



Semantic transparency effects in Persian: The role of modifiers in the processing of endo-centric head-final compounds

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Abstract

The impact of semantic transparency on the processing of morphologically complex words has been a significant topic of interest over the past few decades. This study delves into the processing of head-final endocentric compounds in Persian and investigates the role of semantic transparency through a masked priming experiment. The experiment included three distinct conditions: transparent, opaque, and orthographic-overlap. In this setup, the primes were head-final endocentric compounds, and their modifiers served as the targets for analysis. The results revealed notable priming effects for both the transparent and opaque conditions, indicating that the presence or absence of semantic transparency significantly influenced processing. Conversely, no priming effect was observed in the orthographic-overlap condition, suggesting that orthographic issue does not facilitate processing in the context of Persian head-final endocentric compounds. These findings robustly support the theory of a rapid, automatic sublexical decomposition model. This model operates independent of both semantic transparency and form, specifically in the processing of head-final endocentric compounds in Persian. The study's outcomes underscored the automaticity of morphological processing in Persian, highlighting that even without clear semantic cues, the decomposition of complex words occurs swiftly and efficiently at a sublexical level. This contributes to a deeper understanding of the mechanisms underlying word processing in languages with complex morphological structures.

Keywords: head-final endocentric compounds, masked priming experiment, modifier, orthographic-overlap, Persian language, semantic transparency, sublexical decomposition

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1. Introduction

One of the concerning psycholinguistic issues over the past decades is associated with the storage and the processing of morphologically complex words, that is, inflected forms (e.g., Alegre & Gordon, 1999), derived ones (e.g., Diependaele et al., 2005; Bozic et al., 2013), and compounds (e.g., Fiorentino & Fund-Reznicek, 2009). Morphological complexity in words is crucial because it reflects the intricate relationship between form and meaning, highlighting how human cognition organizes and retrieves linguistic information. In addition, there are various theoretical models such as the full listing perspective that argues for the storage of complex words as an atom (e.g., Butterworth, 1983). In contrast, the decompositional view sees the storage of complex words as constituents (for example see, Taft & Forster, 1976). These theoretical perspectives provide frameworks for understanding the mental lexicon's structure and functionality, emphasizing the significance of both holistic and componential approaches to word storage. Dual-route models are, also, considered the former view, dealing with both full forms and decomposition of morphemes (e.g., Diependaele et al., 2005).

Moreover, the extent to which the processing of morphologically complex words is controlled by different factors, e.g., semantic transparency and frequency, has been one of the central topics among researchers in both written and spoken forms of a certain language (for example see, Feldman & Bentin, 1994; Sandra, 1994; McQueen & Cutler, 1998; Frost et al., 2005; Fiorentino & Fund-Reznicek, 2009; Gagné et al., 2016; Creemers & Embic, 2022). Semantic transparency refers to the clarity with which the meaning of a compound word can be inferred from its parts, while frequency pertains to how often a word is encountered, both playing pivotal roles in word recognition and processing efficiency. This research focuses on compounding since there have been still fewer studies on this type of complex word rather than the other ones. Compounding is a process where two or more words are combined together to form a new word, which presents unique challenges and insights for understanding morphological processing (e.g., Fiorentino & Fund-Reznicek, 2009). The reason for choosing this kind of complex word relies on the fact that compounding is one of the most worldwide word formation types among the languages (Dressler, 2006), and can be investigated based on lexical processing

and representation (e.g., Fiorentino & Fund-Reznicek, 2009). The universality of compounding across languages underscores its importance in linguistic studies, providing a rich ground for examining how different languages handle morphological complexity. The question of how compounds are represented and processed in the mental lexicon can be of interest in Persian because compounding is a productive morphological process in this language.

1.1. Compounding

Compound words consist of at least two open-class morphemes, such as, 'کار' /kər/ (work) + 'خانه' /xane/ (house) yields 'کارخانه' /kər-xəne/ (factory).

Open-class morphemes which include nouns, verbs, adjectives and adverbs, are the main building blocks of compounds, contributing to their semantic richness and syntactic flexibility. Each compound can be uniquely entered into the dictionary and differs from the syntactic phrases such as 'درخت میوه', including 'درخت' /deraxt/ (tree) + 'ـه' /e/ (Ezafe) + 'میوه' /mive/ (fruit), which means 'the tree of fruit' (Tabatabai, 2016). The distinction between compounds and syntactic phrases highlights the importance of structural and functional differences in word formation, which is crucial for accurate lexical representation and processing.

This paper focuses on Persian head-final endocentric compounds, which are composed of two constituents. The first constituent acts as the modifier and the second one are the head of the whole compound, bearing the grammatical category and the semantic features of the compound. In Persian endocentric compounds, the head determines the overall meaning and grammatical properties, while the modifier specifies or restricts the meaning, creating a hierarchical structure within the word. There is no Ezafe (genitive marker) between the constituents. The following examples represent some head-final endocentric compounds:

- | | |
|-----------------|------------------------------|
| A. /kamar-dard/ | b: /ketəb-xəne/ ¹ |
| back-ache | book-house |
| 'backache' | 'library' |

For more clarification with respect to semantic transparency, compounds

1. In the broader sense "letter" is a form of written communication and "house" is a space or place.

can be transparent or opaque. Transparent compounds seemingly allow for easier meaning retrieval because the meanings of their parts directly contribute to the overall meaning, while opaque compounds may require more cognitive effort to decode because their meanings are not straightforwardly derived from their components. In transparent compounds, the meaning of both constituents is consistent with the meaning of the whole word. In semantically opaque compounds, two conditions are considered: 1- fully opaque as the meaning of both constituents is not related to the meaning of the whole word, such as 'Butterfly'; 2- partially opaque as the meaning of one of the constituents is consistent with the meaning of the whole word, such as 'Headlight'.

1.2. Literature

Compound processing, particularly regarding the effect of semantic transparency, has been extensively studied, yielding conflicting findings. Sandra (1990) found that semantically transparent compounds show morphological decomposition, while opaque compounds are processed as whole words, supporting the dual-route model. These findings suggest that the cognitive processing of compounds varies significantly based on their semantic properties, influencing how they are accessed and retrieved in the mental lexicon. In this regard, Zwitserlood (1994) has also found that semantic priming affects transparent and semi-transparent words in Dutch, but access to lexical items is word-centered for opaque words. Semantic priming, where a related word facilitates the processing of a target word, can show that transparent compounds benefit from this effect, whereas opaque compounds do not, indicating different cognitive pathways for their processing.

Isel et al. (2003), in a study on German, presented the first constituent or the modifier auditorily in a combined priming task, followed by the compound word visually. The results indicated that semantic priming only affects the target word in transparent compounds, and this effect is not observed in opaque compound ones. This auditory-visual priming study underscores the importance of cross-modal interactions in compound word processing, highlighting how initial auditory input can influence subsequent visual recognition, particularly for transparent compounds.

In masked priming tasks, Shoolman and Andrews (2003) reported priming effects for both transparent and opaque compounds, suggesting similar decomposition patterns. Masked priming, where a briefly presented prime influences

the processing of a target word, demonstrates that even without conscious awareness, both types of compounds undergo morphological decomposition, revealing the automatic nature of this process. Similarly, Fiorentino and Fund-Reznicek (2009) demonstrated early visual word recognition of compounds independent of semantic transparency in masked priming tasks, indicating dissociation between semantic and orthographic effects. These findings highlight that early stages of word recognition rely heavily on orthographic information, with semantic transparency playing a more significant role in later processing stages.

Researches specific to Persian compound processing are limited from a psycholinguistic approach. The scarcity of psycholinguistic studies on Persian compounds limits our understanding of how morphological processes operate in this language, making it a crucial area for further research. Despite extensive studies on various morphological processes in other languages, there is a notable gap in Persian studies focusing on compounds, especially regarding factors like frequency and semantic transparency. Addressing this gap is essential for developing a comprehensive understanding of Persian morphology and its cognitive underpinnings. This gap is addressed by recent studies such as those by Foroudinejad and Pardis (2009), Najafian (2009), Shabanijadidi (2012, 2016), Torshizi and Service (2018), Torshizi (2020), Momenian et al. (2021), Esmaelpour et al. (2023), and Esmaelpour and Ghatreh (2024). These studies have contributed to understanding how Persian handles complex words, e.g., compound and derived ones, shedding light on processing mechanisms influenced by factors like frequency and semantic transparency.

Foroudi-najad and Pardis (2009) examined compound processing in Persian and English using lexical decision-making, masked priming, and eye tracking, finding no significant difference in processing times between head-final and head-initial compounds. Their study highlighted the universality of certain morphological processing mechanisms, while also pointing out language-specific variations that require further exploration.

In Persian, the study of Najafian (2009) can be considered as the first study to investigate derivation and the way non-simple words are processed, demonstrating that processing these words in Persian is word-centered. This pioneering research laid the groundwork for subsequent studies on Persian

morphology, highlighting the importance of word-level processing in understanding complex words. She employed dual-route models and lexical decision tests and priming tasks to study suffixal and prefixal derived words. She highlights that the processing of derived words is generally based on a whole-word framework in Persian. This research emphasizes the role of morphological structure in lexical access, showing that derived words are processed holistically in Persian.

Shabanijadidi (2012) investigated the processing of compound verbs in Persian, revealing lexical decomposability and the influence of semantic transparency on early processing stages. Similarly, Shabanijadidi (2016) demonstrated dual-route processing in bilingual Azerbaijani-Persian speakers, where opaque words with low frequency underwent lexical decomposition, while transparent words with high frequency were processed monolexically. These studies provide insights into bilingual language processing, illustrating how different factors influence morphological processing in multilingual contexts.

Torshizi and Service (2018) explored the structure of Persian compounds, showing faster recall for head-final compared to head-initial ones. Their findings suggest that the morphological structure of compounds influences recall efficiency, with head-final compounds being more readily retrieved from memory. Torshizi (2020) further examined psycholinguistic aspects using a mixed model, both auditory and visual, confirming faster identification of head-final compounds in comparison with head-initial ones and indicating the need for further exploration of frequency and semantic transparency effects. This research underscores the importance of considering both auditory and visual modalities in studying compound processing, as they can provide complementary insights into cognitive mechanisms.

Momenian et al. (2021) studied semantic transparency effects across Cantonese and Persian using masked priming tests, noting language-specific variations in processing facilitation. Their cross-linguistic approach highlights the universal and language-specific aspects of morphological processing, providing a broader perspective on how different languages handle complex words. Their research underscored that the processing of Persian compounds can be irrespective of semantic transparency levels. Additionally, Momenian et al. (2021) explored language neurology with fMRI and auditory tests, revealing complex word

processing factors such as semantic transparency and frequency. Their findings are in line with Momenian et al. (2021)'s study on semantic transparency effects across Cantonese and Persian.

Esmaeelpour et al. (2023) investigated the processing of endocentric head-initial compounds in Persian, employing masked priming experiments to analyze semantic and syntactic dependencies. Their findings indicated significant priming effects for transparent and opaque conditions, highlighting morpho-lexical processing irrespective of semantic transparency levels. Yet, there was not any significant priming effect for orthographic-overlap conditions. This research contributes to the understanding of how different factors, such as semantic transparency, influence the processing of compounds in Persian.

Esmaeelpour and Ghatreh (2024) focused on Persian endocentric head-final compounds, using a Masked Priming Task to demonstrate faster processing for transparent compounds based on syntactic and semantic head transparency. Their study emphasizes the importance of syntactic and semantic features in compound processing, providing valuable insights into the cognitive mechanisms underlying morphological processing in Persian.

From the neurolinguistics point of view, Ghonchepour et al. (2019) examined the role of semantic transparency in processing non-verbal compound nouns in language-impaired patients and showed that semantic transparency plays no role in word processing in these patients. Their findings have important implications for clinical applications, suggesting that morphological processing in language-impaired patients might rely on different cognitive mechanisms than those in healthy individuals.

In Persian, some researches have also been conducted on the semantic transparency of compounds, such as Afrashi (1999), Badakhshan and Joudaki (2011), and Sabzevari (2013). However, since the current study focuses on the processing of endocentric compounds in Persian based on semantic transparency and from a psycholinguistics perspective, we have just introduced the studies concerning psycholinguistic processing of compounds. These studies provide a comprehensive understanding of how semantic transparency influences compound processing, offering valuable insights for further research in Persian linguistics.

A key question is related to whether all types of compounds are processed

the same or not. The aim of the current study is to examine the effect of the preceding activation of a constituent within a compound on the following processing of that constituent in the visual masked priming task and the influence of semantic transparency on the processing of the compound. Investigating whether different types of compounds undergo similar processing mechanisms can shed light on the cognitive processes involved in morphological decomposition and integration. Our hypothesis is if the compound is disintegrated into its constituent in the visual method, significant priming effects will be observable independent of the semantic transparency of the whole compound. We will also make an attempt to find out whether it is based on the sublexical model, dealing with the automatic decomposition of words into their morphological constituents on the basis of visual modality before the activation of the whole word, or the supralexical model, indicating that morphological representation is reached after whole word recognition, or the hybrid model, including both sublexical and supralexical processing properties. Understanding which model best explains compound processing can help refine existing theories of morphological representation and contribute to more accurate models of lexical access and retrieval.

In this paper, we manipulated the semantic transparency factor in the experiment to observe the differences in modifier processing, leading to identifying their role in the processing of endocentric compounds in Persian. By systematically varying semantic transparency, we aim to uncover the specific cognitive mechanisms that drive the processing of transparent and opaque compounds, providing a nuanced understanding of morphological processing in Persian.

Based on a masked priming experiment, the results will be reported and analyzed in the current study. The experiment will concentrate on the modifier of the head-final endocentric compound as the target while the primed is the compound itself. The orthographic overlap will be considered in the experiment based on the visual modality which is applied in this research, as well. This methodological approach allows for a detailed examination of the interactions between orthographic, semantic, and syntactic factors in compound processing, offering comprehensive insights into the cognitive processes underlying morphological decomposition and integration.

2. Experiment: Priming of Modifier/ Word-Initial Position- Endo-centric Head-Final Compounds

In this experiment, we investigate the priming effect of the modifier in head-final endocentric compounds. The compounds are used as masked primes. Moreover, the modifiers, as the first constituent, are the targets, such as **کمر درد** /kamar-dard/ (backache), **کمر** /kamar / (back).

2.1. Method

2.1.1. Participants:

Sixty Persian native speakers (30 females and 30 males) with normal vision and hearing participated in the experiment. The number of participants was determined based on the study by Brysbaert and Stevens (2018) and the study by Momenian et al. (2021) in the field of semantic transparency and compound verbs. All participants were right-handed and had no cognitive impairments. The age range was 19-27. These experiments were conducted during the COVID-19 pandemic. Each participant's health condition was checked before the test to ensure they were healthy throughout the study.

The experiment took place in a well-ventilated room with sanitization measures in place to prevent any potential spread of the virus. These precautions ensured that the experimental conditions were safe and did not contribute to any external stress factors that could affect the participants' performance.

2.1.2. Stimuli

This experiment consists of 111 primes paired with targets that are monomorphemic words. 37 transparent Persian compounds used as primes (such as **کمر درد**/kamar-dard/ (back-ache), 'backache') with their modifier as targets (i.e., **کمر**, /kamar/ 'back'); 37 opaque Persian compounds used as primes (such as **پایان نامه**, /pɔjɒn-nɒmɛ/, 'end-letter', 'thesis' with their modifier as targets (i.e., **پایان**, /pɔjɒn /'end'); and 37 embedded orthographic words in the pseudoword-initial position used as primes (e.g., **دریافتنی**, /darjɔftani/, 'conceivable'), and the

embedded pseudoword (i.e., **دریا**, /darjɒ/, ‘sea’) used as the targets. Examples of the stimuli can be observed in Table 1.

Table 1.

Examples of the stimuli

Condition	Primed Example	Target Example
Transparent Compound	کمر درد /kamardard/	کمر /kamar/
Opaque Compound	پایان نامه /pɒjɒnnɒme/	پایان /pɒjɒn/
Orthographic-Overlap	دریافتنی /darjɒftani/	دریا /darjɒ/

During the test, each participant saw each pair of target word and primed word only once. The test was designed using the DMDX software, and there was a total of 222 pairs of primed and target words. Each compound and unrelated word were matched in terms of word length and frequency. Additionally, the length of the target word, frequency of the target word, frequency of the primed word, length of the primed word, and the orthographic overlap between the primed word and the target word were controlled across the three conditions during the study. It is noteworthy that the frequency values were logarithmically transformed before statistical analysis.

The meticulous matching of word length and frequency across conditions was essential to ensure that these variables did not confound the results. Word length can influence recognition speed, as shorter words may be typically processed faster than longer ones. Similarly, more frequent words can seemingly be generally recognized more quickly than less frequent ones. By controlling these factors, the study aimed to isolate the effects of semantic transparency and orthographic overlap. The logarithmic transformation of frequency values is a common practice in psycholinguistic studies to normalize the distribution and mitigate the impact of extreme values, thereby providing a more accurate representation of the frequency effect.

Based on a one-way ANOVA test, given the normality of the data distribution, the results are as follows:

- The frequency of the target word showed no statistical significance across the three conditions: ($F(2, 108) = 0.32, p = 0.96$). Since the frequency of the target word needed to be controlled, an attempt was made to examine the statistical significance of the target word frequencies in this test across the three conditions using a one-way ANOVA test. The result showed that this statistical test also did not show significance among the target word frequencies.
- The length of the target word showed no statistical significance across the three conditions: ($F(2, 108) = 3.2, p = 0.68$). Since the length of the target word needed to be controlled, an attempt was made to analyze the statistical significance of the target word lengths in this test across the three conditions using a one-way ANOVA test. The result showed that this statistical test also did not show significance among the target word lengths.
- The frequency of the primed words among the three conditions did not show any statistical significance: ($F(2, 108) = 0.04, p=0.95$). This statistical result indicates that the frequency of the primed words among the three conditions was not statistically significant, and this test demonstrates that this variable was effectively controlled and maintained a nearly consistent state across all conditions.
- The length of the primed words among the three conditions did not show any statistical significance: ($F(2, 108) = 0.59, p=0.55$). Since the test required the absence of statistical significance among the lengths of the prime words, the one-way ANOVA also indicated no statistical significance among the lengths of the primed words.
- The orthographic overlap between the prime word and the target word showed no statistical significance: ($F(2, 108) = 1.93, p = 0.35$). An attempt was made to analyze the statistical significance of the orthographic overlap relationship between the prime word and the target word in this test across the three conditions using a one-way ANOVA test. This statistical test also did not show significance among the orthographic overlap between the primed word and the target word.

It is worth mentioning that WordPars (<https://github.com/ssaneei/Wordpars>, Esmaeelpour et al. 2021) was utilized to find the frequency of the words and measure the lengths. The WordPars tool was integral to ensuring the accuracy and consistency of the word frequency and length measures. Developed specifically for Persian, WordPars provides a comprehensive database and analysis tools that are essential for psycholinguistic research. By leveraging this tool, the study could maintain a high level of precision in selecting and categorizing the stimuli, ensuring that the results are reliable and replicable. This tool also facilitated the handling of large datasets and complex statistical analyses, underscoring the importance of using specialized software in contemporary psycholinguistic research.

2.2. Procedure

In this experiment, stimuli were visually presented in black in the center of a white screen. The B Zar font was used for writing the stimuli, the target word was displayed in a bold and larger font. The DMDX software was used to conduct this test, with the stimuli being presented randomly for each individual. The writing style of compounds in the tests followed the guidelines of the Academy of Persian Language and Literature, although the orthography of the stimuli was based on the Zaya corpus (Eslami et al., 2004).

The choice of the B Zar font and the specific display parameters were carefully considered to ensure maximum readability and minimize visual strain for the participants. The random presentation of stimuli was crucial to eliminate order effects, ensuring that any priming effects observed were due to the nature of the stimuli themselves and not the sequence in which they were presented. Following the guidelines of the Academy of Persian Language and Literature ensured that the stimuli were linguistically accurate and representative of standard Persian usage, enhancing the ecological validity of the experiment.

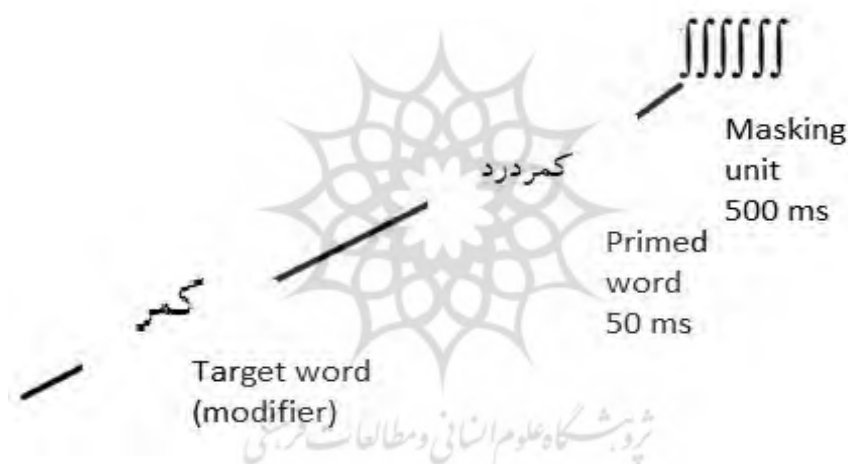
Each participant was instructed to observe a string of letters displayed on the screen. Upon recognizing a word, they pressed the right shift key, and upon seeing a pseudoword, they pressed the left shift key. Additionally, in the masked priming test, a masking unit (#####) was shown for about 500 milliseconds immediately before the prime word to minimize the participant's conscious awareness of the primed. The number of masking characters corresponded to the length of the word. Each trial lasted 2500 ms, during which participants either

responded or the trial ended, and a new one began (the design and timing of these tests were based on the previous studies such as Foster and Forster, 2003).

Initially, each participant completed 10 practice trials to become familiar with the task before starting the main experiment. The participants' performance, including response time, was recorded by the DMDX software. Figure 1 illustrates the procedure for the primed word *کمردرد* /kamar-dard/ (back-ache), 'backache' and its modifier as the target, *کمر* /kamar/ 'back'.

Figure 1.

The procedure for the word and its modifier in the mask priming task



The use of a forward mask and the precise timing of prime and target presentations are standard practices in masked priming experiments to ensure that the prime's influence is subliminal. This setup ensures that participants are not consciously aware of the prime, allowing the study to investigate the automatic processing of the stimuli. The brief presentation times and the controlled experimental conditions help isolate the cognitive processes involved in word recognition and compound processing.

A mixed-effects analysis was performed using the lme4 package in R (Bates et al., 2015). Response times were log-transformed to be fitted with linear mixed-effects models with subjects and items as crossed random effects. Fixed effects included prime type (transparent, opaque, orthographic-overlap) and prime-

target relatedness (related, unrelated).

2.3. Results

For the analysis of this test's results, we utilized both Excel and R software. Response times were recorded using DMDX software. Initially, all incorrect responses were removed from the dataset. Outlier data points were also identified and removed using the median absolute deviation method. The resulting data ranged in response times from 300 to 1300 milliseconds.

Next, response times were log-transformed, and data distribution normality was verified using the Shapiro-Wilk test. The results were examined using a mixed linear effects model based on the logarithm of response times. The analysis was conducted using the lme4 package in R.

We considered three conditions (transparent/opaque/orthographic-overlap) and two types of primes (related/unrelated) as fixed effects. Random variables included test items and participants. The best-fitting model was selected among several, excluding the interaction between the three conditions and the two types of primes. The mean response times and error rates are presented in Table 2. Notably, due to the error rate being 3% or less, error analysis following Libben et al. (2003) was not conducted in this test.

Table 2.

Mean Response Times (Error Rates in Parentheses), Related and Unrelated Primes, Priming Effects across Different Conditions (Transparent, Opaque, orthographic-overlap)

Conditions	Response Time in Milliseconds (Error Rate %)		Priming Effect
	Related Prime	Unrelated Prime	
Transparent	654.59 (1%)	671.52 (1%)	** -16/93
Opaque	663.69 (1.5%)	673.53 (1.5%)	** -9/84
orthographic-overlap	694.16 (3%)	696.7 (3%)	-2/54

As observed in Table 2, the response time in the transparent-related condition is faster than in other conditions, both related and unrelated. The mean response time in this condition is 654.59 milliseconds. Specifically, among the related primes in the other two conditions (opaque and orthographic-overlap), participants showed the fastest response in recognizing transparent endocentric compounds.

In the unrelated prime transparent condition, the mean response time is 671.52 milliseconds, indicating that participants responded more quickly to unrelated transparent primes than to unrelated opaque and orthographic-overlap primes. Additionally, the statistical model indicates a significant facilitation effect of transparent compounds, with a facilitation effect of 16.93 milliseconds, highlighting the difference between mean response times in the transparent-related and transparent-unrelated conditions. The mixed-effects analysis also shows statistical significance ($p < 0.001$, $\beta = 0.0215$).

According to Table 2, the response time in the opaque related condition is faster than in the orthographic-overlap condition, with a mean response time of 663.69 milliseconds. This related prime condition in the opaque state shows weaker performance than the transparent-related condition, but participants' recognition performance in this type of prime is faster than in the orthographic-overlap related, unrelated, and transparent unrelated conditions.

For the unrelated prime in the opaque condition, the mean response time is 673.53 milliseconds, which is faster than in the orthographic-overlap unrelated condition. The statistical model also indicates a significant effect for opaque compounds with faster response times, with a facilitation effect of 9.84 milliseconds, highlighting the difference between mean response times in the opaque related and opaque unrelated conditions. The mixed-effects analysis shows statistical significance ($p < 0.001$, $\beta = 0.0122$).

As seen in Table 2, the response time in the orthographic-overlap related condition is slower than in the other two conditions (transparent-related and opaque-related), as well as in the transparent and opaque unrelated conditions, with a mean response time of 694.16 milliseconds. The slower response times in the orthographic-overlap related condition indicate that mere orthographic similarity between the prime and target is insufficient to facilitate faster word recognition. This suggests that semantic relatedness plays a crucial role in priming effects, as orthographic overlap alone does not provide the necessary cues for quick recognition. The findings highlight the limitations of orthographic priming and the importance of semantic context in word processing.

For the unrelated prime in the orthographic-overlap condition, the mean response time is 696.7 milliseconds, slower than in the other five conditions (opaque

unrelated and related, transparent related and unrelated). The statistical model does not indicate a significant facilitation effect for the orthographic-overlap condition ($p=0.52$), with a facilitation effect of 2.54 milliseconds, which represents the difference between mean response times in the transparent-related and transparent-unrelated conditions. The model also shows a noticeable effect for relatedness ($p<0.001$, $\beta=-0.001$).

3. Discussion

Statistical analysis of the test reveals a significant effect of prime transparency on endocentric compounds with modifiers. The data shows that prime transparency plays a crucial role in lexical access and retrieval, indicating that the transparency of the prime influences how quickly and accurately the target word is processed. A noticeable priming effect was also observed for opaque endocentric compounds. This finding is particularly intriguing because it suggests that even when the semantic relationship between the compound's parts is not immediately clear, the priming effect still facilitates processing. This underscores the robustness of morphological decomposition in lexical processing, regardless of semantic transparency. In this test, the modifier functioned as the target word, and the endocentric compound served as the primed.

This pattern did not hold for the orthographic-overlap condition, where no priming effect was observed. The lack of priming effect in the orthographic-overlap condition suggests that purely orthographic similarities are insufficient to trigger the same level of lexical facilitation observed with semantically transparent and opaque compounds. This finding aligns with the idea that morphological processing is not merely a function of visual similarity but involves deeper cognitive processes related to word structure and meaning. These results suggest that lexical processing of these compounds extends beyond semantic transparency. Lexical processing of transparent and opaque head-final compounds occurs at a sublexical level.

Additionally, based on sublexical theories, the decomposability of endocentric head-final compounds based on the dependent element occurs in the early stages of processing. For example, the compound (such as, *کمر درد* /*kamar-dard*/ (back-ache), 'backache') with their modifier as targets (i.e., *کمر* /*kamar*/

'back') and the compound (such as, پایان‌نامه, /pɒjɒn-nɒme/, 'end-letter'), 'thesis') with their modifier as targets (i.e., پایان, /pɒjɒn /'end') have lexical representations accessible at these early stages. This early accessibility of lexical representations supports the notion that the cognitive system can quickly and efficiently parse complex words into their constituent morphemes, facilitating rapid word recognition and comprehension.

On the other hand, accessing the meaning of transparent and opaque endocentric head-final compounds occurs at later processing stages, according to superlexical theories. Initially, the full form of the compound is activated, followed by access to its semantic components. Consequently, semantic information can be obtained after the structural and lexical representation of the entire compound, indicating that meaning is processed at a level separate from structural representation, which is more abstract and relates to the underlying structure of words. This delayed access to semantic information highlights the hierarchical nature of lexical processing, where initial stages are dominated by structural analysis, and later stages involve the integration of semantic content. The results of this test are consistent with findings from previous studies in English (e.g., Fiorentino & Fund-Reznicek, 2009), which similarly demonstrated that morphological decomposition occurs independently of semantic transparency. These studies suggest that the cognitive mechanisms underlying compound processing might be universal across different language. However, while the alignment between English and Persian in terms of morphological decomposition is intriguing, it is important to consider potential linguistic and structural differences between languages. Although these similarities may point to common cognitive processes, such as the mental lexicon and morphological analysis, further empirical research is necessary to confirm whether these mechanisms are truly universal or if they are language-specific. Therefore, while the observed alignment between English and Persian is promising, we should be cautious in concluding that these findings reflect a universal cognitive mechanism without additional cross-linguistic validation.

Furthermore, the findings indicate that morphological decomposition occurs at a separate level from semantic processing, with meaning being processed at a superlexical level. This separation between morphological and semantic

processing levels supports the idea that different cognitive processes are involved in the recognition and interpretation of complex words, each contributing uniquely to overall word comprehension.

4. General Discussion and Conclusion

This study examines data from a masked priming experiment focusing on the modifier of the endocentric head-final Persian compounds. The masked priming technique, by briefly presenting the prime in a way that participants are not consciously aware of it, allows us to tap into the automatic and unconscious processes involved in word recognition and lexical access. The results indicated that processing of these words occurs at the morpheme-centric levels when they serve as dependent elements. This morpheme-centric processing suggests that the cognitive system is highly adept at breaking down complex words into their constituent parts, facilitating efficient lexical access and retrieval. This finding agrees with the studies conducted in Persian by Esmaeelpour et al. (2023) in terms of endocentric head-initial compounds, Esmaeelpour and Ghatreh (2024) in terms of endocentric head-final compounds with heads as the targets. But it contrasts with the full listing perspective (e.g., Butterworth, 1983) and Dual-route models (e.g., Diependaele et al., 2005). The full listing perspective argues that complex words are stored as whole units in the mental lexicon, while dual-route models suggest that both whole-word storage and morphological decomposition are involved in word recognition. It emphasizes a morpheme-centric processing approach, to better say, the decompositional view and the storage of complex words as constituents (e.g., Taft & Forster, 1976). This study's findings support the decompositional view, highlighting the importance of morphological analysis in the processing of complex words and challenging the notion that whole-word storage is sufficient for efficient lexical access.

Additionally, this study diverges from previous research on derivational affixes (e.g., Najafian, 2009), which treats these words as whole units. Derivational affixes, which alter the meaning and, in some cases, the grammatical category of base words, may involve different processing mechanisms compared to compounding. However, it is important to note that not all types of compounds are processed in the same way. While compounds typically combine existing words to

form new lexical items, the processing of compound words, particularly head-final compounds in Persian, might differ from the processing of derivational affixes. This distinction may highlight important differences in how derivational and compound words are processed in Persian, offering valuable insights into the cognitive mechanisms underlying morphological analysis. Understanding these differences can also shed light on the factors that influence word recognition and comprehension in the Persian language. Furthermore, this study confirms findings by Momenian et al. (2021), demonstrating that processing of compound verbs in Persian occurs independently of semantic transparency. This independence from semantic transparency suggests that the cognitive mechanisms involved in processing compound verbs might prioritize structural and syntactic information over semantic content. However, Shabani-Jadidi (2012) has highlighted the importance of semantic transparency in a similar study, which contrasts with the current findings. The discrepancy between these findings might be attributed to differences in experimental design, participant populations, or the specific linguistic characteristics of the compounds studied. Future researches should aim to reconcile these differences and explore the conditions under which semantic transparency influences compound processing.

The current findings align with Fiorentino and Fund-Reznicek (2009) and Shoolman and Andrews (2003), who designate processing of English compounds as morpheme-centric, irrespective of semantic transparency, and they only examined the head-final form in their studies. These studies reinforce the idea that morphological decomposition is a fundamental aspect of compound word processing, operating independently of the transparency of the compound's meaning. This consistency across different languages and compound types highlights the robustness of morphological analysis in lexical processing.

Regarding orthographic-overlap stimuli and their non-facilitative processing, this study's experiment suggests that dividing a word into two parts can lead to complexities in its composition that is in agreement with Esmaelpour et al. (2023)'s findings. The lack of facilitation for orthographic-overlap conditions indicates that purely visual similarity between parts of a compound is not sufficient to trigger the same cognitive processes involved in morphological decomposition, and other factors such as semantic and syntactic information, play a crucial role in

the processing of compound words.

The findings of this research can be beneficial in the fields of clinical studies, computational studies, first and second-language education, and textbook development. In clinical studies, understanding the cognitive processes involved in compound word processing can inform the development of diagnostic tools and therapeutic interventions for individuals with language impairments. Computational studies can benefit from these findings by incorporating more accurate models of morphological processing into natural language processing algorithms, improving their ability to handle complex words.

In the field of first and second-language education, these findings can inform teaching strategies that emphasize the importance of morphological awareness, helping learners to better understand and use complex words. Textbook development can also benefit from these insights by incorporating exercises and activities that highlight the morphological structure of words, aiding in vocabulary acquisition and reading comprehension.

Overall, this study contributes to a deeper understanding of the cognitive processes involved in the processing of endocentric head-final compounds in Persian. By highlighting the role of morphological decomposition and the factors that influence it, this research provides valuable insights into the nature of lexical access and retrieval. Future studies should continue to explore these processes across different languages and compound types, further elucidating the mechanisms that underlie our ability to understand and use complex words.

Author Contributions

E.E. and F.G. jointly contributed to the conceptualization, methodology, software development, validation, formal analysis, investigation, resource provision, data curation, and the preparation of the original draft of the manuscript, as well as its review, editing, and visualization. Supervision was provided by F.G., while project administration was carried out by E.E.

All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding

author upon reasonable request.

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Ethical Considerations

The study involved human participants and was conducted in accordance with ethical research standards. Participation was voluntary, informed consent was obtained from all participants, and all data were collected and analyzed anonymously.

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Conflict of Interest

The authors declare no conflict of interest.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this manuscript, the authors did not use generative AI or AI-assisted technologies in the writing process. Therefore, no declaration is required.

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