Processing trimorphemic words in a second language: Effects of exposure type

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**Abstract**

A central question in second language (L2) acquisition is whether L2 processing can become nativelike. The Shallow Structure Hypothesis (SSH) posits morphological processing in L2 is qualitatively different from that of L1, whereas the Declarative/Procedural (D/P) Model suggests naturalistic exposure (NE) to L2 can lead to nativelike processing. This study investigated whether L2 morphological processing can become nativelike by examining L1-Persian learners of L2-English with classroom exposure (CE) and those with NE. Using a cross-modal priming task, we presented trimorphemic English words under three different priming conditions: constituent (*rewash* → *rewashable*), nonconstituent (*washable* → *rewashable*), and unrelated (*notify* → *rewashable*). The NE group exhibited stronger priming in the constituent than in the nonconstituent condition, while the CE group showed equal priming in both conditions. The CE group’s performance aligns with the SSH, whereas the NE group demonstrated nativelike processing, supporting the D/P Model and highlighting the importance of NE.

*Keywords*: Cross-modal priming, Declarative/Procedural Model, naturalistic exposure, Shallow Structure Hypothesis, trimorphemic words

**Introduction**

Morphemes, the smallest meaningful units of language, are crucial for understanding morphologically complex words, allowing us to decipher newly created words like *unfaxable* (Rastle et al., 2004). Studies investigating the processing of morphologically complex words can reveal insights into how our mental lexicon makes use of the underlying morphological structure during real-time processing (Heyer, 2024). It is generally believed that there are two ways through which morphologically complex words are processed: (a) decomposition (e.g., *walked* → *walk* + *ed*) and (b) whole-word processing (e.g., *walked* → *walked*). The distinction between decomposition and whole-word processing has been highlighted by several models of morphological processing (see Morphological Processing Models below).

***Trimorphemic Words***

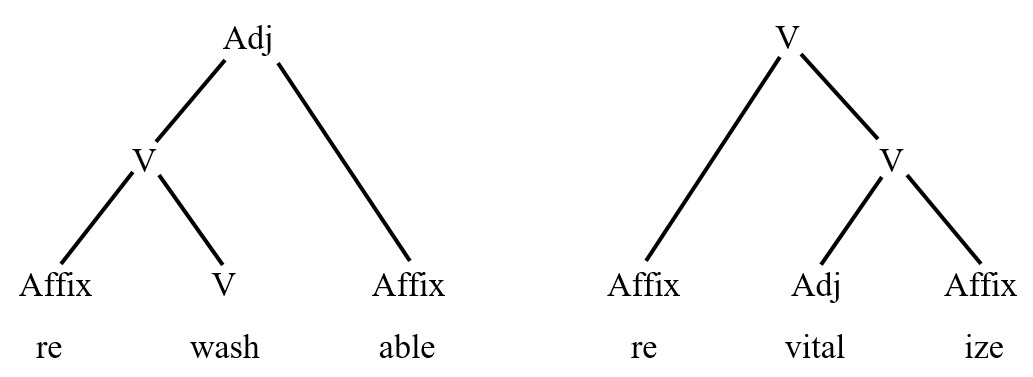
Much research on morphologically complex words has focused on bimorphemic words (e.g., “prefix + root” or “root + suffix”), while trimorphemic words1 (e.g., “prefix + root + suffix”) have received limited attention (see Bertram et al., 2011; Kuperman et al., 2008; Song et al., 2020). As Libben (2006a) states, about a quarter of all English words contain three or more morphemes, yet research into such words has been scarce in psycholinguistic literature. Assuming that trimorphemic words undergo decomposition (as opposed to whole-word processing), the question raises as to the order in which the constituent morphemes are processed (hierarchically vs. linearly). Hierarchical processing occurs when two morphemes are initially accessed, followed by the integration of the third morpheme (e.g., [[[re] + [wash]] + [able]]). In contrast, linear processing involves accessing the three morphemes in a sequential manner (e.g., [[re] + [wash] + [able]]). Altogether, trimorphemic words present an additional layer of complexity due to the hierarchical arrangement of their individual morphemes. This unique characteristic of trimorphemic words (i.e., being hierarchical), which is irrelevant to the processing of monomorphemic words and is of negligible significance for bimorphemic words (where only one type of structure is possible), plays a crucial role in how these words are processed (Libben, 2006a).

Despite Bertram et al.’s (2011) claim that “there is no clear theoretical account on how trimorphemic words are processed” (p. 542), there are generative approaches to morphology (Lieber, 1980; Selkirk, 1982) asserting that morphemes within multimorphemic words are represented according to hierarchical tree structures. More importantly, this assumption of internal hierarchical structure has been widely accepted, leading most, if not all, introductory linguistics and morphology textbooks to address this nested morphological structure (see Anderson et al., 2022, pp. 231-232; Lieber, 2015, pp. 41-42; O’Grady et al., 2010, pp. 109-110). Overall, the concept of hierarchical structure in words has been embraced by many scholars, leading to arguments such as “hierarchical structure guides how word-meaning is computed” (Song et al., 2019, p. 269), “morphological processing can be regarded as syntactic processing within words” (Oseki & Marantz, 2020b, p. 10), and there is no distinction between syntax and morphology in terms of hierarchical structure (Vikner & Vikner, 2008).

Hierarchical structure in trimorphemic words specifies two different branching directions: left-branching (LB) and right-branching (RB). In LB words, the first two morphemes of a trimorphemic word are initially merged (e.g., *rewashable*). In RB words, however, the last two morphemes of a trimorphemic word initially combine (e.g., *revitalise*). Thus, the branching direction of trimorphemic words is determined by their hierarchical structure and the selectional restrictions of their affixes, which dictate the order of morpheme combinations (Libben, 2003; Popescu, 2004). Figure 1 illustrates the morphological representations of the LB word *rewashable* and the RB word *revitalise*.

**Figure 1**

*Morphological Representations of “rewashable” (Left-Branching) and “revitalize” (Right-Branching) as per Hierarchical Structure*



It is important to consider insights from other triconstituent strings such as compounds and phrases. For example, compounds such as *football field* have a LB structure, whereas those like *solid blackboard* have a RB structure (see Bertram et al., 2011; Krott et al., 2004; Libben, 2006a, for a more detailed discussion of triconstituent compounds in Dutch, Finnish, and German). Similarly, a phrase like *public school teacher* is LB, while *young school teacher* is RB. Interestingly, the concept of branching also applies to mathematical equations (e.g., [4 × 3 – 2] LB; [4 – 3 × 2] RB; see Scheepers & Sturt, 2014 for a more detailed discussion). Therefore, the correspondence in structural patterns between trimorphemic words and triconstituent compounds, phrases, and mathematical equations suggests that postulating a comparable structure is plausible. Specifically, trimorphemic words can exhibit a structure or arrangement akin to those illustrated above.

***Native Versus Nonnative Morphological Processing***

While native speakers of many languages have a tendency to decompose morphologically complex words,2 research on nonnative speakers has yielded mixed results. Some studies indicate decomposition (Coughlin & Tremblay, 2015; Dal Maso & Giraudo, 2014; Diependaele et al., 2011; Feldman et al., 2010; Foote, 2017; Freynik et al., 2017), while others suggest that these words are processed holistically as unanalysed wholes (Clahsen & Neubauer, 2010; Farhy et al., 2018a; Heyer & Clahsen, 2015; Jacob et al., 2013, 2017; Neubauer & Clahsen, 2009; Silva & Clahsen, 2008).

Research on trimorphemic words has shown inconclusive results for native speakers. Song et al. (2019) reported that native English speakers process trimorphemic words hierarchically, which was interpreted as evidence exhibiting their sensitivity to the morphological structure of trimorphemic words. Conversely, other studies suggest that English native speakers are not sensitive to the hierarchical structure of trimorphemic words, processing them linearly (Libben, 1993, 2003, 2006b). As for nonnative speakers, there is only one study, to our knowledge, that has investigated nonnative processing of trimorphemic words. Song et al. (2020) found that nonnative speakers process these words linearly, with no sensitivity to their morphological structure. These differences in L1/L2 processing of morphologically complex words are explained by theories such as the Declarative/Procedural (D/P) Model (Ullman, 2001, 2004, 2006, 2020) and the Shallow Structure Hypothesis (SSH; Clahsen & Felser, 2006a, 2006b, 2006c, 2018; see Review of the Literature).

***Can L2 Processing Become Nativelike?***

A central question in bilingualism research is whether L2 processing can become nativelike. Several lines of research have suggested the establishment of nativelike processing by nonnative speakers, motived by a number of factors. For instance, Ullman (2004) maintains that with increased experience and practice in L2, nonnative speakers may use their procedural memory more frequently, thereby exhibiting more nativelike processing patterns (see below for the definition of procedural memory).

Another important factor that could promote nativelike processing is L2 exposure which, as Muñoz (2008) argues, comes in two types: classroom exposure (CE) and naturalistic exposure (NE). In a classroom setting, learners typically receive minimal native speaker input, which is often insufficient and limited in both quantity and quality for achieving nativelike proficiency. Unlike naturalistic settings where input is abundant, L2 exposure in classroom settings is limited. Furthermore, as Pliatsikas and Marinis (2013b) point out, language learning in a naturalistic setting offers unrestricted and unstructured exposure to the target language, unlike the more controlled environment of the classroom, which allows nonnative speakers to interact freely with native speakers. Such rich exposure is likely to foster more nativelike processing.

According to the D/P Model (Ullman, 2020), “exposure to the L2 without explicit instruction, as often occurs in immersion contexts, may enhance grammar acquisition in procedural memory, and thus lead to more L1-like grammatical processing” (p. 139). Therefore, NE to L2 can lead to more nativelike processing, making nonnative speakers with NE to L2 a suitable testing ground for examining L2 processing theories such as the D/P Model and the SSH. It should be noted that this group of learners is understudied in the literature (Berghoff, 2023), especially when it comes to morphology, in which case there is only one study, to our knowledge, that has examined the effects of NE on L2 morphological processing (see Pliatsikas & Marinis, 2013a).

**Review of the Literature**

***Morphological Processing Models***

Research on morphologically complex words has led to several models of morphological processing. According to the affix-stripping hypothesis (Taft & Forster, 1975), morphologically complex words are decomposed into their constituent morphemes before lexical access (i.e., decomposition). On the other hand, full-listing models (Butterworth, 1983) state that morphologically complex words are stored in the mental lexicon holistically and are processed in the same way as monomorphemic words (i.e., whole-word processing). Yet, there are some dual-route models which emphasise the importance of factors such as novelty (Augmented Addressed Morphology; AAM; Burani et al., 1984) and frequency (Morphological Race Model; Frauenfelder & Schreuder, 1992) of words, with unknown and low-frequency words activating the decomposition route, and known and high-frequency ones activating the whole-word processing route. The development of these models reflects the ongoing effort to unravel the intricate mechanisms of morphological processing.

***The Declarative/Procedural (D/P) Model***

The D/P Model put forward by Ullman (2001, 2004, 2006, 2020) proposes two distinct memory systems in language processing: declarative memory (lexical storage) and procedural memory (grammatical rules). According to this model, the mental lexicon underlies the declarative memory, while the mental grammar subserves the procedural memory. The declarative memory plays an important role in the learning, representation and use of lexical knowledge (e.g., irregular inflectional morphology and derivational morphology). The knowledge stored in this memory system is explicitly available to one’s consciousness. The procedural memory, on the other hand, is important in the learning, representation, computation, and processing of sequential and hierarchical structures (i.e., regular inflectional morphology). Knowledge present in this system is implicit, meaning that it is not available to one’s consciousness.

It should be noted that the declarative memory in nonnative speakers is enhanced due to maturational changes from childhood to adolescence, leading to the attenuation of procedural memory (Ullman, 2004). Therefore, nonnative speakers depend more heavily on their declarative memory for both lexical *and* grammatical processing. In other words, whereas grammatical processing in L1 relies on procedural memory, in L2, declarative memory is responsible for such grammatical processing. In terms of morphology, it is said that while native speakers primarily use their procedural memory to decompose morphologically complex words, nonnative speakers mostly rely on their declarative memory for whole-word processing. Ullman (2006) also argues that procedural memory underlies “the rule-governed sequential and *hierarchical* [emphasis added] computation of complex linguistic structures” (p. 99). As nonnative speakers rely more on their enhanced declarative memory and less on their attenuated procedural memory, investigating the real-time processing of trimorphemic words—in which there is a *hierarchy* of three morphemes—can help assess the predictions made by the D/P Model.

***The Shallow Structure Hypothesis (SSH)***

According to the SSH (Clahsen & Felser, 2006a, 2006b, 2006c, 2018), nonnative speakers tend to underuse grammatical information during real-time processing, relying more on lexical-semantic, pragmatic, probabilistic, associative, and surface-level information. The SSH posits two different processing routes which are assumed to operate in parallel: (a) full parsing routes and (b) shallow parsing routes. Full parsing routes provide a detailed grammatical representation, while shallow ones provide a less detailed grammatical representation. What the SSH claims is that shallow parsing routes are predominant in L2 processing, with nonnative speakers relying more on nongrammatical information as opposed to grammatical information, which leads to the following conclusion: according to the SSH, native and nonnative speakers, despite having the same processing mechanisms, are different with respect to their sensitivity to grammatical information.

The evidence supporting the SSH came originally from sentence processing studies (e.g., relative clause ambiguities and filler-gap dependencies). Later, the SSH was extended to the processing of morphologically complex words, with studies indicating that native speakers employed morphological decomposition, whereas nonnative speakers relied more on whole-word processing, suggesting less sensitivity to morphological structure among nonnative speakers. As noted in Introduction, however, most of these studies targeted bimorphemic words. At the time, there were only few studies on trimorphemic words, where hierarchy serves as an important issue. Song et al. (2020) were the first to test the SSH by investigating nonnative processing of trimorphemic words. They concluded that L2 processing of trimorphemic words is guided by nongrammatical information rather than their morphological structure. That is, the SSH attributes the difference between L1 and L2 processing of trimorphemic words to the underuse of morphological structure. Hence, hierarchically complex structures such as trimorphemic words provide a suitable testbed for studying the SSH, particularly because nonnative speakers may face processing difficulty with “the real-time computation of complex *hierarchical* [emphasis added] representations” (Clahsen & Felser, 2006c, p. 568).

***A Comparison of the D/P Model and the SSH***

The D/P Model and the SSH both posit a lack of nativelike processing in nonnative speakers. However, they diverge significantly in several key aspects. Firstly, the D/P Model posits that increased experience and practice in L2 can lead to the proceduralization of grammar, resulting in grammatical processing of L2 akin to that of L1. In contrast, the SSH does not endorse the possibility of such a qualitative transformation over time. Secondly, the D/P Model emphasises the importance of exposure; it suggests that with NE to L2, nonnative speakers may demonstrate more nativelike processing. Finally, while the SSH argues that even advanced nonnative speakers may not reach nativelikeness, the D/P Model asserts that achieving nativelike processing may be possible (see Ullman, 2006, p. 101, for a comparison of the D/P Model and the SSH).

***L1 Processing of Trimorphemic Words***

To investigate the processing of trimorphemic words, several studies have been conducted by Libben, yet the results remain inconclusive. In one of the earliest studies, Libben (1993) presented native English speakers with three stimuli types with nonsense roots: (a) LB (e.g., \**rebirmable*), (b) RB (e.g., \**rebirmise*), and (c) morphologically illegal (e.g., \**rebirmity*). The last category was named morphologically illegal because *re*- cannot attach to nouns (*birmity* is a noun). Nor can -*ity* attach to verbs (*rebirm* is a verb). Libben also inserted a hyphen between the prefix *re*- and the nonsense root (e.g., *re-birmable*, *re-birmise*, *re-birmity*) to encourage participants to parse the stimuli as RB. It was predicted that due to their hierarchical structure, RB stimuli would be easier to process, as placing the hyphen between the prefix and the nonsense root was consistent with the internal structure of RB stimuli. However, no significant difference was found between LB and RB stimuli in naming latencies. In addition, morphologically illegal structures presented the longest response times (RTs), which evidenced that participants noticed the illegality of the way morphemes were combined. This finding suggests that participants were sensitive to morphemic combinations, albeit in a linear way (because if they were sensitive to the hierarchical structure of trimorphemic stimuli, they should have named RB stimuli faster than LB ones). Altogether, the findings questioned the notion of hierarchical structure, as RB stimuli were expected to be processed faster, which was not the case in Libben (1993).

In 2003, Libben conducted another study to examine how trimorphemic words were processed. There were three conditions under which LB and RB stimuli were presented to native English speakers: (a) no-break condition, where stimuli were presented in an undisrupted manner (without any dashes inserted within the stimuli); (b) first-break condition, with three dashes inserted immediately after the prefix (e.g., *re---fillable* or *un---sinkable*); and (c) second-break condition, with three dashes inserted immediately before the suffix (e.g., *refill---able* or *unsink---able*). Libben hypothesised if hierarchical structure was indeed at play, then processing should be easier when the dashes were inserted at the major constituent boundary (e.g., [LB] *refill---able* or [RB] *un---sinkable*). However, this was not supported by the findings, as both LB and RB stimuli patterned alike under both first- and second-break conditions. If hierarchical structure was in effect, then for LB stimuli, the first-break should have been more disruptive than the second-break.

Using a masked priming (visual primes → visual targets) lexical decision task (LDT), Libben (2006b) explored how native English speakers processed trimorphemic words. In priming tasks, participants are typically presented with a visual or an auditory prime followed by a target about which they make a decision; whether it is a word or a nonword. The rationale is that prior presentation of the prime may facilitate subsequent processing of the target, hence the term *priming*.3 In Libben’s (2006b) experiment, primes were the final bimorphemic substrings of LB and RB words (e.g., *fillable* and *sinkable* as primes for *refillable* and *unsinkable*, respectively). As the final bimorphemic substrings in RB words (but not in LB words) were morphological constituents, it was hypothesised that there should be significant differences in the extent to which final substrings could prime their respective target words: RB words should exhibit larger priming effects. However, results showed that priming was stronger in LB than in RB words, suggesting that native speakers may be insensitive to the hierarchical structure of trimorphemic words.

In contrast to Libben’s experiments, Song et al. (2019) showed that native English speakers are indeed sensitive to the hierarchical structure of trimorphemic words. They used a cross-modal (auditory primes → visual targets) LDT in which three different prime types were used: (a) constituent primes: the first two morphemes in LB words (*unkind* → *unkindness*) and the last two morphemes in RB words (*avoidable* → *unavoidable*); (b) nonconstituent primes: the last two morphemes in LB words (*kindness* → *unkindness*) and none for RB words;4 and (c) unrelated primes. Based on the hypothesis that native speakers process trimorphemic words hierarchically, constituent primes were expected to generate larger priming effects compared to nonconstituent primes, as constituent primes are nested in the morphological representation of trimorphemic words. Results revealed that the recognition of trimorphemic words was easier when they were preceded by constituent primes, compared to when they were preceded by nonconstituent primes, suggesting that native speakers were sensitive to the hierarchical structure of trimorphemic words and processed these words hierarchically.

***L2 Processing of Trimorphemic Words***

Song et al. (2020) replicated the experimental design and materials of their 2019 research in a follow-up study, this time examining the processing of trimorphemic words by nonnative speakers. Results demonstrated equal priming effects for both constituent and nonconstituent primes, indicating that nonnative speakers did not process trimorphemic words hierarchically, but rather linearly. This was interpreted as evidence in support of the SSH’s claim that nonnative speakers may be insensitive to the morphological structure (of trimorphemic words). As Song et al. (2020) is the only study, to our knowledge, investigating nonnative speakers’ processing of trimorphemic words, the current study aims to contribute to the literature by further examining how these words are processed by another group of nonnative speakers: those with NE to L2.

***The Role of Naturalistic Exposure (NE) in L2 Processing***

The existing literature exploring the effects of NE to L2 centers particularly on sentence level studies such as relative clause attachment preferences and processing long-distance *wh*-dependencies. Dussias (2003), Dussias and Sagarra (2007), and Frenck-Mestre (2002) all reported that nonnative speakers with NE to L2 had similar relative clause attachment preferences as native speakers. In their studies on *wh*-dependencies, Berghoff (2023), Pliatsikas et al. (2017), and Pliatsikas and Marinis (2013b) found evidence of nativelike processing by nonnative speakers with NE to L2. Furthermore, Cheng, Cunnings et al. (2022) and Cheng, Rothman et al. (2022) demonstrated similar nonlocal agreement processing patterns between native and nonnative speakers with NE to L2. Finally, using an artificial language paradigm, Morgan-Short et al. (2010, 2012) indicated an association between NE to L2 and nativelike grammatical processing.

The effect of NE on L2 morphological processing is less clear, as we are aware of only one study in this domain. Pliatsikas and Marinis (2013a) investigated the potential effects of L2 NE on the processing of regular and irregular inflected verbs, with results indicating no significant difference between nonnative speakers with CE and those with NE. In other words, type of L2 exposure did not influence the processing of regular and irregular past tense English morphology.

Interestingly, in a relevant study, Durand-López and Garrido-Pozú (2024) reported a shift in morphological processing route from decomposition to whole-word processing as a result of intensive exposure to infrequent morphologically complex Spanish words. Following input-based training on low-frequency bimorphemic and trimorphemic Spanish words, nonnative speakers of Spanish were found to switch their processing route from decomposition to whole-word processing, thereby exhibiting more nativelike processing patterns (see also Durand-López, 2021). Although the authors do not specify how trimorphemic words were decomposed (linearly vs. hierarchically), their findings provide evidence that exposure may play a significant role in L2 morphological processing.

***The Present Study***

Against this background, how L2 exposure type would affect the processing of trimorphemic derived words in English remains unclear. As far as we know, there is no previous study exploring this issue. Therefore, this study examines how NE to L2 affects morphological processing by investigating how an understudied population, namely advanced L1-Persian learners of L2-English with CE and those with NE process trimorphemic words. The study by Song et al. (2020) targeted advanced L1-Cantonese learners of L2-English with only CE to L2. The current study, however, seeks to extend previous research from nonnative speakers with CE to those with NE to L2. Specifically, this study seeks to answer the following research question:

How do nonnative speakers with classroom exposure (CE) and those with naturalistic exposure (NE) to L2 English decompose trimorphemic English words?

Although the rich literature on (L2) morphological processing has primarily focused on the distinction between decomposition and whole-word processing, this study contributes to the field by specifically examining the mechanisms behind decomposition, which can only be analysed in the context of trimorphemic words containing both prefixes and suffixes—a largely unexplored area of research. By focusing exclusively on these types of words, we ask whether decomposition occurs hierarchically or linearly.

As there is a paucity of research into trimorphemic words in general and as, to date, Song et al. (2020) is the only study that has investigated the processing of trimorphemic words by nonnative speakers, the present study aims to add to the existing literature by further exploring how these words are processed by another group of nonnative speakers: those with NE to L2. This will contribute to a deeper understanding of L2 processing theories and address the existing gap in research into trimorphemic words.

Given that both the D/P Model and the SSH posit that nonnative speakers may face difficulty when processing hierarchical linguistic structures, investigating how nonnative speakers process trimorphemic words can indicate whether these words are processed linearly or hierarchically. This could further provide insights into the D/P Model and the SSH, indicating whether L1 versus L2 processing of trimorphemic words differs and whether L2 exposure type (CE vs. NE) influences nonnative processing of these words.

According to the SSH, both CE and NE groups are predicted to be insensitive to the morphological structure of trimorphemic words, thus processing them linearly. Evidence supporting this claim comes from Song et al. (2020) who found that constituent and nonconstituent primes preceding trimorphemic words yielded equal priming effects. Therefore, following the SSH, we would expect that trimorphemic words would be equally primed by constituent and nonconstituent primes in both CE and NE groups. On the other hand, the D/P Model predicts that the NE group might exhibit more nativelike processing patterns, processing trimorphemic words hierarchically. Specifically, unlike the CE group, the NE group is expected to be more strongly primed by constituent than by nonconstituent primes.

**Method**

***Participants***

Seventy-eight advanced L1-Persian learners of L2-English with either CE or NE participated in this study. Proficiency was assessed using the Quick Placement Test (QPT; UCLES, 2001). The CE group comprised 48 participants residing in Iran at the time of the experiment, none of whom reported having been to any English-speaking country. The NE group included 30 participants, who had lived in Canada5 for at least three years prior to the experiment. It is important to note that both CE and NE groups received formal classroom L2 English instruction in Iran (see Table 1). As Muñoz (2008) asserts, it is common for NE learners to have some formal classroom L2 instruction before relocating to the target language speaking environment. That said, the key difference between the CE and NE groups is the length of time spent in a naturalistic setting. While the NE group had lived in Canada for about five years, the CE group had not been to any English-speaking country. Therefore, the CE group consisted of learners who only received formal classroom L2 instruction in Iran, while the NE group included learners who, besides receiving formal classroom L2 instruction in Iran, experienced NE to L2 English in Canada.

**Table 1**

*Demographic Information and Language Use Characteristics of NE and CE Groups*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | NE |  | CE |  |  |
|  |  | *M* (*SD*) [*Range*] |  | *M* (*SD*) [*Range*] |  | *p*6 |
| Age |  | 29.86 (2.68) [25 - 35] |  | 24.02 (3.54) [19 - 33] |  | <.001\* |
| Age of L2 Acquisition |  | 11.93 (2.7) [7 - 22] |  | 11.08 (2.53) [5 - 15] |  | .171 |
| Daily Use of |  |  |  |  |  |  |
| English (%) |  | 61.5 (14.45) [40 - 95] |  | 15.6 (6.65) [5 - 30] |  | <.001\* |
| Persian (%) |  | 38.5 (14.45) [5 - 60] |  | 84.4 (6.65) [70 - 95] |  | <.001\* |
| QPT Score (0 – 60) |  | 53.56 (2.4) [50 - 57] |  | 52.02 (2.34) [48 - 56] |  | <.01\* |
| Self-Rating in |  |  |  |  |  |  |
| Listening English (1 – 6) |  | 5.26 (.63) [4 - 6] |  | 4.83 (.63) [4 - 6] |  | <.01\* |
| Speaking English (1 – 6) |  | 5.33 (.6) [4 - 6] |  | 4.72 (.57) [4 - 6] |  | <.001\* |
| Reading English (1 – 6) |  | 5.53 (.5) [5 - 6] |  | 4.89 (.66) [4 - 6] |  | <.001\* |
| Writing English (1 – 6) |  | 5.06 (.58) [4 - 6] |  | 4.77 (.62) [4 - 6] |  | <.05\* |
| Years of English Learning in Classroom |  | 7.43 (1.94) [4 - 12] |  | 7.62 (2.58) [4 - 12] |  | .662 |
| Years of Residency in Canada |  | 4.9 (.88) [3 - 6] |  | 0 (0) [0 - 0] |  | <.001\* |

*Note*. CE = Classroom Exposure; NE = Naturalistic Exposure; QPT = Quick Placement Test; \* = Significant Difference.

Additionally, 24 native English speakers served as the control group (*M* age = 25.25, *SD* age = 1.14, range = 24 - 28). All participants initially signed a digital consent form which contained all information regarding the study. They were instructed that they would go through two phases: first the QPT (except for the control group of native speakers) and then the LDT. Provided that participants scored higher than 48 in the QPT (indicating advanced proficiency based on the QPT manual), a language background questionnaire was also administered to gather the following data: age, age of L2 acquisition, daily use of English/Persian, self-rating in the four language skills, years of English learning in a classroom, and years of residency in Canada. Table 1 provides a summary of the NE and CE groups’ demographic information and language use characteristics. All participants were right-handed, with normal or corrected-to-normal vision; none reported to have any hearing problem.

***Materials***

Thirty-six trimorphemic derived English words, all in the form of [prefix-root-suffix], were used as stimuli (see Appendix S1 in the Supplementary Materials). Note that the stimuli were all *unambiguous* unlike several other studies (e.g., de Almeida & Libben, 2005; Pollatsek et al., 2010; Popescu, 2004) in which the stimuli were *ambiguous* trimorphemic words having twofold (LB and RB) interpretations (e.g., *undoable*, *unlockable*). Half of the stimuli were LB and half RB. In LB words, the first two morphemes of a trimorphemic word are initially merged (e.g., [[[re] + [wash]] + [able]]), whereas in RB words, the last two morphemes are first combined (e.g., [[re] + [[vital] + [ise]]]). RB words were included to help address the concern that the overlap between the prime and target in LB words, occurring from the beginning, might be unfairly boosting priming effects. In LB words, the constituent prime overlaps with the target from the start, while the nonconstituent prime overlaps from the middle. By including RB words where the constituent prime overlaps from the middle (mirroring the nonconstituent prime in LB words), the influence of the starting position of the overlap is neutralised. This allows us to determine whether the priming effect is morphological in nature or merely a coincidence caused by the order of morphemes.

Unlike Song et al. (2019, 2020), who had an unbalanced number of items in the two sets (18 LB and 12 RB trimorphemic words), in this study, the number of words in both branching directions was equal, with 18 LB words of either [[re-[root]]-able] or [[un-[root]]-ness] structure (e.g., *rewashable*, *unsilliness*) and 18 RB words of either [re-[[root]-ise]] or [un-[[root]-ful]] structure (e.g., *revitalise*, *unforgetful*). In each branching direction, half of the words began with the prefix *re*- and half with the prefix *un*-. The stimuli were evenly distributed such that there were 18 *re*- words (half LB, half RB) and 18 *un*- words (half LB, half RB). This distribution was done to prevent participants from assigning LB exclusively to *re*- words or RB exclusively to *un*- words, and vice versa.

Following the AAM (Burani et al., 1984) and the Morphological Race Model (Frauenfelder & Schreuder, 1992), we ensured that the stimuli involved low-frequency trimorphemic words, the inclusion of which could help promote morphological decomposition and prevent whole-word processing (Hay, 2003; Oseki et al., 2019; Oseki & Marantz, 2020a, 2020b; Song et al., 2019, 2020; Ullman, 2001).7 To this end, the surface frequency of all trimorphemic words was checked to be zero (or near zero) per million. This was done using the webCELEX database (<http://celex.mpi.nl/>). Following the procedure in Song et al. (2019, 2020), if a given trimorphemic word did not exist in the database, the frequency of the word was coded as zero. Also, all trimorphemic words were matched based on the number of syllables and letters, with the former being fixed for all items (i.e., four syllables) and the latter ranging from nine to eleven letters.

Prior to the visual presentation of LB and RB trimorphemic target words on the screen, participants were presented with various auditory prime types through headphones which included constituent, nonconstituent, and unrelated primes. The constituent prime was the first two morphemes of the LB target word (prefix + root; e.g., *rewash* in the word *rewashable*), and the last two morphemes of the RB target word (root + suffix; e.g., *vitalise* in the word *revitalise*). The nonconstituent prime in the LB target word was the last two morphemes (root + suffix; e.g., *washable* in the word *rewashable*). However, RB words did not have nonconstituent primes, as there is no RB trimorphemic word in English, where the initial two morphemes constitute a legitimate word (e.g., \**unthink*). Finally, unrelated primes were bimorphemic derived words which were not related to the target words (e.g., *disallow* or *sisterhood* as primes for the words *rewashable* and *revitalise*, respectively).

All prime types were matched in both frequency and length; they all had a low frequency, ranging between six and eleven letters, were bimorphemic and trisyllabic, except for the constituent primes of nine LB words of [re-root-able] structure which were bisyllabic (e.g., *rewash*, *rebuild*, *reload*). Moreover, since primes were presented aurally, their audio tracks were downloaded from a text-to-speech conversion robot (<https://www.voiceoftext.com/>) with an American English accent. Tables 2 and 3 display the properties of experimental items and their respective primes.

**Table 2**

*Means (Standard Deviations) for the Properties of Left-Branching Items*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Left-Branching Items | Prime Type | | | Target |
| Constituent | Nonconstituent | Unrelated |  |
| Frequency (per Million) | 0.16 (0.51) | 0.33 (0.68) | 0.38 (0.5) | 0 (0) |
| Number of Syllables | 2.5 (0.51) | 3 (0) | 3 (0) | 4 (0) |
| Number of Letters | 6.55 (0.51) | 8.5 (0.51) | 8.61 (1.24) | 10.5 (0.51) |
| Number of Morphemes | 2 (0) | 2 (0) | 2 (0) | 3 (0) |

**Table 3**

*Table 3. Means (Standard Deviations) for the Properties of Right-Branching Items*

|  |  |  |  |
| --- | --- | --- | --- |
| Right-Branching Items | Prime Type | | Target |
| Constituent | Unrelated |  |
| Frequency (per Million) | 1.11 (1.32) | 0.61 (0.84) | 0.05 (0.23) |
| Number of Syllables | 3 (0) | 3 (0) | 4 (0) |
| Number of Letters | 8.27 (0.66) | 8.88 (1.32) | 10.27 (0.66) |
| Number of Morphemes | 2 (0) | 2 (0) | 3 (0) |

The 36 experimental items were interspersed with 84 fillers (24 words + 60 nonwords; see Appendices S2 and S3 in the Supplementary Materials). Created using the English Lexicon Project (ELP; Balota et al., 2007), the 60 nonwords were comprised of 16 trimorphemic, 22 bimorphemic (11 prefixed + 11 suffixed), and 22 monomorphemic nonwords. Nonword roots were first extracted from the ELP and both prefixes *and* suffixes (for trimorphemic nonwords) and either prefixes *or* suffixes (for bimorphemic nonwords) were attached to them, resulting in 16 trimorphemic and 22 bimorphemic nonwords. The 22 monomorphemic nonwords were created by blending two other nonwords extracted from the ELP (e.g., *banor* + *setip* = *banorsetip*). All 60 nonwords had four syllables (i.e., quadrisyllabic) and ranged between ten and twelve letters. The remaining 24 word fillers were eight trimorphemic, eight bimorphemic (four prefixed + four suffixed), and eight monomorphemic words. They were all quadrisyllabic and ranged between eight and thirteen letters. Also, they had a higher frequency than that of experimental items (*M* = 47.88, *SD* = 68.80, range = 6 - 294 [per Million]).

There were also 84 primes for the 84 fillers, all of which were bimorphemic and trisyllabic and ranged from six to thirteen letters. Primes for bimorphemic and trimorphemic nonwords were all morphologically related to each other such that they shared an affix (e.g., *nonstandard* and *ladylike* as primes for *nonaxlisal* and *aspiroslike*, respectively). However, primes for monomorphemic nonwords were all unrelated to each other. Regarding the 24 word fillers, the first or the last two morphemes of trimorphemic word fillers served as their own primes (e.g., *personal* as a prime for *impersonal*). For bimorphemic word fillers, primes were four prefixed/suffixed morphologically-related bimorphemic words (e.g., *confusing* as a prime for *interesting*).Finally, four unrelated bimorphemic words and four semantically-related bimorphemic words (e.g., *assistant* as a prime for *secretary*) functioned as primes for monomorphemic word fillers.

The 120 (36 experimental items [30%] + 84 fillers [70%]) prime-target pairs were presented across six lists (three lists for LB items × two lists for RB items = six lists overall) in a pseudorandomised order such that each target word appeared only once in each list preceded by only one prime type. In other words, experimental items were counterbalanced across six lists, each having 36 experimental items and 84 fillers; fillers were identical across the lists. Each participant was randomly assigned to one of the lists and each list was given to 17 participants (eight from the CE group, five from the NE group, and four native English speakers).

***Cross-Modal Priming Task***

Cross-modal priming (auditory primes → visual targets) was employed for the LDT, ensuring that priming effects are not due to orthographic overlap, unlike masked priming, where both primes and targets are presented visually. Moreover, cross-modal priming taps into central-level representations (Marslen-Wilson, 2007) which are modality-independent and involve abstract (e.g., syntactic and semantic) information. Thus, the mediation between primes and targets likely occurs through their modality-independent lexical representations (Marslen-Wilson et al., 1994).

Participants completed the LDT administered online using PsychoPy (Version 2022.1.1; Pierce et al., 2019). Initially, all participants received oral and written instructions about the task. They were instructed that they would first hear a word via headphones, followed by a string of letters shown on the screen. Upon seeing the string, they had to decide as quickly and accurately as possible whether or not the string was a word by pressing the up-arrow key for words and the down-arrow key for nonwords. The task began with 15 practice items (seven words and eight nonwords) with feedback provided on the screen after each item.

Each trial started with a 500 ms display of a plus sign (+) at the center of the screen, followed immediately by the auditory prime. After the prime, a string of letters appeared in 18-point Arial font, in white on a dark gray background. Participants had to make a lexical decision as quickly and accurately as possible. The string of letters disappeared once the decision was made or after a timeout of 2000 ms. The next trial would begin after 1000 ms, during which the screen remained blank. The entire experiment lasted no more than 10 minutes.

***Procedure***

The experiment began with a 20-minute online QPT to assess proficiency. Only nonnative speakers with advanced proficiency (according to the QPT manual) completed the language background questionnaire. Following that, all participants underwent the cross-modal LDT.

**Results**

***Data Cleaning***

Both by-participant and by-item accuracy rates were above 70%, indicating participants’ attentiveness to the task. For this reason, we did not exclude any participants’ or any items’ data. Similarly, as evident in Table 4, participants’ accuracy rates were high in all conditions (i.e., constituent, nonconstituent, and unrelated), demonstrating that participants performed well across all conditions. Consequently, no accuracy analysis was conducted.8

Based on the visual inspection of the RT distribution, RTs shorter than 400 ms and longer than 1600 ms were considered extreme values, resulting in the exclusion of 4.05% of data. Additionally, RTs that fell two standard deviations below or above each participant’s mean RT were classified as outliers, leading to the exclusion of another 4.1% of the data points. Overall, this resulted in the exclusion of 8.15% of the RT data points. Table 4 as well as Figures 1 and 2 summarise mean RTs and error rates per each group for the two branching directions.

**Table 4**

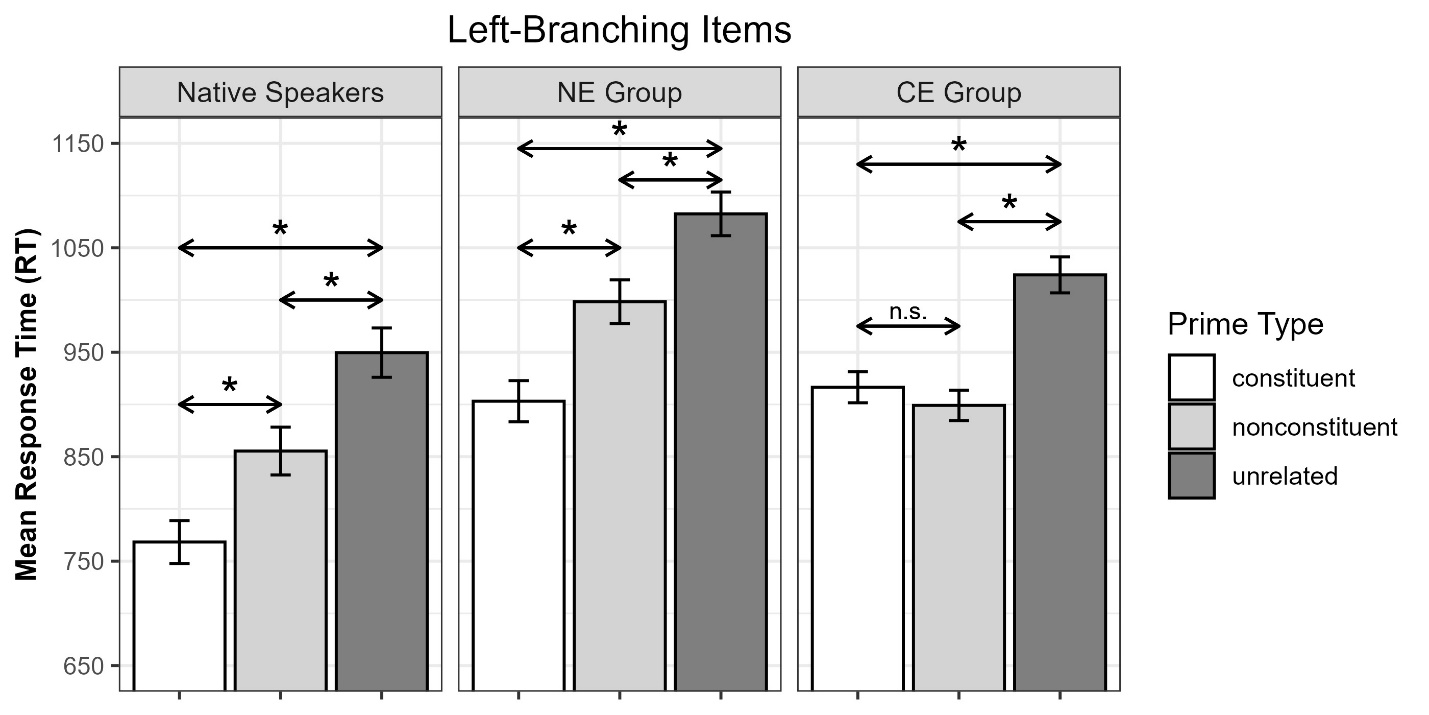
*Mean Response Times in Milliseconds (Standard Deviations) and Error Rates per Group and Branching Direction*

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Prime Type | | | | | | | | | | |
|  |  | Constituent | | |  | Nonconstituent | | |  | Unrelated | | |
| Group |  | NS | CE | NE |  | NS | CE | NE |  | NS | CE | NE |
| LB |  |  |  |  |  |  |  |  |  |  |  |  |
| Mean RT |  | 734  (264) | 953 (277) | 933 (285) |  | 880  (292) | 935 (283) | 1052 (312) |  | 1003  (295) | 1124 (302) | 1172 (311) |
| Error Rate |  | 4.87% | 7.64% | 4.45% |  | 3.48% | 8.69% | 3.89% |  | 11.12% | 24.31% | 9.45% |
| RB |  |  |  |  |  |  |  |  |  |  |  |  |
| Mean RT |  | 755  (272) | 888 (266) | 896 (264) |  | - | - | - |  | 875  (274) | 1018 (299) | 1019 (283) |
| Error Rate |  | 4.63% | 4.63% | 3.71% |  | - | - | - |  | 9.73% | 16.67% | 12.97% |

*Note*. CE: Classroom Exposure; LB: Left-Branching; NE: Naturalistic Exposure; NS: Native Speakers; RB: Right-Branching; RT: Response Time.

**Figure 2**

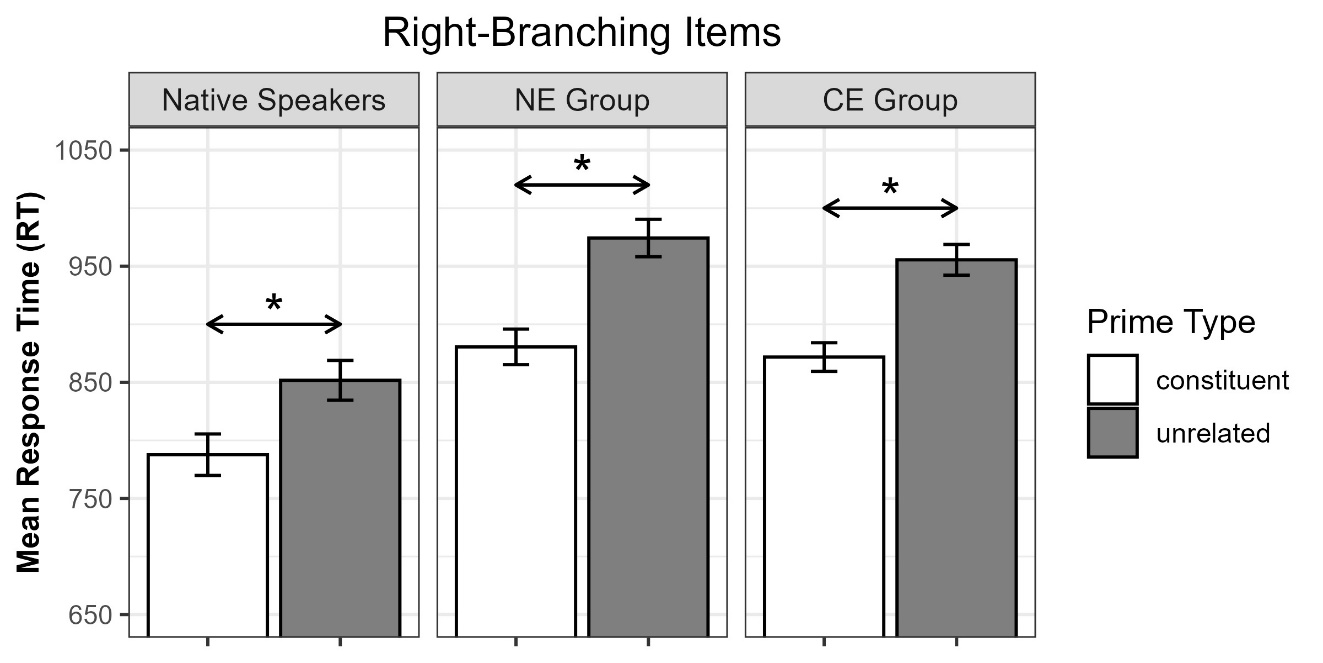
*Mean Response Times (in Milliseconds) to Left-Branching Items with 95% Confidence Intervals per Group*



*Note*. CE = Classroom Exposure; NE = Naturalistic Exposure. Arrows indicate comparisons along with their corresponding *p* values (\* = *p* < .05; n.s. = not significant).

**Figure 3**

*Mean Response Times (in Milliseconds) to Right-Branching Items with 95% Confidence Intervals per Group*



*Note*. CE = Classroom Exposure; NE = Naturalistic Exposure. Arrows indicate comparisons along with their corresponding *p* values (\* = *p* < .05; n.s. = not significant).

***Data Analysis***

Mixed-effects models (Baayen et al., 2008) were created in R (Version 4.4.1; R Core Team, 2021) using *lmerTest* package (Kuznetsova et al., 2016) which adds *p* values to the output of *lme4* package (Bates et al., 2015). We also used the *effectsize* package to estimate Cohen’s *d* (Ben-Shachar et al., 2020), and fitted the models using data from experimental items with only correct lexical decisions. To reduce skew, log-transformed RTs were used as the dependent variable in all fitted models which also included random intercepts for both participants and items.

To address the research question—How do nonnative speakers with classroom exposure (CE) and those with naturalistic exposure (NE) to L2 English decompose trimorphemic English words?—two different models were created. The first model included both LB and RB items (global model), excluding nonconstituent primes, while the second model focused exclusively on LB items (LB model). In both models, the fixed effect of Group was treatment-coded, with the NE group serving as the baseline. This coding enabled comparisons of priming effects between native speakers and the NE group (Contrast 1) and between the CE group and the NE group (Contrast 2).

As in Song et al. (2020), Branching and Prime Type in this study were not fully crossed. That is, while there were constituent, nonconstituent, and unrelated primes in LB words, RB words only involved constituent and unrelated primes. Therefore, by excluding nonconstituent primes, we created a global model which included sum-coded fixed effects of Prime Type (constituent [+0.5], unrelated [-0.5]) and Branching (LB [+0.5], RB [-0.5]) to compare priming effects in the two branching directions across the three groups. The global model could demonstrate whether or not morphological priming effects occur independently of the linear position of constituent primes.

In the LB model, we focused only on LB items and examined priming effects elicited by constituent and nonconstituent primes (relative to unrelated primes). This model involved treatment-coded fixed effect of Prime Type, with unrelated primes as the baseline. In this model, the first contrast for Prime Type compared constituent with unrelated primes, while the second contrast compared nonconstituent with unrelated primes. This allowed us to examine which of the two prime types (constituent or nonconstituent) yielded larger priming effects across the three groups.

In the case of significant Prime Type by Branching interactions, separate models were created for LB and RB items to locate the source of this interaction. Similarly, where interactions with Group were significant, we created additional models to compare the different groups.

*Global Model*

As shown in Table 5, the main effects of Prime Type and Branching were significant, as was the difference in the overall log-RT between native speakers and the NE group. These effects were not, however, interpretable due to the significant two-way interaction between Prime Type and Branching and the three-way interaction between Group (CE vs. NE), Prime Type, and Branching. To better understand these interactions, we constructed separate models for each group and branching direction. First, the interaction between Prime Type and Branching showed larger priming effects in LB (estimate = -.223, SE = .022, *t* = -10.067, *p* < .001, effect size = -.79) than in RB items (estimate = -.112, SE = .018, *t* = -6.087, *p* < .001, effect size = -.41). Furthermore, native speakers and the NE group showed larger priming effects in LB (native speakers: estimate = -.257, SE = .028, *t* = -9.207, *p* < .001, effect size = -.82; NE: estimate = -.222, SE = .023, *t* = -9.569, *p* < .001, effect size = -.77) than in RB items (native speakers: estimate = -.01, SE = .024, *t* = -3.977, *p* < .001, effect size = -.35; NE: estimate = -.113, SE = .019, *t* = -5.872, *p* < .001, effect size = -.43), as confirmed by a significant Prime Type by Branching interaction for both groups (native speakers: estimate = -.155, SE = .039, *t* = -3.979, *p* < .001, effect size = -.53; NE: estimate = -.112, SE = .031, *t* = -3.598, *p* < .001, effect size = -.41). By contrast, the CE group showed similar levels of priming in the two branching directions (LB: estimate = -.149, SE = .016, *t* = -9.214, *p* < .001, effect size = -.6; RB: estimate = -.121, SE = .012, *t* = -9.731, *p* < .001, effect size = -.46), as the interaction between Prime Type and Branching was not significant for this group (estimate = -.029, SE = .020, *t* = -1.426, *p* = .154, effect size = -.11).

**Table 5**

*Results of Linear Mixed-Effects for Global Model*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *Fixed Effects* |  | Estimate | SE | *t* | *p* |
| Intercept |  | 6.843 | .034 | 199.654 | <.001\* |
| Group (CE vs. NE) |  | -.007 | .043 | -.156 | .876 |
| Group (Native vs. NE) |  | -.147 | .05 | -2.932 | .003\* |
| Prime Type (Constituent vs. Unrelated) |  | -.161 | .015 | -10.926 | <.001\* |
| Branching (LB vs. RB) |  | .07 | .021 | 3.305 | .001\* |
| Group (CE vs. NE) × Prime Type |  | .029 | .019 | 1.524 | .128 |
| Group (Native vs. NE) × Prime Type |  | -.015 | .022 | -.697 | .486 |
| Group (CE vs. NE) × Branching |  | .007 | .019 | .351 | .725 |
| Group (Native vs. NE) × Branching |  | -.033 | .022 | -1.511 | .131 |
| Prime Type × Branching |  | -.114 | .029 | -3.863 | <.001\* |
| Group (CE vs. NE) × Prime Type × Branching |  | .087 | .038 | 2.277 | .023\* |
| Group (Native vs. NE) × Prime Type × Branching |  | -.037 | .044 | -.825 | .409 |

*Note*. CE: Classroom Exposure; NE: Naturalistic Exposure; \* = Significant Difference.

Overall, the global model showed that constituent primes resulted in faster RTs than unrelated primes. Moreover, LB items had slower RTs compared to RB items, suggesting that participants were faster in recognising RB items. Also, native speakers had overall faster RTs compared to the NE group, whereas CE and NE groups had comparable RTs. Finally, while the NE group and native speakers exhibited larger priming effects in LB items, the CE group displayed comparable priming effects in the two branching directions. Taken together, these results suggest that morphological priming effects were observed irrespective of the linear position of constituent primes in LB items; otherwise, constituent primes preceding RB items could not have produced priming effects, that is, a significant drop in RTs to RB items following constituent primes compared to those following unrelated primes. Therefore, the nature of priming effects observed in the two branching directions was morphological.

*LB Model*

As shown in Table 6, results showed that native speakers were overall faster than the NE group, while the log-RT difference between CE and NE groups was not significant. Also, there were simple effects of Prime Type (contrast 1: constituent vs. unrelated primes; contrast 2: nonconstituent vs. unrelated primes), suggestive of significant priming effects for both constituent and nonconstituent primes (relative to unrelated primes).

**Table 6**

*Results of Linear Mixed-Effects for LB Model*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *Fixed Effects* |  | Estimate | SE | *t* | *p* |
| Intercept |  | 6.991 | .039 | 177.795 | **<.001\*** |
| Group (CE vs. NE) |  | -.041 | .05 | -.821 | .412 |
| Group (Native vs. NE) |  | -.151 | .058 | -2.603 | **.009\*** |
| Prime Type (Constituent vs. Unrelated) |  | -.223 | .022 | -10.118 | **<.001\*** |
| Prime Type (Nonconstituent vs. Unrelated) |  | -.108 | .022 | -4.904 | **<.001\*** |
| Group (CE vs. NE) × Prime Type (Constituent vs. Unrelated) |  | .078 | .029 | 2.681 | **.007\*** |
| Group (Native vs. NE) × Prime Type (Constituent vs. Unrelated) |  | -.029 | .033 | -.868 | .386 |
| Group (CE vs. NE) × Prime Type (Nonconstituent vs. Unrelated) |  | -.058 | .029 | -2.001 | **.046\*** |
| Group (Native vs. NE) × Prime Type (Nonconstituent vs. Unrelated) |  | -.019 | .033 | -.586 | .558 |

*Note*. CE: Classroom Exposure; NE: Naturalistic Exposure; \* = Significant Difference.

Similar to the global model, these effects cannot be interpreted due to interactions between Group (CE vs. NE) and Prime Types. To better understand these interactions, we created additional models for each group to assess priming effects elicited by constituent and nonconstituent primes. Specifically, both native speakers and the NE group demonstrated significantly larger priming effects elicited by constituent (native speakers: estimate = -.251, SE = .029, *t* = -8.543, *p* < .001, effect size = -.8; NE: estimate = -.222, SE = .022, *t* = -9.783, *p* < .001, effect size = -.78) than by nonconstituent primes (native speakers: estimate = -.127, SE = .028, *t* = -4.438, *p* < .001, effect size = -.4; NE: estimate = -.108, SE = .022, *t* = -4.762, *p* < .001, effect size = -.38). That is, the magnitude of priming effects yielded by nonconstituent primes was smaller for both native speakers and the NE group, whereas the CE group exhibited larger priming effects elicited by nonconstituent primes (constituent: estimate = -.147, SE = .015, *t* = -9.255, *p* < .001, effect size = -.59; nonconstituent: estimate = -.167, SE = .015, *t* = -10.55, *p* < .001, effect size = -.67).

We also reran this model by releveling the fixed effect Prime Type, setting nonconstituent primes as the baseline. Prime Type (contrast 1: unrelated vs. nonconstituent; contrast 2: constituent vs. nonconstituent) interacted with Group (CE vs. NE). Again, we constructed separate models for each group. The difference between constituent and nonconstituent primes (relative to unrelated primes) was not significant for the CE group (estimate = .02, SE = .014, *t* = 1.44, *p* = .15, effect size = .08), suggesting that the CE group was equally primed by constituent and nonconstituent primes. On the contrary, the NE group was more strongly primed by constituent than by nonconstituent primes (estimate = -.114, SE = .021, *t* = -5.258, *p* < .001, effect size = -.4). Native speakers exhibited a similar pattern as the NE group, indicating larger priming effects elicited by constituent than by nonconstituent primes (estimate = -.123, SE = .028, *t* = -4.415, *p* < .001, effect size = -.39). Overall, while the CE group displayed comparable priming effects yielded by both constituent and nonconstituent primes, the NE group performed like native speakers, exhibiting larger priming effects elicited by constituent than by nonconstituent primes.

**Discussion**

While the literature on (L2) morphological processing spans various languages and provides extensive insights into how morphologically complex words are processed, most studies have targeted bimorphemic words. The literature has largely overlooked trimorphemic words in English, particularly those with both prefixes and suffixes (e.g., *rewashable*), which present an additional layer of nested hierarchy. According to the predictions of generative morphology (Lieber, 1980; Selkirk, 1982), morphemes within multimorphemic words are represented hierarchically. This raises an important question concerning the processing of these words. Assuming that these words are decomposed into their constituent morphemes, a further question then arises regarding the nature of the decomposition: does it occur hierarchically or linearly? Empirical evidence on this matter has been inconclusive, leaving unclear how native English speakers process these words (Libben, 1993, 2003, 2006b: linear processing; Song et al., 2019: hierarchical processing). The situation is particularly unclear for nonnative speakers, as research in this area is limited to a single study (Song et al., 2020: linear processing).

Extensive literature and empirical studies have demonstrated that NE to L2 may lead to more nativelike processing (Berghoff, 2023; Cheng, Cunnings et al., 2022; Cheng, Rothman et al., 2022; Dussias, 2003; Dussias & Sagarra, 2007; Frenck-Mestre, 2002; Morgan-Short et al., 2010, 2012; Pliatsikas et al., 2017; Pliatsikas & Marinis, 2013b; Ullman, 2020). However, research exploring the impact of different L2 exposure types (CE vs. NE) on morphological processing remains limited (Pliatsikas & Marinis, 2013a). This study, therefore, explored the processing of trimorphemic words by two different groups of nonnative speakers: those with CE and those with NE. Our study is the first to report on the potential effects of NE on L2 morphological processing of trimorphemic words in English.

***The SSH and Trimorphemic Words***

Following the SSH’s predictions (Clahsen & Felser, 2006a, 2006b, 2006c, 2018), both CE and NE groups were expected to be insensitive to the morphological structure of trimorphemic words, thus processing them linearly because shallow parsing routes are arguably predominant in L2 (morphological) processing. In other words, constituent and nonconstituent primes were predicted to generate equal priming effects for both CE and NE groups.

The results of our statistical analyses partially confirmed this prediction. Specifically, all three groups were significantly primed by constituent and nonconstituent primes (relative to unrelated primes) in LB items. However, native speakers and the NE group were more strongly primed by constituent than by nonconstituent primes, whereas the CE group exhibited equal priming effects for both constituent and nonconstituent primes. Following Song et al. (2020), these findings can be taken to suggest that native speakers and the NE group demonstrated higher levels of sensitivity to different prime types, with constituent primes—nested in the morphological representation of trimorphemic words—yielding larger priming effects. This indicates that both native speakers and the NE group were sensitive to the morphological structure of trimorphemic words and processed them hierarchically.

Conversely, the CE group did not show a difference in sensitivity to constituent and nonconstituent primes, as no significant difference was observed between the effects of the two prime types on the subsequent processing of LB items. This then supports the idea that the CE group was likely to process these words linearly. Therefore, it could be argued that nonnative speakers with CE to L2 English may be insensitive to the morphological structure of trimorphemic words. This finding lends support to the SSH positing that L2 (morphological) processing may not primarily be guided by grammatical information. Overall, the findings of this study regarding the CE group (not the NE group) were supported by the SSH.

As per the SSH’s prediction, derivational priming (which was the case with trimorphemic words in this study) occurs through lexical mediation (not morphological mediation), stemming from lexeme-level representations for derived forms that share partial overlap with the lexeme representation of their base forms (Clahsen & Felser, 2018, p. 9). Based on this assumption, there would be no difference in the magnitude of derivational priming between the two experimental prime-target pair conditions: constituent prime: *rewash* → LB target: *rewashable* and nonconstituent prime: *washable* → LB target: *rewashable*. Nonnative speakers with CE in this study conformed to this pattern, indicating that they were insensitive to morphological structure and instead relied more on nongrammatical information. This reliance implies that they focused on lexical information, specifically the fact that both primes and targets were lexically related to each other.

***The D/P Model and Trimorphemic Words***

The D/P Model (Ullman, 2001, 2004, 2006, 2020) predicts that NE to L2 could lead to hierarchical processing of trimorphemic words, similar to how native speakers process them. Specifically, it was predicted that the NE group would show larger priming effects for constituent primes compared to nonconstituent primes. Results confirmed this prediction, as the NE group was more strongly primed by constituent than by nonconstituent primes. That said, the performance of the NE group cannot be accounted for by the SSH. This is because according to the SSH, the NE group should have displayed equal priming effects elicited by both prime types. Notably, the control group of native English speakers demonstrated a similar pattern as observed in the NE group. This suggests that the NE group behaved more nativelike than the CE group, as the NE group (like native speakers) was shown to be sensitive to the hierarchical structure of trimorphemic words, processing them hierarchically.

The D/P Model may be better able to account for the discrepancy in performance between CE and NE groups, highlighting the importance of exposure type and its effects on L2 processing. According to this model, exposure to English in an L2 setting has contributed to the NE group’s hierarchical processing of trimorphemic words. This is in line with Ullman (2020) who argues that NE to L2 is likely to enhance the attenuated procedural memory of nonnative speakers, enabling them to employ their procedural memory for grammatical processing, which leads to more nativelike processing patterns. Overall, the performance of the NE group in this study is consistent with the prediction of the D/P Model, suggesting that L2 (morphological) processing can become nativelike.

***The Nature of Priming Effects in Trimorphemic Words***

As constituent primes in RB items elicited significant priming effects, it could be argued that the priming effects in LB items occurred irrespective of the linear position of constituent primes. One can then conclude that the nature of priming effects observed in both branching directions was morphological. As noted before, constituent primes preceding RB items produced significant facilitation on target RTs, and this was true for all three groups, which suggests that priming in both LB and RB items was morphological in nature.

Consistent with the literature (e.g., Song et al., 2019, 2020), RB words were processed and recognised faster in all three groups compared to LB words. Although this finding runs counter to the left-to-right parsing directionality (Hudson & Buijs, 1995; Libben, 2006b), it is consistent with the affix-stripping hypothesis proposed by Taft and Forster (1975), according to which the parser assumes that a major constituent boundary exists right after the prefix, which aligns with the internal hierarchical structure of RB words, not LB ones. The faster processing of RB words compared to their LB counterparts happens because applying affix-stripping to LB words disrupts their processing.

***The Role of Proficiency and Age of L2 Acquisition***

Given that CE and NE groups were both advanced in proficiency, their discrepant performance may suggest that proficiency does not account for the difference between them.9 Otherwise, both CE and NE groups should have behaved similarly in terms of processing. According to the SSH, both groups were expected to show similar processing patterns irrespective of exposure type; however, their differing performances underscore the claim that exposure type may have played an important role in the processing of trimorphemic words. Thus, as far as the results of this study are concerned, the SSH may apply only to nonnative speakers with CE to L2, and not necessarily to those with NE to L2.

Besides proficiency, age of L2 acquisition, as maintained by Clahsen and Veríssimo (2016), has a bearing on L2 processing. Closer inspection of participants’ demographic information reveals that both CE and NE groups started learning English at roughly the same age (see Table 1), ruling out the possibility that differences in age of L2 acquisition between CE and NE groups have led to divergent performance by the two groups. Everything considered, the difference in performance between the two groups is unlikely to be explained by factors such as proficiency and age of L2 acquisition, but more likely reflects the nature of exposure type received by the two groups.

***Potential Factors Leading to Nativelike Processing***

Our study revealed distinct processing patterns between two groups of nonnative speakers, that is, those with CE to L2 and those with NE to L2. To fully understand these differences, we need to consider the potential contributing factors. Specifically, we need to explore how subtle variations in learning environments might have influenced L2 morphological processing. While our study was not designed to test these factors directly, two interrelated aspects stand out as potential explanations: input and frequency.

*Input*

As Muñoz (2008) maintains, in a classroom setting, CE learners generally receive minimal input from native speakers, which is often inadequate in both quantity and quality. In contrast to a naturalistic setting where input is plentiful, a classroom setting offers limited exposure that is significantly restricted. Altogether, the need for optimal learning conditions—characterised by input that is neither limited in quantity nor quality—is not fulfilled in a classroom setting. Moreover, as noted by Pliatsikas and Marinis (2013b), language learning in a naturalistic setting, unlike the more regulated classroom setting, provides unrestricted and unstructured exposure to the target language. This facilitates opportunities for NE learners to interact freely with native speakers. Such rich input is likely to promote more nativelike processing.

A recent study by Durand-López and Garrido-Pozú (2024) highlights the importance of input. They demonstrated that following input-based training on infrequent morphologically complex Spanish words (through intensive exposure to such words), nonnative speakers of Spanish, who participated in a pre/post LDT involving low-frequency Spanish words, switched their morphological processing route from decomposition to whole-word processing. Given that input can lead to such a significant shift in L2 morphological processing route, it is not unexpected that the NE group in this study was influenced by naturalistic input and processed trimorphemic words hierarchically, consistent with native speakers’ processing patterns.

Moreover, Portin et al. (2007, 2008) emphasised the language learning background of learners which can affect L2 morphological processing as well. They found that participants who learned L2 Swedish by immersion processed Swedish inflected forms via whole-word processing, while those who had formal classroom instruction processed such words via decomposition. Based on Portin et al.’s findings, different learning environments (or exposure types) may lead to different morphological processing patterns. More importantly, as Portin et al. claim, in an immersion-like environment, the most available input is auditory, whereas in a classroom environment, visual input predominates (see also Gor & Cook, 2010). Since the task used in this study employed cross-modal priming technique (auditory primes → visual targets), it is possible that the NE group in this study was more sensitive to the auditory primes (due to the rich auditory input they were exposed to). The CE group, on the other hand, may have been less sensitive to the auditory primes and, thus, focused more on the visual targets. Therefore, the nature of exposure, whether it is classroom or naturalistic, determines the extent to which learners are primarily exposed to visual or auditory input (Gor & Cook, 2010).

It is also argued that word length plays an important role in the processing of multimorphemic words, with longer words promoting decomposition (Hyönä, 2015) and possibly leading to processing cost and slower RTs. Although length (the number of letters and syllables) was kept constant across all LB targets in this study, their constituent and nonconstituent primes differed slightly in length. On average, nonconstituent primes (*M* = 8.33, SD = .47) were two letters longer than constituent primes (*M* = 6.33, SD = .47). Consequently, the auditory nonconstituent primes were presented for a longer duration compared to constituent primes, making it more challenging for participants to process nonconstituent primes. Due to this length effect, the NE group as well as native speakers—being more sensitive to the auditory primes—may have faced more difficulty processing nonconstituent primes. On the other hand, constituent primes, which were shorter than nonconstituent primes, were processed more easily, producing significantly larger priming effects compared to their nonconstituent counterparts. In contrast, the CE group, as noted before, may have been less sensitive to the auditory primes, thereby processing both prime types similarly, which is why equal priming effects were yielded by both prime types. Altogether, while we do not draw any strong conclusions about the factors that might have led to nativelike morphological processing among the NE group, similar to Portin et al. (2007, 2008), we argue that different learning environments (or exposure types) as well as input modalities likely influence how nonnative speakers process trimorphemic words.

*Frequency*

The other factor that could account for the NE group’s nativelike processing is frequency. Specifically, CE learners may not experience naturalistic frequencies10 to the same extent as NE learners, who receive relatively rich input (Gor & Long, 2009). Furthermore, the rules and probabilities model proposed by Gor (2003, 2004) posits that in languages characterised by rich inflectional morphology, patterns or rules occurring with high frequency will be utilised prior to, and more rapidly than, those that are less frequent. This model suggests that the probabilistic aspects of morphological processing evolve through linguistic experience and are significantly influenced by the frequency of the input encountered. It applies to both L1 and L2, indicating that variations in how inflection is processed in L1 versus L2 can be attributed, at least in part, to differences in the frequency of exposure to native and nonnative linguistic input (Gor & Cook, 2010).

The insights originated from the rules and probabilities model can also be applied to derivational morphology. As such, similar to how the model predicts variations in inflectional processing between native and nonnative speakers based on exposure, it is plausible that derivational morphology may exhibit analogous patterns of processing influenced by the frequency of derived forms. Specifically, high-frequency derived forms are prioritised over low-frequency ones. Therefore, it is plausible that trimorphemic words are used more frequently in a naturalistic setting than in a classroom setting. In other words, it could be argued that NE learners are more likely to encounter trimorphemic words compared to CE learners. Nevertheless, one should approach this claim with caution, as suggested by Pliatsikas and Marinis (2013a, p. 962).

***A Comparison of Pliatsikas and Marinis (2013a) and This Study***

As previously mentioned, there is only one study, to our knowledge, that has investigated the effects of NE to L2 on morphological processing. Pliatsikas and Marinis (2013a) examined how nonnative speakers with CE and those with NE processed regular and irregular English past tense morphology. Results revealed no significant difference between CE and NE groups. It should be noted that the stimuli used in their study were bimorphemic. Therefore, nonnative speakers in Pliatsikas and Marinis (2013a) may have experienced less difficulty in processing bimorphemic inflected words simply because morphemes in these words are not hierarchically represented. As Clahsen and Felser (2006c) and Ullman (2006) suggest, nonnative speakers may face processing difficulty in *hierarchically* complex structures, one example of which could be trimorphemic words with both prefixes and suffixes. As a result, nonnative speakers may experience processing difficulty with trimorphemic words. However, as shown in this study, only nonnative speakers with CE to L2 processed trimorphemic words linearly; those with NE to L2 were shown to be more nativelike and processed trimorphemic words hierarchically. As such, the results of this study contrast with those of Pliatsikas and Marinis (2013a). While this study demonstrated a significant role of NE in L2 morphological processing, Pliatsikas and Marinis (2013a) found no such effect.

***A Comparison of Song et al. (2019, 2020) and This Study***

The performance of native speakers in this study, as well as that of the NE group, partially aligns with the findings of Song et al. (2019). Although both native speaker groups were significantly primed by constituent primes in LB items, nonconstituent primes in Song et al. (2019) did not lead to significant priming effects, whereas in this study both native speakers and the NE group were significantly primed by nonconstituent primes as well. The difference in the pattern of results could be interesting, as Song et al. (2019) consider the nonsignificant priming effects elicited by nonconstituent primes to be an unexpected finding (p. 273). This is because nonconstituent primes and their targets are still morphologically, phonologically, and semantically related to each other, and one would expect significant priming effects to arise when LB items are preceded by nonconstituent primes, albeit to a lesser extent than when LB items are preceded by constituent primes. This is because constituent primes are morphologically nested in the representation of trimorphemic words, whereas nonconstituent primes are not. Altogether, while native speakers in Song et al. (2019) were only primed by constituent primes, native speakers and the NE group in this study also exhibited significant priming effects by nonconstituent primes.

As for the CE group, the results of this study are consistent with those of Song et al. (2020) whose nonnative speakers were equally affected by both constituent and nonconstituent primes and processed trimorphemic words linearly, in line with the SSH. Overall, while nonnative speakers in Song et al. (2020) and the CE group in this study showed no sensitivity to the morphological structure of trimorphemic words, resulting in linear processing, the NE group, along with native speakers from both this study and Song et al. (2019), demonstrated sensitivity to morphological structure and processed these words hierarchically. The NE group exhibited patterns similar to those of native speakers, in line with the D/P Model.

***A Note of Caution Regarding the SSH***

An important issue deserving attention is the distinction between representation and processing. As noted by VanPatten and Jegerski (2010, p. 8), the acquisition of relevant grammatical knowledge (i.e., representations) does not necessarily lead to its nativelike processing. Similarly, learners exhibiting nativelike grammatical representations may occasionally display processing patterns that are not nativelike (e.g., Felser & Cunnings, 2012). The SSH (Clahsen & Felser, 2018, p. 4) posits that both nontargetlike grammatical representations and a nontargetlike processing system can contribute to the differing grammatical processing patterns observed between L1 and L2, highlighting the important distinction between representations and processing.

Therefore, it could be argued that the difference between the NE group (as well as native speakers) and the CE group does not necessarily imply that the CE group has failed to acquire nativelike representations of trimorphemic words (see Song et al., 2020). Perhaps the CE group, like native speakers and the NE group, has developed hierarchical representations of trimorphemic words, but what they have difficulty with is related to processing. Specifically, while the CE group may have acquired the hierarchical arrangement of morphemes within trimorphemic words, this does not necessarily mean that their processing is hierarchical. This claim should, however, be treated with caution, as we did not directly test participants’ representations of trimorphemic words.

***Limitations of the Present Study***

While this study provides valuable insights into morphological processing research—particularly regarding L1 and L2 processing of trimorphemic words in English—it is important to acknowledge several limitations that may impact the interpretation and generalizability of the findings.

First, the CELEX database did not directly include trimorphemic words in English; in other words, there were no entries for any of the trimorphemic words used in this study. Therefore, following Song et al. (2019, 2020), we coded the frequency of the items—those not present in the database—as zero (per million).

Next, we did not control for neighborhood density and phonotactic probability of our stimuli. As Durand-López (2021) and Durand-López and Garrido-Pozú (2024) assert, these linguistic variables could potentially affect RTs, so it is important to consider controlling for these factors in future studies.

Furthermore, as Ellis and Sagarra (2010a, 2010b) argue, the salience of a given stimulus in the input is a key factor influencing L2 processing. Similarly, Laudanna and Burani (1995) highlight the importance of salience, proposing the notion of affix salience, defined as the likelihood of a derivational affix serving as a processing unit in the recognition of a morphologically complex word. This likelihood is based on the affix length, frequency, and productivity. It would be beneficial to account for these factors in future studies.

Finally, given the paucity of research into trimorphemic words and different L2 exposure types, further investigation is warranted to validate the results of this study. By acknowledging and addressing these limitations, future studies can provide a more comprehensive understanding of L2 processing of trimorphemic words, thereby enhancing the generalizability, robustness, and validity of the findings as well as the conclusions drawn about L2 morphological processing.

**Conclusion**

This study investigated the processing of trimorphemic English words—which are represented hierarchically (e.g., [[[re] + [wash]] + [able]])—by two different groups of nonnative speakers: those with classroom exposure to L2 English and those with naturalistic exposure to L2 English. Results indicated significant differences between the two groups of nonnative speakers, suggesting that L2 exposure type can impact how trimorphemic words are processed. Specifically, the CE group was found to be insensitive to the constituency of different prime types, a finding mirroring that of Song et al. (2020). In other words, the CE group was shown to process trimorphemic words linearly, supporting the idea that they may be insensitive to the morphological structure of trimorphemic words, which is consistent with the SSH.

On the contrary, the NE group, being more strongly affected by constituent than by nonconstituent primes, showed sensitivity to the constituency of different prime types, thereby processing trimorphemic words hierarchically (similar to native speakers). This finding was taken to suggest the NE group’s (and native speakers’) sensitivity to the morphological structure of trimorphemic words, which can further signify that as a function of NE to L2, and as per the prediction made by the D/P Model, the NE group moved away from shallow/linear (nonnative) processing to detailed/hierarchical (nativelike) processing of trimorphemic words. Therefore, the results of this study lend support to the D/P Model, highlighting the impact of L2 exposure type and suggesting that L2 (morphological) processing can indeed become nativelike.

**Footnotes**

1 As this study focuses on trimorphemic English words, it is important to note that such words with both prefixes and suffixes are exclusively derived; trimorphemic inflected forms are not grammatically possible in English. For brevity, we will use “trimorphemic words” throughout the manuscript to denote trimorphemic derived English words.

2 There have been some exceptions where native speakers of Finnish (Lehtonen & Laine, 2003), Spanish (Durand-López, 2021; Durand-López & Garrido-Pozú, 2024), Swedish (Lehtonen et al., 2006; Portin & Laine, 2001), and Turkish (Gürel, 1999; Gürel & Uygun, 2013; Uygun & Gürel, 2016) have demonstrated a preference for whole-word processing, suggesting that morphological processing (decomposition vs. whole-word processing) may be language-dependent. However, it is worth mentioning that the above studies used *unprimed* lexical decision tasks as opposed to *primed* ones, which may lead to different results. This discussion is, however, beyond the scope of the present study.

3 Priming (effect) in this study refers to the difference in RTs when targets are preceded by constituent and nonconstituent primes, compared to when they are preceded by unrelated primes.

4 There is no RB trimorphemic word in English, where the initial two morphemes constitute a legitimate word (e.g., \**unthink*). For this reason, nonconstituent primes do not exist in RB words.

5 Participants with NE to English all lived in Canada; none of them lived in Quebec (French-speaking region).

6 These are based on the results of *t* tests comparing CE and NE groups.

7 Including low-frequency stimuli may enable us to discern whether trimorphemic words are processed hierarchically or linearly. This approach addresses our research question which focuses not on whether participants process the stimuli via decomposition or whole-word processing, but rather on the nature of their decomposition: whether it occurs hierarchically or linearly.

8 The same procedure was followed by Clahsen and Jessen (2020), Ciaccio and Veríssimo (2022), and Farhy et al. (2018b) who did not conduct accuracy analyses due to high accuracy rates.

9 Although both CE and NE groups were of advanced proficiency according to the QPT manual, there was a statistically significant difference between the two groups (as Table 1 suggests), with the NE group (*M* = 53.56, SD = 2.4, range: 50 - 57) having higher proficiency than the CE group (*M* = 52.02, SD = 2.34, range: 48 - 56). To address the potential confounding influence of proficiency on the differing performance of the two groups, we reanalysed the data by including the centered proficiency covariate in the models. Not only did the inclusion of proficiency not significantly improve the models, but the effect of proficiency was also not significant in any of the models. Furthermore, we compared our models with and without the proficiency covariate. Yet, the results remained unchanged. Therefore, proficiency cannot account for the different morphological processing patterns observed between the CE and NE groups.

10 Naturalistic frequencies refer to the occurrence rates of specific language features in real, authentic, and unmodified communication among native speakers. This contrasts with L2 settings or classroom environments, where learning materials are often tailored to meet the needs of nonnative speakers. In such contexts, teachers typically emphasise certain language features, leading to an artificial frequency of exposure. This is in contrast to naturalistic exposure, where nonnative speakers encounter genuine input reflective of native speakers’ usage.

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