”	معالج [mu.ʃaa.liʒ] “Healer”	حكمة [hik.mah] “Wisdom”	شكل [ʃakl] “Shape”	اجتماع [ʔiʒ.ti.maaʃ] “Meeting”	مخاشز [mu.xaa.ʃiz]

APPENDIX O: Low productive nouns with the template [maC.CaC], type frequency: 273

Target word	Test prime	Unrelated control prime	Orthographic control	Semantics control	Target nonword
مَسْرَح [mas.raħ] “Stage”	مَقْبِض [maq.baðʕ] “Handle”	تَرْكِيز [tar.kiiz] “Focus”	خَرَج [xa.raʒ] “Exit”	تَمَثِيل [tam.θiil] “Acting”	مَكْدَع [mak.daʕ] “Acting”
مَدْخَل [mad.xal] “Entrance”	مَشْرَب [maʃ.rab] “Bar”	عَاطِفَة [ʕaa.tʔi.fah] “Emotion”	دَوْل [du.wal] “Countries”	بَاب [baab] “Door”	مَجْفَخ [maʒ.fax] “Door”
مَقْعَد [maq.ʕad] “Seat”	مَشْغَل [maʃ.yal] “Workshop”	ثَلَاثَة [θal.laa.ʒah] “Refrigerator”	عَدْل [ʕadl] “Justice”	كُرْسِي [kur.si] “Chair”	مَكْقَط [mak.qatʕ] “Chair”
مَسْكَن [mas.kan] “Residence”	مَعْرَض [maʕ.radʕ] “Exhibition”	قَفَّاز [quf.faaz] “Gloves”	قَدَم [qa.dam] “Foot”	بَيْت [bajt] “Home”	مَفْجَش [maf.ʒaʃ] “Home”
مَصْنَر [masʕ.dar] “Source”	مَلْعَب [mal.ʕab] “Playground”	سُكُوت [su.kuut] “Silence”	فَرْد [fard] “Individual”	أَسَاس [ʔa.saas] “Foundation”	مَخْشَج [max.ʃaʒ] “Foundation”
مَقْصِد [maq.sʕad] “Destination”	مَطْبَخ [matʕ.bax] “Kitchen”	جَمْهُور [ʒum.huur] “Audience”	صَنْدَر [sʕadr] “Chest”	غَايَة [yaa.jah] “Goal”	مَغْكَش [may.kaf] “Goal”
مَخْزَن [max.zan] “Warehouse”	مَبْدَأ [mab.daʔ] “Principle”	إِعْتَذَار [ʔiʕ.ti.ðaar] “Apology”	عَدَم [ʕa.dam] “Absence”	مَسْتَوْدَع [mus.taw.daʕ] “Warehouse”	مَلْسَز [mal.saz] “Warehouse”
مَرْكَز [mar.kaz] “Center”	مَصْنَع [masʕ.naʕ] “Factory”	فَرْح [fa.raħ] “Joy”	خَدَر [ħa.ðar] “Caution”	تَسَوَّق [ta.saw.waq] “Shopping”	مَغْكَق [may.kaq] “Shopping”

APPENDIX P: Low productive nouns with the template [Ca.CaaC], type frequency: 294

Target word	Test prime	Unrelated control prime	Orthographic control	Semantics control	Target nonword
طَلَّاق [tʔa.laaq] “Divorce”	سَمَاد [sa.maad] “Compost”	نَهْر [na.har] “River”	قِطَار [qi.tʔaar] “Train”	إِنْفَصَل [ʔin.fa.sʕal] “Separated”	طَجَاص [tʔa.ʒaasʕ] “Separated”
زَمَان [za.maana] “Time”	خَيَال [xa.jaal] “Imagination”	وَرْشَة [war.ʃah] “Workshop”	زَمِيل [za.miil] “Colleague”	سَاعَة [saa.ʕah] “Hour”	زَشَاخ [za.ʃaax] “Hour”
سَحَاب [sa.haab] “Clouds”	كَلَام [ka.laam] “Speech”	قَلْعَة [qal.ʕah] “Castle”	بَحْث [bahθ] “Research”	غَيُوم [yu.juum] “Clouds”	سَغَاط [sa.yaatʕ] “Clouds”
جَمَال [ʒa.maal] “Beauty”	سَوَاد [sa.waad] “Blackness”	عَقْرَب [ʕaq.rab] “Scorpion”	خَرَج [ħa.raʒ] “Embarrassment”	وَسَامَة [wa.saa.mah] “Handsome”	جَغَاش [ʒa.yaaʃ] “Handsome”
مَزَاد [ma.zaad] “Auction”	عَفَاف [ʕa.faaf] “Chastity”	سِلْسِلَة [sil.si.lah] “Chain”	قَفَز [qa.faz] “Jump”	بَائِع [baa.ʔiʕ] “Seller”	مَجَاث [ma.ʒaaθ] “Seller”
مَزَاج [ma.zaaʒ] “Mood”	يَسَار [ja.saar] “Left”	بُرْتُقَال [bur.tu.qaal] “Orange”	مَجْد [maʒd] “Glory”	شَخْصِيَّة [ʃax.sʕij.jah] “Personality”	قَخَاش [qa.xaaʃ] “Personality”
سَمَاح [sa.maah] “Permission”	غَزَال [ya.zaal] “Gazelle”	بِنْت [bint] “Girl”	سَرَح [sa.raħ] “Daydreamed”	عَفُو [ʕa.fu] “Pardon”	سَغَاط [sa.yaatʕ] “Pardon”
زَوَاج [za.waaʒ] “Marriage”	رَمَاد [ra.maad] “Ash”	صَفَر [sʕaqr] “Falcon”	زَمَن [za.man] “Time”	حَفْلَة [ħaf.lah] “Party”	غَرَاغ [ya.raaʕ] “Party”

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