Received: October 2021 / Accepted: December 2021

Published online: July 2022

Graded morphological processing in French

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Abstract

Understanding how morphologically complex words are processed is crucial to understanding the structure of the mental lexicon. Decomposition accounts of morphological processing receive the most support within the psycholinguistic literature, although some of these accounts have difficulty with words where the morphological status is unclear (e.g., *hardly*; *grocer*). These issues of murky morphology may be better accounted for by learning models of processing such as emergentist or discriminative models that derive morphological relationships from semantic and phonologically consistent regularities among words. Graded morphological priming effects have been demonstrated in English which support learning accounts of lexical processing (Gonnerman *et al.*, 2007; Quémart *et al.*, 2018). In this study, we examine semantic similarity and processing of morphologically complex words in Quebec French to determine whether graded effects can be found in other languages, and in particular in a language with a richer morphological system than English. Results reveal graded semantic similarity and graded morphological priming effects supporting an emergentist account of lexical processing.

Keywords: Lexical processing, derivational morphology, emergentism, priming.

Résumé

L'étude du traitement de mots complexes est importante pour comprendre la structure du lexique. Les modèles de décomposition sont les plus fréquents dans la littérature du traitement lexique, bien que certains de ces modèles aient des difficultés avec les mots dont le statut morphologique n'est pas clair (*directeur*; *breuvage*). Des modèles d'apprentissage tels que les modèles émergents ou discriminants sont davantage capables de rendre compte du traitement des mots ambigus car ces modèles se basent sur des régularités dans le langage. Des effets d'amorçage morphologiques dépendant de la similarité sémantique ont été mis en évidence en anglais, ce qui serait plutôt en faveur d'une explication connexionniste du traitement lexical (Gonnerman *et al.*, 2007; Quémart *et al.*, 2018). Pour déterminer si un modèle est robuste et efficace dans des langues autres que l'anglais, cette étude examine différents degrés de similarité sémantique et le traitement de mots morphologiquement complexes en français québécois. Les résultats révèlent des relations sémantiques et des effets

d'amorçage morphologiques gradués, qui situent la morphologie à l'interface de la forme et du sens décrivant les mots du lexique mental.

Mots-clefs : Traitement lexical, morphologie dérivationnelle, émergentisme, amorçage.

1. Introduction

The mental lexicon is the collection of linguistic knowledge that every human possesses; it is enigmatic to researchers who use various behavioural and neurophysiological techniques to glean information about its structure and underlying cognitive processes. Learning about the lexicon informs us about a crucial part of our humanity: our use of language. How morphologically complex words, in particular, are processed and stored in the lexicon are questions at the heart of research on the mental lexicon. Complex words are interesting because they are made up of segments that contribute to the overall meaning of the word, which raises questions about whether complex words are processed and stored as wholes or if they are broken down at any point. Several models of lexical access have been proposed and this has been a fruitful area of study since seminal work by Taft and Forster (1975), who proposed a model of word recognition in which morphologically complex words are decomposed prior to lexical access.

To explain how words are stored and processed in the lexicon several models of lexical processing have been proposed including decomposition, emergentist, and discriminative accounts among others, with decomposition accounts being the most prevalent within the psycholinguistic literature (e.g., Marslen-Wilson & Tyler, 1998). Under this type of model, semantically transparent morphologically complex words are decomposed during processing and their component morphemes are represented sublexically. Alternatively, words that cannot be decomposed are stored as whole word forms. The timing and mechanism of decomposition is up for debate, with evidence for early morpho-orthographic decomposition finding a great deal of support (e.g., Longtin, Segui, & Hallé, 2003; Morris, Grainger, & Holcomb, 2013) and later decomposition based on semantics also being supported (e.g., Feldman, O'Connor & del Prado Martin, 2009). According to decomposition models, facilitation effects arise due to the pre-activation of the target stem (e.g., *teach*) upon the presentation of the prime (e.g., *teacher*) which is decomposed to *teach* and *-er* during processing.

Alternative models can mainly be classified as learning-based (Milin, Smolka & Feldman, 2017). These learning models include emergentist or distributed connectionist models, and discrimination models. According to emergentist models, morphemes are not stored as discrete units in the lexicon; morphology arises from interlevel regularities in the processing of phonology, orthography, and semantics (e.g., Seidenberg & Gonnerman, 2000).

Morphological priming effects represent similarities in the patterns of activation of the prime and the target, which are graded in nature.

Similarly, discriminative models have eschewed the morpheme as a unit of lexical organization. The twin models, naïve discriminative learning (Baayen *et al.*, 2011) and linear discriminative learning (Baayen *et al.*, 2019) take n-grams (2- or 3-letter segments) as input and map these to semantic representations called lexomes (semantic vectors). These models are simple, two-layer learning models based on the Rescorla-Wagner equation (Rescorla, 1972). Learning takes place both by strengthening or weakening connections between n-grams and lexomes depending on their co-occurrence. According to discriminative models, morphological priming effects arise from the magnitude of association between the n-grams of the prime and the lexome of the target, thus, priming effects would again be graded depending on associations between items.

While decomposition models are the most widely used, there is an ongoing debate in the literature regarding which type of model best captures lexical processing. For that reason, it is important to investigate issues within the literature to determine which models are best able to address them. The following paragraphs present three issues that a model of lexical processing must account for.

First, there are issues about the role of semantics in lexical processing. For instance, the distinction between semantically similar and dissimilar words is not always obvious. As shown in Gonnerman *et al.* (2007) semantic similarity ratings between stems and complex words form a graded distribution; there is not a clear-cut distinction between semantically similar and semantically dissimilar items. For instance, items such as *hardly – hard* are only moderately overlapping in meaning. This raises the question of what happens to a word that is only moderately transparent? Under a dual route-model, would a word such as *hardly* be decomposed or be processed as a whole word form? Furthermore, decomposition models disagree on the time and role, if any, of semantics in decomposition during processing, whereas emergentist and discriminative models propose that morphological effects are based, at least in part, on the semantic similarity between items.

Second, there are issues surrounding how morphology is defined, specifically how morphemes and complex words are conceptualized. Decomposition models suggest that the morpheme is a universal unit represented in the mental lexicon, along with whole word forms that do not decompose. Cross-linguistically this seems unlikely as not all languages are equally morphologically rich. In a language such as Hebrew, the morpheme may very well be a logical unit of regularity by which the lexicon should be organized, but in a less morphologically rich language such as Chinese, lexical organization based on morphology makes much less sense. Even the English language is not morphologically productive enough to suggest that morphemes should be represented in the lexicon. Take for example the derivational suffix *-er*:

according to Milin *et al* (2017), in 57% of all English words containing this unit, the agentive suffix does not act as a suffix at all, meaning that the unit *-er* does not reliably act as a suffix. Furthermore, when the unit *-er* does act as a suffix, there are multiple meanings associated with it which can imply comparison, agency, instrument, causation, or patiency (Milin *et al.*, 2017). This raises the question: why would the lexicon be organized around units with such irregular semantic mappings? Learning models avoid this issue by not explicitly representing morphemes, but by describing morphological effects in terms of regularities in activation.

Third, when considering complex words, one must ask how complex words are defined. The simplest definition of a complex word is a word composed of more than one morpheme: a stem and one or more affixes. Each morpheme should contribute to the meaning of the complex word, with inflectional morphemes modifying grammatical information and derivational morphemes modifying the meaning of the stem. However, words such as *grocer* cannot easily be defined as complex or simple. In *grocer*, the segment *-er* seems to function as an agentive, similar to how it would in words such as *singer* and *baker*, however *grocer* cannot be decomposed as *groc-*, lacking meaning, cannot be stored as a stem. Such nuances in the relationships between words should be accounted for by a model of lexical processing. While a decomposition model would store *groc-* as a whole form as it cannot be decomposed, an emergentist model would likely show some relationship between the words *grocer, baker,* and *singer* due to some degree of shared meaning and form of those words (Booij, 1986; Blevins, 2012; Bybee, 1988). Similarly, in a discriminative model, the semantic vectors for *grocer, baker,* and *singer* may share some similarities.

Overall, these three issues are difficult for a decomposition model to address because no clear-cut line separating semantically transparent and opaque items, just as there is no clear line between morphologically complex and simple words.

Further complicating these issues, one must consider how a model of lexical processing can function cross-linguistically. Current research into lexical processing has certainly encompassed many languages beyond English (e.g., Frost & Grainger, 2000). Generally, these studies follow a decomposition paradigm (Longtin & Meunier, 2005); few experimental designs explicitly look for graded effects, which are key to an emergentist account (see Feldman *et al.*, 2004; Gonnerman *et al.*, 2007; Quémart *et al.*, 2018 for exceptions). Discrimination models have, however, been tested in various languages including German (Heitmeyer, Chuang, & Baayen, 2021), Dutch, and Mandarin (Chuang *et al.*, 2021).

Semantic gradations should affect morphological processing in any language to some extent. Some evidence has been found that this happens in English (Gonnerman, 2007; Feldman and Prostko, 2002), but most studies have treated semantic similarity as a binary variable: either transparent or opaque. This holds true in French, where studies on processing of derived words

(with the exception of Quémart *et al.*, 2018) have not used semantic ratings to quantify semantic similarity, but again treat it as a binary variable (e.g., Longtin, Segui, & Hallé, 2003).

Similarly, graded morphological effects have mainly been found in studies of English. In order to find graded effects, one must look for them by designing an appropriate experiment. One method to do so is to select stimuli with graded degrees of semantic similarity as measured by participant ratings (Gonnerman *et al.*, 2007) or Latent Semantic Analysis scores (Quémart *et al.*, 2018) The idea here is that graded semantic ratings will produce graded morphological priming effects when the overlap in form is kept consistent. To sum up the current state of affairs, graded effects have been found in English, but not yet in French as these experiments have not been conducted.

While English and French are both morphologically productive, French is arguably more productive, with a greater inventory of morphological units, for example 170 suffixes exist in French, whereas only 50 are of common use in English (Duncan *et al.*, 2009). Exposure to such morphological richness may lead French speakers to be more sensitive to morphological regularities than their English-speaking counterparts. This sensitivity to morphological regularity may result in French speakers showing graded priming effects as in English, or in fact greater priming for less semantically similar word pairs. Given the ubiquitous nature of morphological systematicity in French, it is possible that French speakers are sensitive to morphological regularities when the semantic relationship is not very strong, for example where a word pair like *infirmerie – infirme* may prime in French, a similar pair such as *lately – late* may not in English. In part, this discrepancy between the systematicity of morphology in the whole language system of French versus English may explain why graded effects have not been found for French to date.

To address the question of whether graded priming effects *can* be found for morphologically complex French words, we first collect semantic similarity ratings to develop appropriately graded stimuli for a priming experiment. We have chosen priming because it is the most common experimental paradigm used to answer questions about lexical processing. In a priming task, a prime stimulus is presented prior to a target stimulus. The presentation of the first stimulus activates its lexical representation, which facilitates the subsequent activation of the target stimulus, leading to faster processing. Various priming paradigms may be employed depending on the aim of the experiment, for example: repetition, masked, and cross-modal priming. Additionally, either visual or auditory stimuli may be used. In line with related experiments conducted in English (e.g., Marlsen-Wilson *et al.*, 1994) and French (e.g., Meunier and Segui, 2002) we have chosen a cross-modal presentation for this study. In this cross-modal paradigm, the prime stimulus is presented auditorily, the target visually, and the participant response is a lexical decision to the visual target. Because the prime and target are presented in different modalities, the participant must process the target more deeply to determine whether the target is a real word or not. Thus, the cross-modal paradigm avoids

modality specific superficial processing effects and so we have chosen it to address whether French morphology is processed in a graded fashion.

2. Objectives and Hypotheses

To address some of the above issues while examining how complex words are stored and processed by speakers of Quebec French, we ask four questions. First, are semantic representations graded in Quebec French. If so, it would be possible to then determine whether morphological effects are graded in Quebec French when semantic similarity varies but formal overlap stays consistent. Second, is the processing of morphologically complex words graded, as measured by a cross-modal priming paradigm? If graded effects are found which reflect the semantic similarity of items, this would provide evidence for a learning account of lexical processing. Third, what is the role of semantics in lexical processing? Under an emergentist account, we would expect semantic similarity between items to influence magnitude of priming, but for the strongest priming effects to come from the convergence of form and semantic representations. Fourth, is there evidence of morpho-orthographic segmentation? If we do find evidence that facilitation occurs in items such as *corner* – *corn*, above the level of items such as *brothel* – *broth* this would be evidence in support of a decomposition account of lexical processing as it would imply that *corner* was decomposed and the activation of the stem lead to faster processing of the target.

The current paper describes two experiments conducted to answer the questions proposed above. The first experiment, reported in Section 3, answers our first question about semantic representations using a semantic similarity task, and the second experiment, reported in Section 4, answers the second through fourth questions about lexical processing using a cross-modal priming task.

3. Semantic similarity in French

This experiment determines whether explicitly obtained semantic similarity ratings are graded, using a semantic similarity rating task. Graded semantic similarity ratings would imply that underlying lexical relationships are also graded in nature. Additionally, graded semantic similarity ratings would indicate that when semantic transparency is used as a variable, it should be treated as a continuous factor rather than binary as it often is in lexical processing research.

3.1. Participants

Twenty-four native Quebec French speaking adults from the McGill University and University of Montreal communities participated in this study. Participants had a mean age of 27.7 years and included 18 women and 6 men. Participants had varied levels of education; three had a high school diploma, eight had a college or professional degree, six had an undergraduate degree, and six had a master's degree or higher; one participant failed to report her level of education. While French was the native language of all participants, 23 of 24 participants spoke at least one other language; 23 participants also spoke English, ten spoke Spanish, two spoke Quebec Sign Language, one spoke Créole, one spoke Chinese, one spoke German, and one spoke Japanese.

3.2. Materials

Stimuli (N = 42) were designed by creating word pairs with the longer of the two items ending in a segment that commonly acts as a derivational suffix (e.g., *infirmerie*), and the shorter item being the stem of the longer item (e.g., *infirme*). These pairs were selected purposefully to range in semantic similarity, from semantically different to similar, including items that share a moderate amount of semantic overlap thus comprising a full range of similarity values. A variety of derivational suffixes were used, all of which are listed in Table 1. Word length, part of speech, and frequency were controlled so that these factors did not correlate with any particular suffix.

Suffix	Example prime	Example target
-erie	infirmerie	infirme
-ment	clément	clé
-eux	tortueux	tortue
-ure	posture	poste
-ette	toilette	toile
-age	message	messe
-ier	peuplier	peuple
-able	cartable	carte
-esse	prouesse	proue
-eur	directeur	direct
-té	lacté	lac

-iste	spécialiste	spécial
-ité	localité	local
-é	retraité	retrait
-al	central	centre

Table 1. Experimental suffixes used to create the test materials, each is shown with one example prime.

Special attention was paid to the suitability of each word pair in Quebec French which is distinct from standard French. In particular, there are no phonological shifts between complex words and their stems, which sometimes occur in Quebec French. For instance, the word pair *draperie – drap* would not be included in this experiment as /a/ is pronounced differently in either word; the /a/ in *draperie* does not occur in final open syllables in Quebec French, instead becoming /ɑ/ in *drap* through vowel backing (Walker, 1984).

In order to anchor the scale, additional items with either no semantic similarity (e.g., *barbecue-barbe*) or very high similarity (e.g., *chandelle-bougie*) were added. At the low end of the semantic similarity scale, phonologically overlapping items (N = 14) were added; these were created to match the amount of phonological overlap of the pairs with "suffix", but to share no synchronic semantic overlap (e.g., *barbecue – barbe*). Additionally, the phonologically similar items do not end in a segment that commonly functions as suffixes. At the high end of the semantic similarity scale, synonymous word pairs were added (N = 14). Synonyms were selected to have a high level of semantic similarity, but no phonological overlap (e.g., *chandelle – bougie*). The inclusion of synonyms also helps participants to focus on the meaning of the items, not the phonological overlap which is high for all other items included in this experiment.

3.3. Procedure

A semantic similarity rating task was administered to participants as part of a larger battery of tests. Each prime-target pair was rated on a scale of 1 (different) to 7 (similar). As part of the instructions, participants were presented with three practice word pairs and told to rate them based on meaning; examiners asked, "*Est-ce que ces mots ont un sens similaire? Est-ce qu'ils se ressemblent dans ce qu'ils veulent dire?*" Participants were also reminded that they were allowed to use the whole scale when rating each pair's semantic similarity. Feedback was given for the practice items to ensure that participants understood the instructions prior to beginning the task.

3.4. Results

All analyses were conducted using R version 4.0.2 (R core team, 2020). Mean similarity ratings were calculated for each pair, as shown in Table 2. The pairs with "suffix" Had a mean semantic similarity rating of 3.43 (SD = 1.22) on a scale of 1 to 7. These items ranged from very semantically similar such as *central – centre* (M = 5.71, SD = 1.23) to not very similar such as *peuplier – peuple* (M = 1.04, SD = 0.20) with some items being moderately related such as *infirmerie – infirme* (M = 3.58, SD = 1.84). Importantly, the items with moderate ratings still had fairly low standard deviations, meaning the participants were using the middle of the rating scale. The phonologically overlapping items such as *toilette – toile* were rated as not semantically similar with a mean rating of 1.08 (SD = 0.27). Synonyms such as *bicyclette – vélo* were rated as highly similar as expected, with a mean rating of 6.17 (SD = 0.99).

	Mean	SD	Minimum	Maximum
Pairs with "suffix"	3.43	1.22	1.31	5.67
Phonologically overlapping	1.08	0.27	1	2.21
Synonyms	6.17	0.99	3.79	7

Table 2. Descriptive statistics for pairs with "suffix," phonologically overlapping pairs, and synonyms

Visual inspection of mean item ratings shows that for pairs with "suffix", semantic similarity ratings are distributed along the full range of the scale as pictured in Figure 1. Thus, the graded nature of the semantic relationships of words in the pairs with "suffix" condition was visually confirmed.

Standard deviations were examined for each item to determine the reliability of each semantic similarity rating. The mean standard deviation across all items is 0.98. Only one item had a standard deviation above 2, *pommette – pomme*, this distribution of ratings was likely due to the fact that *pommette* has two meanings that may elicit different responses on this task: the first being a small apple, and the second being the apple of a cheek. Low standard deviations for item ratings indicate that each item has been assigned a fairly consistent rating by all participants. Further, this means that for each item, its mean semantic similarity score is not a result of participant scores all over the scale, but localized ratings. This is especially important when considering items with moderate semantic similarity ratings; low standard deviations indicate that true moderately semantically related word pairs exist.

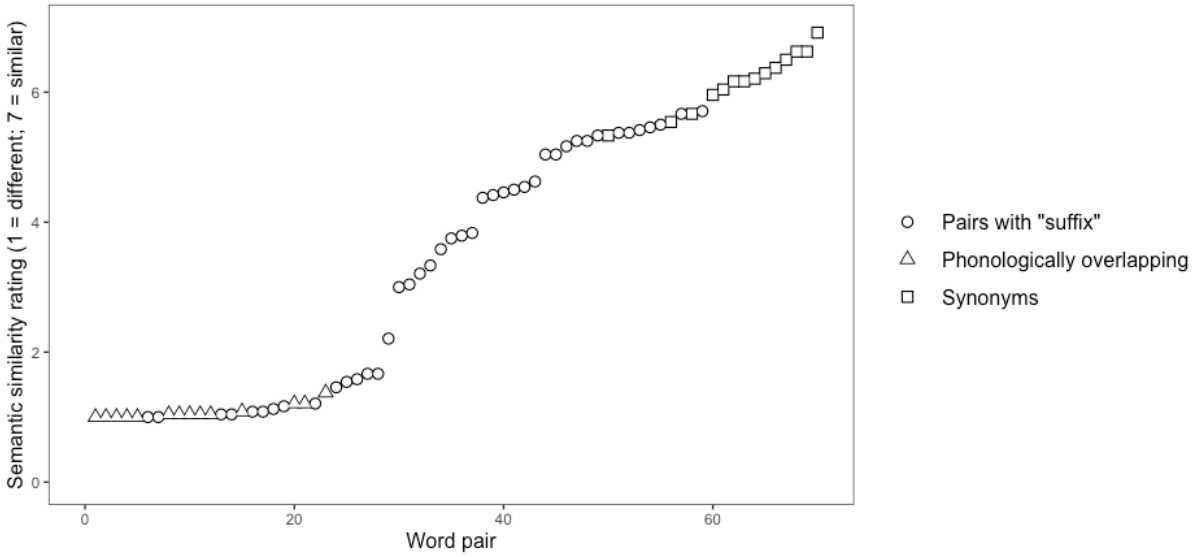

Figure 1. Mean semantic similarity ratings on scale of 1 (different) to 7 (similar) for each of 70 word pairs[1].

In order to examine the homogeneity of the group's semantic similarity judgments, each participant's set of ratings was correlated to the mean item ratings of the group. Each participant's ratings were revealed to be very consistent with the ratings of their peers, with correlations ranging from $r = 0.80$ to $r = 0.97$. These results indicate that semantic ratings tend to be similar when obtained from individuals within a language community.

The semantic similarity scores for phonologically overlapping and synonymous word pairs were examined. The phonologically overlapping items have consistently low scores, all below 2, and the synonyms have consistently high scores, all above 5 on a scale of 1 to 7.

3.5. Discussion

Overall, these results show that the semantic relationships between pairs with "suffix" are graded in nature. The accuracy and reliability of the semantic similarity ratings obtained in this study were confirmed by verifying that each item received consistent ratings by each participant and that each participant provided ratings consistent with group means. This result implies that semantic similarity should not necessarily be treated as a binary variable as it often is in studies of morphological processing (e.g., Feldman & Soltano, 1999). Additionally,

[1] Pairs with "suffix", labelled with circles, overlap in phonology and semantics, with one word containing an ending that acts as a derivational suffix, and the other item being the stem of the longer item (e.g., *infirmerie – infirme*). Phonologically overlapping word pairs share as much phonological overlap as do the pairs with "suffix," but do not contain an ending that functions as a suffix, nor should they share any semantic overlap (e.g., *barbecue – barbe*). Synonyms overlap in semantics but do not overlap in phonology at all (e.g., *chandelle – bougie*). Items are arranged with ascending mean semantic similarity scores. Visual inspection reveals that semantic similarity ratings are graded.

phonologically overlapping pairs received low semantic similarity scores, synonyms received high semantic similarity scores, as predicted.

4. Morphological priming effects in French

This experiment employs a lexical decision task with cross-modal priming to investigate lexical processing in Quebec French speakers. Stimuli were carefully designed to reflect the graded nature of the semantic relationships between word pairs as demonstrated in the previous experiment. The analyses of the data collected here aimed to answer three questions: First, are morphological priming effects graded, reflecting the graded nature of semantic similarity ratings? Second, what is the role of the semantic component in word recognition? Third, can morphological priming effects be attributed to morpho-orthographic effects, supporting a decomposition account of lexical processing?

4.1. Participants

Thirty-eight native Quebec French speaking adults from the McGill University and University of Montreal communities participated in this experiment as part of a larger battery of tests. Participants had a mean age of 30.6 years and included 26 women and 12 men. Participants had varied levels of education; six had a high school diploma, ten had a college or professional degree, 13 had an undergraduate degree, and nine had a master's degree or higher. All participants reported French as their native language; 36 of 38 also spoke at least one other language. 35 participants also spoke English, 13 spoke Spanish, 2 spoke Quebec sign language, 2 spoke German, 2 spoke Créole, 1 spoke Chinese, 1 spoke Swahili, and 1 spoke Japanese. A subset of these participants also provided the semantic similarity ratings reported in the previous section. During testing sessions, the semantic similarity task was always administered after the priming experiment to avoid influencing the priming task's sensitive response time measures by exposing the items to participants beforehand.

4.2. Materials

The same 70 word pairs which were examined in the previous experiment, *Semantic similarity in French,* were used as test items in this experiment. See preceding section for a description of item design and control.

Recall, pairs with "suffix" (N = 42) were designed such that the target item is a stem (e.g., *infirme*) and the prime is a word, composed of the same stem and an ending that commonly functions as a derivational suffix (e.g., *infirmerie*). As shown in the previous experiment, these word pairs are graded in semantic similarity with ratings comprising the full range of semantic

similarity rating values, from high (*central – centre*), to moderate (*infirmerie – infirme*), to low (*peuplier – peuple)*. Additionally, phonologically overlapping (N = 14) word pairs were included; these items are not semantically related (*e.g., barbecue – barbe*) and were accordingly rated as semantically unrelated by participants. Finally, synonyms (N = 14) were included; these pairs do not overlap phonologically and were rated as being very semantically similar (*e.g., chandelle – bougie*). For the purpose of this study, the pairs with "suffix" were divided into three groups of 14 items, called low mid and high, based on their semantic similarity ratings; this ensured that the items included represented graded semantic relationships with ratings falling across the entire scale.

For each test pair in each of the three conditions mentioned above, a control pair was created with the same target word and an unrelated prime word (e.g., *esthétique – chance* is the control word pair for the test pair *chanceux – chance*). The control primes were matched with the test primes on part of speech, word frequency, and number of syllables to minimize the effect of those factors on reaction time. Control pairs had no semantic or phonological overlap between the prime and the target. See Table 1 for sample test items and corresponding controls from each condition.

In addition to the 70 test pairs and 70 control pairs, 70 non-word target pairs were created in order to balance yes and no button presses on the lexical decision task. While these pairs contained non-words, they were created to resemble the test pairs. Some of the non-word pairs were phonologically related (*e.g., buveur – buve*), and others were not (*e.g., terminus – clige*). Some phonologically overlapping non-word pairs like *esprit - espe* mirrored those in the phonologically overlapping condition (*e.g., barbecue – barbe*); in both of these cases there is no sequence that could act as a suffix at the end of the prime. Other phonologically related non-word pairs such as *frileux – frile* are similar to the pairs with "suffix" (*e.g., tortueux – tortue);* both of these primes end with a sequence that functions as a derivational suffix. To ensure that participants did not learn to respond to all phonologically overlapping or suffix-containing pairs as members of the French language, for example, the proportion of non-word pairs that overlapped in formal similarity matched that of the real word pairs.

To limit order effects, four presentation orders were created. To do so, the real word pairs were separated into two lists; the first list contained half of the control-prime pairs and half of the test-prime pairs for a total of 70 items. The second list contained the remaining 70 real word pairs. To each of these lists, the 70 non-word pairs were added. Both of these lists were put into two pseudorandom orders, creating a total of four lists, with 140 items in each list. Each participant responded to one list, meaning each encountered each of the 70 targets only once, half of which were preceded by a test prime and half by a control prime, preventing repetition priming effects.

4.3. Procedure

A lexical decision task with cross-modal priming was conducted. This task requires participants to answer yes if the target is in fact a word that exists in the French language, or answer no if the word does not exist in French. The lexical decision task was administered to participants individually, in a quiet room. During the task, participants sat in front of a Macintosh computer, on which stimuli were presented via PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993). The audio primes were played on speakers placed in front of the participant. Responses to the lexical decision task were indicated by pressing a button on a button box placed on the table in front of the participant. The right, green button indicated yes and the left, red button indicated no.

Before beginning the experiment, participants were instructed to respond to the lexical decision task by indicating their decision on the button box as quickly and as accurately as possible. A series of practice items were presented first and the participant was given the opportunity to ask questions about the instructions before beginning experimental trials. Participants were instructed to attend closely to the auditory primes; their attention was tested periodically by presenting the on-screen instruction to "repeat what you just heard"; those responses were recorded by the experimenter.

At the beginning of each trial, a fixation mark, composed of three asterisks appeared in the center of the screen for 1 second. The auditory prime then played over the speakers. At the offset of the audio prime, the target appeared on the screen for 200 ms at which point the participant would respond using the button box. Once the response was recorded, there was a delay of 500 ms before the onset of the next trial.

4.4. Results

All analyses were conducted using R version 4.0.2 (R core team, 2020). Accuracy rates were calculated for each participant and each item. All participants were retained in the analysis, having accuracy rates greater than 90% on the lexical decision task. Four items were removed from analysis: one, *pommette – pomme*, due to high variance in semantic similarity rating as reported in the previous experiment, and three others due to high mean error rates: *caribou – carie* (mean error rate = 42%); *sondage – proue* (mean error rate = 26%); *tradition – berge* (mean accuracy = 26%).

Only trials with correct responses were analysed for response time; trials with incorrect responses making up 1.3% of the data were removed. Reaction times were then trimmed using the R package trimr version 1.0.1 (Grange, 2015). Trials on which the reaction time was greater than 2.5 standard deviations above the mean reaction time or faster than 300 ms were

discarded resulting in 2.3% of the data being removed. Reaction times were log transformed to correct for positive skew. See Table 3 for mean priming effects in each condition

Condition		Target	Primes		Priming effect (ms)
			Related	Unrelated	
Pairs with "suffix"	Low	*peuple*	*peuplier*	*silhouette*	13
	Mid	*infirme*	*infirmerie*	*grenadine*	38***
	High	*centre*	*centrale*	*nocturne*	43***
Synonyms		*bougie*	*chandelle*	*cactus*	10
Phonologically overlapping		*barbe*	*barbecue*	*cornichon*	-24*

Table 3. Mean priming effects measured in milliseconds with example items in each condition.

Linear mixed-effect modelling (Baayen, Davidson, & Bates, 2008) was used to analyze results using the R package lmerTest version 3.1-2 (Kuznetsova, Brockhoff, & Christensen, 2017). Three models were specified, the first to determine whether graded priming effects can be found in French as they are in English, the second to evaluate whether priming effects could be attributed to semantic overlap alone, in the absence of any formal overlap (e.g., *chandelle – bougie*), and the third to evaluate whether facilitation occurs due to morpho-orthographic effects in presence of a derivational morpheme, without any semantic overlap (e.g., *tortueux – tortue*).

4.4.1. Graded priming effects

To determine whether graded effects of morphological priming exist in French, a model of data from pairs with "suffix" (e.g., *chanceux – chance*; *tortueux – tortue*) was specified with log transformed response time as the dependent variable. Three fixed effects were specified: prime type (test or control), semantic similarity (mean ratings on a scale of 1 to 7), and target word frequency (log transformed), as well as the interaction between prime type and semantic similarity. Frequency measures were obtained from the Lexique database (New *et al.*, 2004) and were included in the model order to control for frequency effects when examining the effects of interest: prime type and semantic similarity. Random intercepts for participant and word pair were included. The model was fitted using backward fitting with maximum likelihood, resulting in a final model[2] that included random intercepts for participants and

[2] *Formula in R: logRT ~ test * semantic similarity + log target frequency + (1 + log target frequency | participant) + (1 | word pair)*

word pairs, as well as a random slope for log target frequency. All three fixed effects and the interaction between prime type and semantic similarity were retained, see Table 4 for estimates of fixed effects.

Fixed effects	**Estimate**	**Std. error**	**t**
Intercept	2.860	0.019	153.54***
Main effect: Prime type (test vs. control)	-0.001	0.005	-0.156
Main effect: Semantic similarity (rating scale of 1 to 7)	-0.004	0.003	-1.469
Main effect: Log target frequency	-0.024	0.008	-3.153**
Test * Semantic similarity	0.003	0.001	2.979**

Table 4. Fixed effects from the model of RTs of pairs with "suffix".

The model reveals no significant main effects of prime type (test or control) or semantic similarity for these items. The effect of interest, the interaction between prime type and semantic similarity, was significant ($F(1, 1298) = 8.87$, $p < 0.01$); see Figure 2 for partial effects of prime type and semantic similarity. This result indicates that the magnitude of priming for the pairs with "suffix" are influenced by the semantic similarity of each pair, with greater facilitation in pairs with higher semantic similarity ratings. The effect of target item frequency was also significant ($F(1, 37) = 9.94$, $p < 0.01$), with higher target frequencies corresponding to faster response times.

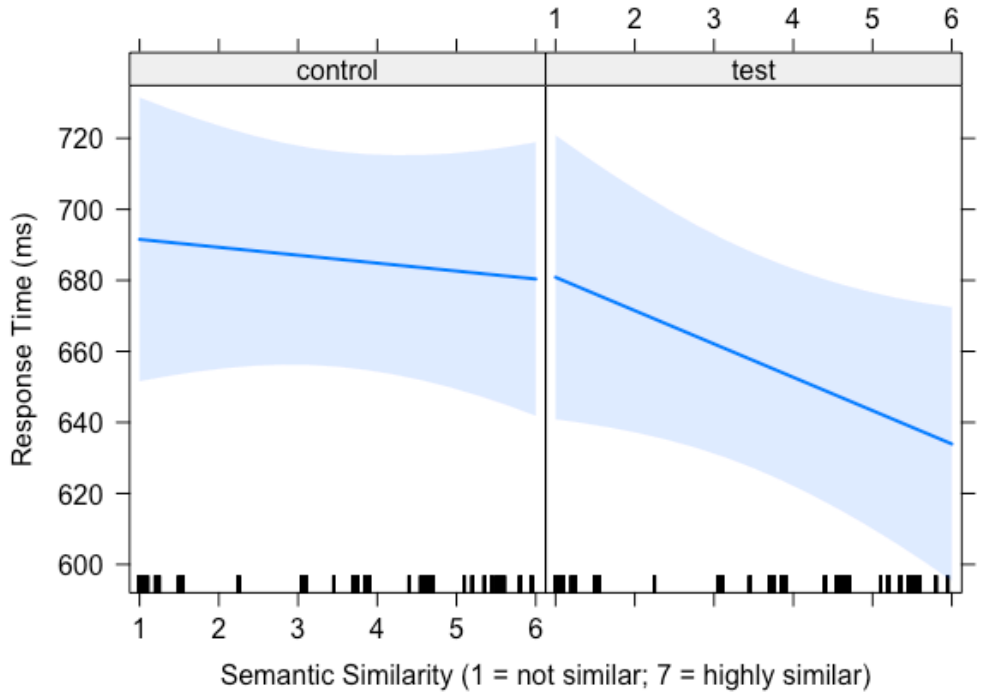

Figure 2. Partial effects of prime type (control or test) and semantic similarity for pairs with "suffix."[3]

4.4.2. Semantic effects

To evaluate whether a high degree of semantic similarity between word pairs is sufficient to elicit facilitation effects, synonyms such as *chandelle – bougie* were compared to pairs with "suffix" with high semantic overlap such as *chanceux – chance*. Word pairs in both conditions shared a high degree of semantic similarity as shown in the results of the semantic similarity ratings task, while differing such that the word pairs in the pairs with "suffix" condition also overlapped phonologically, with the longer of the two items ending in a segment that commonly acts as a derivational suffix.

Three fixed effects were specified: prime type (test or control), condition (high semantic overlap or synonyms), and target word frequency (log transformed), as well as the interaction between prime type and condition. Random intercepts for participant and word pair were included. The model was fitted using backward fitting, resulting in a final model[4] that included random intercepts for participants and word pairs, but no random slopes. The effect of target frequency was not retained as it did not improve the fit of the model. The effects of prime type and condition, and their interaction were retained in the final model as fixed effects; see Table 5 for estimates of fixed effects. No further trimming of data was conducted as residuals appeared normal upon visual inspection. The results of the model indicate that there is a significant main effect of prime type ($F(1, 945) = 18.63$, $p < 0.05$), with shorter response times for related than unrelated pairs, but no significant main effect of condition. The interaction between prime type and condition is significant ($F(1, 945) = 5.72$, $p < 0.05$), with a greater priming effect highly semantically related pairs with "suffix" (43 ms) than the synonyms (10 ms).

Fixed effects	**Estimate**	**Std. error**	**t**
Intercept	2.796	0.010	287.332***
Main effect: Prime type (test vs. control)	0.010	0.002	4.316***
Main effect: Condition (synonym vs. high semantic similarity)	0.007	0.004	1.467

[3] In the control condition, when the prime does not overlap semantically or phonologically with the target, average response times are consistent. Test items show graded response times with faster responses corresponding to higher semantic similarity ratings.

[4] *Formula in R: logRT ~ test * condition + (1 | participant) + (1 | word pair)*

Test * Condition	0.006	0.002	2.392*

Table 5. Fixed effects from the model of RTs of semantically related word pairs

4.4.3. Morpho-orthographic effects

To evaluate whether morphological priming occurs automatically upon presentation of a derivational suffix, pairs related in phonologically overlapping condition such as *barbecue – barbe* were compared with pairs with "suffix" with low semantic overlap such as *tortueux – tortue*. These two groups of word pairs have low semantic similarity ratings; refer to Table 1 for mean semantic similarity ratings. Three fixed effects were specified: prime type (related or unrelated), condition (phonologically overlapping or low semantic), and target word frequency (log transformed), as well as the interaction between prime type and condition. Random intercepts for participant and pair were included. The model was fitted using backward fitting, resulting in a final model[5] that included random intercepts for participants and pairs, but no random slopes. Only the fixed effect of log transformed target frequency was retained, see Table 6 for estimates of fixed effects.

Fixed effects	**Estimate**	**Std. error**	**t**
Intercept	2.871	0.016	184.8 ***
Main effect: Log target frequency	-0.034	0.009	-3.73**

Table 6. Fixed effects from the model of RTs of semantically dissimilar word pairs

This model reveals a significant effect of target frequency, $F(1, 25) = 13.73$, $p < 0.05$, with higher target frequency corresponding to faster response times on the lexical decision task.

4.5. Discussion

We reported results of three linear mixed effects models of the priming data. The first revealed graded priming effects for pairs with "suffix." These results reflect the graded nature of morphological representations. These findings are in line with those of Gonnerman *et al.* (2007) who reported graded morphological priming effects in English. These findings support an emergentist account of lexical processing in which morphology arises from regularities in interlevel connections between phonological, orthographic, and semantic units.

The second set of results indicates that a high degree of semantic overlap alone is not sufficient to elicit facilitation effects, rather, it is necessary for items to both share a high

[5] *Formula in R: logRT ~ log target frequency + (1 | participant) + (1 | word pair)*

degree of semantic similarity and overlap in form in order for significant facilitation to be observed in a cross-modal priming task. This finding is in line with an emergentist view of morphological processing in which facilitation effects are elicited by a convergence of formal and semantic properties.

The results in the third analysis revealed no facilitation for the items low in semantic similarity, nor a difference in priming effect between the items related in phonologically overlapping (*barbecue – barbe*) and those that included a derivational suffix (*tortueux – tortue*).

Taken together, the second and third analyses reveal that neither form nor semantics are sufficient to elicit priming effects, only the convergence of form and semantic overlap in the highly semantically related items elicited facilitation.

5. Conclusion

Taken together, the results of this study provide support for an emergentist account of morphological processing. On such an account, morphological effects arise from regularities in the patterns of activation between phonological and semantic codes. Emergentist systems predict the types of graded priming effects shown first for English in earlier studies and in this study for French, as they allow for degrees of overlap amongst complex words. These results are also in line with discriminative models which are based on similar underlying assumptions of neural processing. Finally, the results presented here for French demonstrate that graded effects can be found in languages with morphological systems that are richer than that of English.

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Appendix 1. List of stimuli

Unrelated prime	Related prime	Target	Target frequency
écureuil	abricot	abri	22.7
vampire	boulevard	boule	19.29
bijou	autruche	autre	668.48
asile	lingot	lin	1.76
lama	félin	fée	8.3
lavabo	défile	défi	10.23
mammouth	foulard	fou	181.51
cornichon	barbecue	barbe	23.4
parure	moutarde	mou	5.53
gouvernail	caribou	carie	0.38
testament	vaseline	vase	9.83
circulaire	troubadour	trou	75.32
garderie	clandestin	clan	7.61
prodigue	cordial	corde	28.89
tradition	bergerie	berge	1.79
hideux	clément	clé	68.73
esthétique	tortueux	tortue	4
endive	posture	poste	72.64
garage	toilette	toile	11.75
soulier	message	messe	16.14
bouteille	hommage	homme	781.11
silhouette	peuplier	peuple	105.65
tonnerre	cartable	carte	96.11
sondage	prouesse	proue	1.3
apostrophe	directeur	direct	14.29
fiction	lacté	lac	31.16
rondelle	morsure	morse	3.5
chocolat	escalier	escale	2.25
grenadine	infirmerie	infirme	2
paragraphe	spécialiste	spécial	48.12
végétarien	localité	local	6.05
humeur	casquette	casque	12.11
vapeur	charrette	char	8.6

crouton	nettement	net	14.31
chantage	glaçage	glace	58.09
découverte	cavité	cave	19.98
suspect	durable	dur	145.55
bouffon	largesse	large	14.25
volontiers	justement	juste	653.49
gratuite	retraite	retrait	4.63
brouette	armure	arme	114.4
blocage	ânerie	âne	12.33
camionneur	fromagerie	fromage	25.68
environ	poliment	poli	2.93
discret	chanceux	chance	334.02
fourneau	danseur	danse	46.92
fumoire	pommette	pomme	19.77
boussole	feuillage	feuille	13.24
mensuel	soucieux	souci	26.73
nocturne	central	centre	53.46
songeur	poirier	poire	5.67
couloir	journaliste	journal	72.5
viril	taxable	taxe	1.86
plumage	jeunesse	jeune	234.9
grillade	lâcheté	lâche	75.31
documentaire	égalité	égal	27.4
éponge	combat	guerre	212.82
rançon	sofa	divan	4.89
écriture	bicyclette	vélo	32.95
craintif	pesant	lourd	10.15
tiroir	pelouse	herbe	27.64
cactus	chandelle	bougie	7.4
explication	anniversaire	fête	138.03
compagnie	incendie	feu	215.87
désobéissance	rémunération	salaire	22.99
carbone	vidange	poubelle	14.85
igloo	souffrance	douleur	65.78
satisfaction	locomotive	train	244.4
redoutable	imbécile	idiot	55.73
embuscade	monarche	roi	166.34