Sensitivity to Morphological Composition in Spoken Word Recognition: Evidence from Grammatical and Lexical Identification Tasks

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Abstract

Access to morphological structure during lexical processing has been established across a number of languages; however, it remains unclear which constituents are held as mental representations in the lexicon. The present study examined the auditory recognition of different noun-types across two experiments. The critical manipulation was morphological complexity and the presence of a verbal derivation or nominalising suffix form. Results showed that Nominalisations, such as *explosion*, were harder to classify as a noun, but easier to classify as a word, when compared to monomorphemic words with similar "action-like" semantics, such as *avalanche.* These findings support the claim that listeners decompose morphologically complex words into their constituent units during processing. More specifically, the results suggest that we hold representations of base morphemes in the lexicon.

Keywords: morphological processing; spoken word recognition; decomposition; derivational suffixation

1. Introduction

1.1 Processing Polymorphemic Words

The processing of morphologically complex words (e.g., stem "*argue*" + suffix "-*ment*") has played a central role in our current understanding of the mental lexicon. A number of theories have been proposed to explain the mental representation of complex words, differing in the degree of decomposition assumed during lexical storage and retrieval. These accounts span a continuum between two primary models of morphological processing: the word-whole or "continuous" approach (Butterworth, 1983; Janssen, Bi and Caramazza, 2008; Norris and McQueen, 2008) and the decomposition "parsing" approach (Cutler and Norris, 1988; Marslen-Wilson, Tyler, Waksler and Older, 1994; Pinker and Ullman, 2002).

In the visual domain, there is considerable evidence consistent with a decompositional theory of word recognition, wherein morphologically complex words are segmented into their constituent morphemes prior to retrieval. Visual masked priming behavioural studies, for example, consistently find that the covert presentation of a complex word, such as "government" or a pseudo-complex word, such as "corner", aids lexical identification of the stem or pseudo-stem (e.g., "govern" or "corn"). This result is taken as evidence that regularly derived forms are automatically decomposed into constituent morphemes prior to lexical access (English: Rastle, Davis and New, 2004; Arabic: Boudelaa and Marslen-Wilson, 2001; Hebrew: Frost, Forster and Deutsch, 1997; see Rastle and

Davis, 2008 for a review). Corroborating findings have also been reported in the neurophysiological literature, supporting decomposition of regularly derived forms and pseudo-derived forms (Lewis, Solomyak and Marantz, 2011; Lehtonen, Monahan and Poeppel, 2011; Solomyak and Marantz, 2010; Whiting, Shtyrov, Marslen-Wilson, 2014; Zweig and Pylkkänen, 2008), in addition to decomposing irregulars, such as "taught" into "teach + [past]" (Stockall and Marantz, 2006) and compounds, such as "teacup", into constituent stems (Fiorentino and Poeppel, 2007). Furthermore, there is research to support the significance of stem frequency in predicting response times of complex forms, suggesting that access to the whole word entails primary access to the constituent stem morpheme (Taft, 1979; Taft, 2004; Taft and Ardasinski, 2006).

The role of morphology in auditory word recognition, however, has been much less explored, with contention remaining regarding the importance of morphological structure to parsing the speech signal. Continuous models, such as Shortlist B (Norris and McQueen, 2008) and the Cohort model (Marslen-Wilson and Welsh, 1978), assume that internal word structure is irrelevant, and that onset-aligned *word-whole* competitors are eliminated with each incoming phoneme. Consequently, the target is recognised at the position within the word at which it is unique from all onset-aligned words: the Uniqueness Point. This approach allows for a model that does not require a large number of exception rules (e.g., to avoid false decomposition of *corner*); however, the approach entails substantial redundancy, because strict left-to-right parsing requires independent representations despite semantic transparency among morphologically related forms (e.g., 'covered', 'uncover' and 'discover' [see Wurm, 1997]).

To test the continuous Shortlist B model, Balling and Baayen (2012) assessed the influence of different uniqueness point measures on auditory word recognition. They compared a measure that identifies a target word once the sensory input is inconsistent with all onset-aligned words, including morphological continuations (Complex Uniqueness Point, CUP), to a measure that does not take morphologically related words into consideration (UP). For example, in a word such as "acceptable", the UP occurs at /t/, and the CUP occurs at the following vowel. The locations of both UP and CUP were significant determiners of response latency in lexical-decision, suggesting that both morphological and word-whole competitors are relevant to auditory word recognition.

Decomposition models propose that auditory processing involves recognition of constituent morphemes rather than whole words, with individual morphemes represented lexically. Although there is evidence to support sensitivity to morphological structure during processing, it is unclear which morphemes are represented in the lexicon. Cross-modal priming studies have found evidence to support stem access during comprehension (Marslen-Wilson, Tyler, Waksler and Older, 1994), although only in the presence of a sufficient semantic relationship between the whole word and the root (e.g., "government" and "govern"). More recent investigations (Kielar and Joanisse, 2011) found that both form and meaning co-determine the degree of observed morphological priming.

Evidence for suffix decomposition is also unclear. In an auditory priming study, Emmorey (1989) found no affix-priming for inflectional (*joking*/*typing*) or derivational (*tightly/cheaply*) pairs, suggesting that suffixes do not have lexical representations that can be primed during lexical access. In a cross-modal task, however, Marslen-Wilson, Ford, Older and Xiaolin (1996) reported evidence for derivational affix priming for words, such as *darkness* and *toughness.* Furthermore, in a mismatch negativity (MMN) study, Whiting, Marslen-Wilson and Shtyrov (2013) found evidence for automatic recognition and decomposition of suffixes, both for "real" (e.g., baker) and "pseudo" (e.g., beaker) suffixed items, in agreement with what had been previously found for visual processing of similar items (e.g., Rastle et al., [2004] as discussed above). The authors propose that there is an automatic recognition of suffixes, even for the pseudo-suffixed items that are not composed of stem and suffix units. Due to methodological constraints, they used a small set of experimental items, making it hard to generalise the results; however, their findings support suffix identification in spoken word recognition, and isolable processing structures in the mental lexicon for affixes.

1.2 The Current Approach

We present the results of two experiments that used the same critical items. The experiments were run in Spanish with native Spanish speakers (from the Spanish speaking portion of the Basque Country) as participants. Our main comparison was between two types of "action" nouns: Regularly derived nominalisations which could be decomposed into [verb stem] + [nominal suffix] (e.g., *dona[r] + -ción* "donation") and monomorphemic "Event Nouns" that could not be decomposed (e.g., *avalancha* "avalanche"). The two types of items were selected to have similar verb-like semantics but with only the first type potentially having a verbal stem in the lexicon. Importantly, due to the morphological characteristics of Spanish, all of the morphologically complex items selected for the current experiments were constructed through the combination of a bound attested stem and suffix, such as “donación”: the listener was therefore not exposed to a free stem (e.g., “donar”), but rather an attested stem (e.g., “dona-“).

Psycholinguists have used a wide range of tasks to explore different aspects of lexical access. For example, naming/shadowing has been used to tap early encoding, and semantic categorisation (e.g., does a word refer to an animate versus an inanimate object) has been employed in studies focusing on access to meaning. Given our interest in morphosyntactic processing, in one experiment, listeners classified spoken words as either a “noun” or a “verb” (i.e., grammatical-decision task); in the other, listeners classified items as either real Spanish words or not (i.e., auditory lexical-decision task). If stems are accessed during spoken word recognition, the decomposable nominalisations should be more difficult to identify as a noun than the monomorphemic event nouns due to the mismatch between verb stem and the “noun” final response. In contrast, during lexical-decision the nominalisations should be easier to identify, as access to the stem would bolster the “word” response. Decomposition (i.e., access to the stem) should therefore produce an interaction between the two conditions of interest and the two experimental tasks.

We also included a condition to test the representation of affix units. Because derivational morphology provides direct information regarding word-class, if an affix is identified during word recognition, it allows faster identification of the word's grammatical category. To test this, we compare monomorphemic nouns (e.g., *medicina* "medicine") to nouns containing a "pseudo" derived suffix and a false stem, [false stem] + [nominal suffix] (e.g., *excursión* "excursion"). These pseudo-suffixed nouns provide a legitimate nominal suffix, but they cannot be decomposed in the same way as "explosion" due to the absence of a legitimate stem (e.g., there is no base verb "excur", or anything similar, for "excursion"). Such items test whether there is sensitivity to the word-final morphological unit, and whether the item is decomposed despite the absence of a free base morpheme. If affix decomposition occurs in the pseudo-suffixed words, they should produce faster responses in the grammatical-decision task in comparison to monomorphemic "prototypical" nouns.

2. Experiment 1

2.1 Methods

2.1.1 Participants

Twenty-five native Spanish participants with normal hearing volunteered and were compensated for their time (12 female, mean age = 22.4, *SD* = 3.74). Participants were either students of, or employed by, the University of the Basque Country. All participants provided written informed consent.

2.1.2 Materials

Thirty-nine critical items were selected from the Spanish Es-Pal database (Duchon et al., 2013) to form three subsets of nouns. Critical stimulus items and their glosses are presented in Appendix 1. These consisted of: 13 “event nouns”, selected to have an event/action semantic representation but no verbal derivation; 13 deverbal nominalisations selected to have a clear verbal derivation and nominalising suffix; and 13 “pseudo-suffixes” selected to have a word-final “nominal” form, identical to a nominalising suffix, but without the corresponding verbal derivation. Item selection was based on the judgments of ten native Spanish speakers. In addition to the 39 critical items, 26 “prototypical nouns” were selected. These were monomorphemic nouns that referred to objects rather than events.

Critical stimulus properties are presented in Table 1. Length and UP are measured in number of phonemes. UP is the position of the first phoneme in the word where it becomes unique from all other onset-aligned words (Marslen-Wilson, 1984). Phonological neighborhood density (ND) is measured as the number of words that can be formed by substituting, adding or deleting one phoneme. Imageability is also reported, as it affects reaction times for nouns (Kacinik and Chiarello, 2002).

(Table 1 about here)

For the word-class judgment, we included 104 verbs (52 infinitive verbs and 52 inflected verbs). The verbal inflection was a conjugation indicating either person or tense agreement. Sets of stimuli were created by matching for length in terms of phoneme number (LP), log frequency (log.), log frequency of the base “stem” (base log.) and UP of the nominalisations. Thirteen sets were created using this structure (see Appendix 2 for all critical stimuli).

All stimuli were recorded by a female native speaker of Spanish in a sound-treated room at a sampling rate of 44.1 kHz. Each item was read in isolation with sentence-internal intonation, and amplitude was equalised to 70 dB SPL using Praat (Boersma and Weenink, 2014).

2.1.3 Procedure

Before the experiment, noun and verb definitions and examples were provided to ensure that participants had a full understanding of the task. Participants were invited to ask clarification questions.

The word *Verbo* (“verb”) was always presented on the left side of the visual display and *Sustantivo* (“noun”) on the right. Stimuli were presented over Beyerdynamic DT-770 headphones at a comfortable listening level. Participants categorised each word as a verb or noun by pressing the left or right key on a response board using their index fingers. They were instructed to respond as quickly and as accurately as possible. The inter-trial interval was 750 ms and began upon the response to the prior stimulus. The next item was presented regardless of accuracy on the previous trial. If no response was made after 2500 ms, the next trial would begin. No feedback was provided.

Three pseudo-randomised presentation lists were composed, each combining the 65 nouns and 104 verbs. Critical items did not appear until the 11th word to allow for task habituation.

Participants listened to all three lists, with a short break between lists. Presentation was counter-balanced so that each list was presented equally as the first, second and third pass. The experiment lasted approximately 30 minutes.

2.2 Results and Discussion

Figure 1 displays the mean reaction times and percentages of errors, both for noun and verb conditions. Reaction times were measured from word onset. Trials with response times that were more than 2.5 standard deviations from the by-subject or by-item means were removed from the analysis (2.6% of the responses). No participants or items were eliminated from the final analyses. The generally high levels of accuracy indicate that participants did not have difficulty making the noun-verb judgment.

(Figure 1 about here)

Figure 1. Grammatical decision error rates and reaction times for noun and verb conditions. Error bars represent standard error from the mean. Eve = "Event Noun", Nom = "Nominalisation", Prot = "Prototypical Noun", Pse = "Pseudo-suffixed Noun", Infin = "Infinitive Verb", Inflec = "Inflected Verb".

Our primary question is whether “action nouns” are treated differently depending upon morphological composition: Are there differences between the monomorphemic event nouns (e.g., *avalancha*) and the nominalisations (e.g., *donación*)? To address this question, reaction times and error rates were analysed using linear mixed-effects models in the *lme4* package (Bates, Maechler & Bolker, 2012) in *R* (R Core Team, 2012) using a mixed logit model (Jaeger, 2008). Each model included random by-item and by-subject intercepts, a random slope of Condition over subjects (following Barr et al., 2013), and fixed effects for all potentially relevant predictors: Condition, Imageability, Uniqueness Point, Phonological Neighborhood Density, Length and Stimuli List.

2.2.1 Mixed-Model Analysis

As shown in Figure 1, performance for the critical noun conditions patterned in the same way for accuracy and response times. As our experimental hypothesis was based upon nominal processing, our statistical analyses compared performance across the four types of nouns in our design. Estimates of the linear model for accuracy and reaction time are provided in Table 2. The analyses revealed a significant effect of Condition for accuracy ($\chi^2 = 13.1$, $p < .01$), indicating that noun “type” was a strong predictor of processing behavior. For reaction times, Condition did not reach significance ($\chi^2 = 5.6$, $p = .13$) but as noted, patterned in the same way as the error data. The results shown in Figure 1 and the estimates of the model reflect poor performance on the Nominalisations and good performance on the Event Nouns.

(Table 2 about here)

2.2.2 Noun Composition

To assess whether decomposable nouns were processed differently from items that could not be decomposed, we conducted post-hoc comparison tests using generalised hypothesis testing with the Tukey-adjustment procedure for multiple comparisons in the *multcomp R* package (Hothorn, Bretz & Westfall, 2008). This allowed us to compare conditions while taking both by-subject and by-item variability into account. Event Nouns were identified significantly more accurately than Nominalisations (z = -3.39, p < .01), and Event Nouns were responded to faster than Nominalisations, although this comparison did not reach significance (z = -2.15, p = .14). These results suggest that the decomposable words were significantly more difficult to identify as nouns than the monomorphemic words. Nominalisations were also identified less accurately than Prototypical Nouns, but not significantly so (z = -2.18, p = .13), with no reaction time difference (z = 0.86, p = .82).

2.2.3 Pseudo-Suffix

The second question addressed by this experiment is the importance of a suffix to auditory word recognition. To explore this, we compared responses to the Pseudo-Suffix and Prototypical Nouns. Post-hoc tests did not reveal any significant differences (accuracy: z = -0.16, p = .99; RT: z = 0.63, p = .92).

2.3 Experiment 1 Conclusions

Overall, the results from the first experiment indicate that morphological composition is an important determiner of lexical processing. The grammatical-decision task was designed to be sensitive to any disagreement between the decomposed stem (verbal) and the required word-whole response (noun) in a nominalisation. The clear results for accuracy and the corresponding (non-significant) trends in reaction times provide evidence for the decomposition of the decomposable items: Responses were significantly less accurate and numerically slower than responses to the monomorphemic words.

Our interpretation focuses on the conflict between the required nominal response and the hypothesised activated verbal root for the decomposable test items. It is also possible, however, that the difficulty lies in decomposition itself; perhaps decomposition requires additional time and increases errors. To decide between these two possibilities, Experiment 2 uses the same items in a lexical-decision task. In lexical-decision, the response to any activated verbal root is the same as the word-whole "final response" because both are "word" units. Thus, there is no conflict for the nominalisations. If the results of Experiment 1 were due to such a conflict, the impairment relative to the matched monomorphemic words should not occur in Experiment 2. If, however, the cost is due to decomposition per se, we should see the same pattern in the lexical-decision task as we did for the noun-verb judgments: Nominalisations should yield slower and less accurate responses than Event Nouns.

3. Experiment 2

3.1 Method

3.1.1 Participants

Twenty-five volunteers (18 women; mean age = 23.8, *SD* = 4.9) participated in the experiment. All were native Spanish speakers recruited from the same population as Experiment 1. All participants provided written informed consent and were compensated for their time.

3.1.2 Materials

The stimuli used in Experiment 1 were used in Experiment 2. As the task was now auditory lexical-decision, we also included a set of non-words. Each word was used to construct a non-word by changing one to three phonemes while maintaining the overall syllabic structure. For example, "*purtir*" was a non-word formed from the word "*portar*" (to carry), and "*anobéis*" was formed from the word "*amabais*" (loved). This procedure yielded 169 word/non-word pairs. Twenty-six of these pairs also included a nominal suffix. For example, the pseudo-suffixed non-word "*vatición*" was formed from the pseudo-suffixed word "*vocación*" (vocation). This was done both in order to assess the significance of the nominal suffix in the absence of a valid stem, and to make sure that listeners could not simply use the presence of such a suffix to respond "word" for the nominalisation and pseudo-suffix items.

3.1.3 Procedure

Participants received standard lexical-decision instructions in writing and were invited to ask clarification questions. The phrase *Palabra inventada* "invented word" was always displayed on the left side of the display, and *Palabra real* "real word" was always displayed on the right. The rest of the procedure was as in Experiment 1.

Two presentation lists were created, each of which included all 169 word/non-word pairs. Each list had the same order of "item type" with words pseudo-randomised within-condition across the two lists. As in Experiment 1, critical words did not appear until the 11th item. All participants received both lists of stimuli, with a short break between the two blocks. Presentation order was counter-balanced so that each list was presented equally often as the first or second pass. There were two passes, rather than the three used in Experiment 1, because of the larger number of items that resulted from including non-words.

3.2 Results and Discussion

Trials that were 2.5 standard deviations from the by-subject and by-item means were removed from the analysis (2.1% of the responses – just 0.5% less than the grammatical decision task). Only correct responses were included in the analysis of RT. Mean response times and error rates are displayed in Figure 2.

(Figure 2 about here)

Figure 2. Lexical decision error rates and reaction times for noun and verb conditions. Error bars represent standard error from the mean. Eve = "Event Noun", Nom = "Nominalisation", Prot = "Prototypical Noun", Pse = "Pseudo-suffixed Noun",Infin = "Infinitive Verb", Inflec = "Inflected Verb".

3.2.1 Mixed-Model Analysis

Reaction times for all conditions patterned in the same way as the errors. The models summarised in Table 3 were reached by performing the same mixed model analysis as Experiment 1. We found a significant effect of Condition for both measures (accuracy: $\chi^2 = 15.32$, $p < .01$; RT: $\chi^2 = 9.78$, $p = .02$).

(Table 3 about here)

3.2.2 Morphological Composition

Our central comparison is again between monomorphemic Event Nouns and Nominalisations chosen to match the Event Nouns on both surface properties and semantic properties. In the current experiment, stem decomposition would aid the identification of Nominalisations because the verbal stem is consistent with the required "word" response; this would produce the opposite pattern to what we saw with grammatical category judgments. This reversal is indeed what we find: Nominalisations were identified significantly more accurately than Event Nouns (z = 3.36, p < .01); their RT advantage did not reach significance (z = -1.71, p = .22). Nominalisations were also identified more easily than Prototypical Nouns (accuracy: z = 3.71, p < .01; RT: z = -3.1, p < .01). This reversal across experiments provides strong support for the decomposition interpretation.

3.2.3 Nominal Suffix

The results also provide a test of the importance given to the presence of a derivational suffix. Two comparisons are relevant to this question. First, for the real word stimuli, Pseudo-Suffix and Prototypical Nouns differed in the presence versus absence of such a suffix. Pseudo-Suffixed items were identified marginally more accurately than Prototypical nouns (z = 2.31, p = .09), although not significantly faster (z = -1.71, p = .31).

Second, we can compare non-words containing a nominal suffix (e.g., *nasición*) to those without such suffixes (e.g., *mevorir*). The suffixed non-words were more difficult to dismiss as real words, as indexed by significantly higher error rates (z = -10.62, p < .001) and slower reaction times (z = 2.06, p < .05). This suggests that listeners were sensitive to the suffix unit, even in the absence of a valid word stem, when asked to judge whether an item was a real word or not.

4. Combined Data Analysis

In the Introduction we noted that if the stem is being decomposed during processing, we expect Nominalisations to be more difficult to identify as a noun, but easier to identify as a word. To test this prediction we conducted a mixed-model analysis across the two experiments. We followed the same methods used in the main experiment analyses, testing the additional factor of "Task" and its interaction with "Condition" in the fixed effects. Only the two main conditions of interest (Nominalisations versus Event Nouns) were included in the Condition factor. Results are displayed in Figure 3.

(Figure 3 about here)

Figure 3. Interaction between task and condition (Event Nouns and Nominalisations) for accuracy and response latencies.

The analysis revealed a significant main effect of Task (accuracy: $\chi^2 = 6.03$, $p = .014$; RT: $\chi^2 = 13.91$, $p < .001$) and a highly significant interaction between Condition and Task (accuracy: $\chi^2 = 41.7$ $p < .001$; RT: $\chi^2 = 33.67$, $p < .001$). This interaction suggests that access to the stem is indexed by poor performance in grammatical-decision and good performance in lexical-decision, consistent with the predictions of decomposition theories of lexical processing.

5. General Discussion

The current study addressed the question of whether morphological constituents are processed and represented as distinct units during auditory lexical processing. The primary comparison of interest was between classifications of monomorphemic Event Nouns (e.g., *avalancha* "avalanche"), and polymorphemic Nominalisations, which are composed of a verb stem and nominal suffix (e.g., *donación* "donation"). We also tested Pseudo-Suffixed nouns containing a nominal suffix but no corresponding verb stem (e.g., *excursión* "excursion"). These three conditions provide insight into the representation of stem and affix units during spoken word recognition.

5.1 Sensitivity to the Stem of Morphologically Complex Items

Our main finding was that morphologically complex nominalisations were more difficult to identify in the grammatical-decision task, but easier to identify in lexical-decision, when compared to semantically-matched monomorphemic items. The morphological structure of the Spanish nominalisations we selected consisted of a bound stem (e.g., *dona*-) and a bound derivational suffix (e.g., -*ción*); the stems were well-attested morphemes of the language but did not constitute discrete words on their own. Because of this, participants never heard a complete verbal base form (e.g., *donar*), but rather a stem that must be appended with a derivational or inflectional morpheme (e.g., *dona* + *ción*). The interaction we observed across tasks suggests that this stem was supporting a "verb" response for the whole word, but slowing down nominal classification.

One interpretation is that in accessing the representation of the stem morpheme, the processing system activates the possible morphological continuations that may subsequently occur. For example, when identifying the grammatical class of a nominalisation, such as "*donation"*, once an individual has recognised the bound stem *"dona-"* there is greater summative likelihood of a verbal continuation (e.g., *"donate"* and its verbal inflections) than a nominal continuation (e.g., *"donation"*). Situations in which the predicted morphological unit is not the same as the outcome are associated with slower responses and increased errors (Balling and Baayen, 2012; Ettinger, Linzen and Marantz, 2014). Due to the less likely occurrence of a nominal suffix, greater cognitive effort is needed to switch from the predicted (verb) to the non-predicted (noun) outcome, therefore increasing errors and response times for the nominalisations in the grammatical-decision task.

By contrast, in Experiment 2's lexical-decision task, all morphologically valid units support the "word" response, meaning all activated continuations of the root support the same outcome. Indeed, earlier access to a valid lexical representation, such as an attested stem, provides an advantage relative to the monomorphemic words whose representation(s) cannot be accessed until the full word unfolds. As there is evidence that bound and free morphemes are processed comparably in the visual domain (Pastizzo and Feldman, 2004), our results are likely to be generalisable to both forms of stem morphemes.

A less interesting possibility is that because there were more verbs (104) than nouns (65) in Experiment 1, there could have been a bias for participants to respond "verb", making it harder to respond "noun", and thus disproportionately affecting the classification of nominalisations. Any such bias would be expected to develop over the course of the experiment, as the listeners were exposed to the noun-verb distribution, with increasing difficulty in classifying the nominalisations. When looking at the mean error rates and RT's across each pass of Experiment 1 no such trend is observed: Nominalisations are poorly identified from the beginning, with no increase in difficulty across passes. Moreover, the critical comparison is between Nominalisations and Event Nouns, both of which would presumably suffer from any distribution-based bias against responding "noun".

Our findings converge with previous studies supporting activation of stems during processing of morphologically complex forms. Significant stem-priming of semantically transparent prime-target pairs (*driver – drive*) has been established in both visual masked priming (Rastle et al., 2000; Rastle et al., 2004; Silva and Clahsen, 2008) and cross-modal priming (Kieler and Joanasse, 2010; Marslen-Wilson et al., 1994). This suggests that listeners are sensitive to the morphological structure of complex items, and that the observed priming effect is due to the activation of the corresponding stem during lexical retrieval, and not simply a consequence of semantic overlap. Collectively, the evidence indicates that decomposition of constituent units occurs in both the visual and auditory modalities.

5.2 Sensitivity to Word-Final Grammatical Cues

In addition to probing the status of the stem in morphologically complex words, we also investigated whether listeners were sensitive to a word-final suffix. For this issue, the main comparison was between Pseudo-Suffixed words (e.g., *excursión*) and Prototypical Nouns (e.g., *medicina*). We observed an interesting difference as a function of the task that the listeners were given: The presence of an identifiable suffix did not have a significant impact on grammatical decisions but did produce significant differences in lexical decisions.

In Experiment 2, the Pseudo-Suffixes were identified as words more accurately and more quickly than the Prototypical Nouns, suggesting easier identification of words with such pseudo-suffixes. The non-words containing pseudo-suffixes were more difficult to dismiss as valid words, compared to non-words without these suffixes, again suggesting that the processing system is sensitive to the presence of derivational morphemes as valid lexical units.

Findings for printed words are consistent with the results of Experiment 2. A visual priming experiment conducted by Rastle et al., (2004) found evidence for decomposition of words with an identifiable suffix, even in the absence of a semantic relationship between the stem and word-whole unit (e.g., department-DEPART). No priming effect was found when there was no identifiable suffix (e.g., demonstrate-DEMON), despite the stem overlapping in form to the same extent. Lehtonen, Monahan and Poeppel (2011) conducted a similar study employing the same materials and found consistent behavioral and MEG results in a masked-priming experiment.

In the domain of spoken word recognition, similar results were also found in a cross-modal priming study of regular derivations in pseudo-words, with significant priming effects for items with an interpretable stem + suffix combination (e.g., "*rapid + ifier*") (Meunier and Longtin, 2007). Furthermore, Whiting et al. (2013) found both pseudo-suffixed (e.g., beaker) and truly suffixed (e.g., baker) words elicited comparable neural activation in the left superior temporal cortex, as compared to items that did not contain an affix (e.g., bacon). The authors suggest that the pseudo-suffix is automatically recognised as a distinct unit, even when the item is not morphologically complex.

The lack of facilitation shown for Pseudo-Suffixes in Experiment 1 is interesting, given that the derivational suffixes are strongly associated with the nominal word class and that we found evidence for listener sensitivity to this information in Experiment 2. The contrasting results suggest that the demands of each task elicit retrieval of different elements of information: grammatical-decision requires retrieval of the "function" of morphological units on the lexical level to aid classification (e.g., the presence of the derivational suffix "-ción" modifies the class of the lexeme to become a noun), whereas lexical-decision only requires recognition of the "form" of that same unit to aid identification.

One possibility is that a derivational suffix is represented both by form and lexical function, but its syntactic function is only accessed in the presence of a valid stem morpheme. Otherwise, the suffix is identified with shallower processing that does not go beyond physical recognition of a highly frequent phoneme/character string, and the word is processed through the whole-word representation like other morphologically simplex items. This explanation is consistent with the lack of facilitation we observed for pseudo-suffixed words, as well as the high accuracy for the nominalisations on the grammatical judgment task (~86%), as the suffix was the only indicator of the complex lexeme's word class. Furthermore, in a comparison between the inflected and infinitive verbal conditions of Experiment 1, verbs that contained an inflection (and had no incongruency between the stem and final response) were easier to identify than the infinitive verbs (accuracy: $z = 2.62$, $p = .016$; RT: $z = 2.79$, $p = .015$), suggesting that the presence of a suffix-inflection may facilitate the recognition of these items.

This is a viable interpretation given the number of pseudo-complex words that would be inefficient to process compositionally. The present account can also explain the variable results across studies that compare truly complex and pseudo-complex words, as the interaction between pseudo-stem and pseudo-suffix units will depend on the task. The equivocal results obtained in some studies regarding the status of suffix morphemes may trace to tasks such as lexical decision and MMN only probing the surface properties of suffixes and not their functional syntactic representation.

6. Conclusion

The primary aim of the present study was to elucidate whether the morphological composition of a word determines the processing path employed for lexical recognition, and to shed light on the mental representation of morphologically complex words. Our findings suggest that a decomposable word like "*explosion*" is processed differently than a non-decomposable word such as "*avalanche*", and that this is due to activation of the stem within the morphologically complex item. The results therefore support a decomposition theory of word processing. Furthermore, it appears that individuals were sensitive only to the surface form of a derivational suffix and not the functional link to its word class. Taken together, the evidence suggests that morphologically complex words are stored and processed primarily through the base stem and that the functional representation of suffixes is crucially dependent upon the validity of the stem onto which it attaches.

In the auditory domain specifically, our results support a model of spoken word recognition that identifies morphemes as distinct lexical units during the unfolding of the speech stream. The present evidence is not compatible with continuous models of processing such as Cohort or Shortlist B because such models assume that lexical competitors are eliminated phoneme-by-phoneme regardless of sub-lexical structure. Instead, we consider our findings to support a model of spoken word recognition that actively predicts upcoming morphological units, and the phonemes that comprise them, during processing.

The evidence from the current experiments, together with the large number of studies conducted in the visual domain (and the few in the auditory domain), supports the hypothesis that the representations of morphological constituents are represented as distinct lexical units and are processed as such regardless of language modality. Specifically, our results suggest that the stem morpheme is represented in the mental lexicon, accessed during spoken word recognition, and serves to inform predictions of subsequent morphemes.

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Appendix 1: Noun Items

Nominalisation	English Translation	Log. Freq.	Base Freq.
Argumento	argument	1.67	4.49
Duración	duration	1.62	4.11
Creencia	belief	1.34	4.10
Ganancia	gain	1.22	3.94
Herencia	heritage	1.36	3.85
Matanza	slaughter	1.22	3.80
Donación	donation	0.98	3.69
Fijación	fixation	0.99	3.45
Curación	healing	0.94	3.43
Mudanza	move	0.77	3.26
Crianza	breeding	0.72	3.13
Alzamiento	lift	0.67	3.10
Abdicación	abdication	0.43	2.75

Pseudo-suffix	English Translation	Log. Freq.	Base Freq.
Adicción	Addiction	0.78	4.49
Comunión	Communion	0.90	4.11
Excursión	Excursion	0.63	4.10
Vocación	God call	1.21	3.94
Desventura	Misfortune	0.47	3.85
Ruptura	Rupture	1.30	3.80
Lección	Lesson	1.23	3.69
Audición	Audition	0.69	3.45
Falacia	Fallacy	0.55	3.43
Noción	Notion	1.22	3.26
Vigencia	Validity	1.06	3.13
Coalición	Coalition	1.62	3.10
Sección	Section	1.83	2.75

Event Noun	English Translation	Log. Freq.
Campaña	Campaign	2.02
Accidente	Accident	1.69
Huelga	Strike	1.52
Tormenta	Storm	1.32
Terremoto	Earthquake	1.19
Trayecto	Journey	1.18
Huracán	Hurricane	1.17
Cirugía	Surgery	1.01
Travesía	Crossing	0.91
Avalancha	Avalanche	0.71
Ciclón	Cyclone	0.53
Cataclismo	Cataclysm	0.39
Escaramuza	Skirmish	0.35

Prototypical Noun	English Translation	Log. Freq.
Organismo	Organism	1.68
Facultad	Faculty	1.69
Salario	Salary	1.28
Catálogo	Catalogue	1.21
Infierno	Hell	1.37
Clínica	Clinic	1.25
Alcaldía	Major's Office	1.04
Estatura	Height	1.00
Diagrama	Diagram	0.89
Afrenta	Insult	0.70
Ensueño	Dream	0.76
Locomotora	Locomotive	0.61
Pasatiempo	Hobbie	0.45
Comisaria	Presinct	1.63
Medicina	Medicine	1.67
Experto	Expert	1.23
Dictador	Dictator	1.24
Mediodía	Noon	1.29
Pantano	Swamp	1.13
Goleador	Scorer	1.02
Elefante	Elephant	0.91
Desayuno	Breakfast	0.90
Corbata	Tie	0.79
Mancebo	Assistant	0.72
Caricatura	Caricuture	0.65
Portezuela	Door	0.40

Appendix 2: Verb Items

Decomposable Verb	ENG.	Base Freq.	Decomposable Verb	ENG.	Base Freq.
acud[irían	to come	4.43	Cesa[remos	to stop	4.10
roga[bais	to pray	4.09	Medi[rías	to measure	4.23
reg[iría	to govern	3.99	Ama[bais	to love	4.43
suma[rías	to add	4.19	Obra[steis	to do	3.75
así[amos	to grasp	3.80	Fia[rían	be reliable	4.03
besa[réis	to kiss	3.82	Guia[bais	to lead	3.75
borra[rían	to delete	3.70	Bati[rías	to sweep	3.74
chupa[steis	to suck	3.42	Odia[rías	to hate	3.70
nada[réis	to swim	3.60	Roza[bais	to touch	3.54
mece[rías	to rock	3.13	Urdi[rían	to weave	2.87
liga[bais	to bind	3.16	Tose[réis	to cough	2.93
reñi[ríamos	to scold	3.09	Serra[ríamos	to saw	3.04
incuba[rían	to incubate	2.75	Delira[rían	talk nonsense	2.71
Llena[rías	to fill	4.17	Dura[rían	to last	4.23
Viaja[ban	to travel	4.47	Agita[mos	to shake	3.74
Situa[rían	to put	4.41	Juzga[rías	to judge	4.33

Temí[amos	to fear	4.37	Calla[rían	to shut up	3.87
Acentua[ron	to emphasise	3.51	Reanuda[mos	to resume	3.82
Rei[rán	to laugh	4.34	Hiri[eron	to hurt	3.83
Osa[rías	to venture	3.34	Rae[ríais	scrape off	3.14
Ole[rían	to smell	3.57	Ara[rías	to plow	3.66
Jura[ste	to swear to	3.72	Honra[ste	to honor	3.50
Loa[rías	to praise	2.99	Hui[rías	to run away	4.33
Apea[bais	to take down	3.04	Rugi[réis	to roar	3.13
Cifra[bais	to code	3.12	Aloja[rías	to host	3.47
Asa[réis	to roast	3.12	Pia[rías	to chatter	2.90

Infinitive Verb	**Eng.**	**Freq.**	**Infinitive Verb**	**Eng.**	**Freq.**
aparecen	appear	1.70	mejorar	improve	1.92
continuar	continue	1.71	reconocer	recognise	1.70
dirige	lead	1.55	merece	deserve	1.49
construyó	construct	1.37	preocupa	worry	1.37
advierte	warn	1.21	mantenía	maintain	1.21
sostener	support	1.18	imaginar	imagine	1.23
cortar	cut	1.18	refiero	refer	1.22
acabaron	end	0.98	recupero	recouperate	1.02
difundir	broadcast	0.94	expulsar	eject	0.85
convivir	coexist	0.68	presumir	show off	0.62
aludir	mention	0.49	jugarán	play	0.51
amontonaba	pile up	0.35	recomponer	repair	0.39
desactivar	deactivate	0.40	subestimar	underestimate	0.38
cumplir	carry out	1.86	esperar	wait	1.84
establece	establish	1.74	responder	respond	1.68
llevaron	wear	1.48	sucedió	happen	1.53
discutir	discuss	1.28	subrayar	emphasise	1.30
componen	compose	1.22	competir	compete	1.22
mostraba	show	1.19	distingue	distinguish	1.15
llamaban	call	1.17	suponen	suppose	1.15
conlleva	carry	1.01	valorar	appreciate	1.05
lanzando	throw	0.90	proponía	propose	0.93
derrotaron	defeat	0.66	pretendemos	pretend	0.74
flotar	float	0.45	portar	wear	0.48
compaginar	combine	0.31	sobreviene	happen	0.33
replantear	think over	0.32	tratándo	treat	0.32