Listeners perceive prefixes differently: Evidence from a noise-rating task[1]

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Abstract

When compared to suffixes, prefixes possess several distinctive but largely unexplained properties. This paper explores the idea that these properties might arise from a common source, namely discontinuous recognition of spoken prefixed words, in which listeners 'skip' to that portion of the speech stream which contains the root. If this occurs, listeners could potentially perceive prefixes very differently than roots and suffixes. We investigated this idea with a noise-rating task, which measures the extent to which noise subjectively interferes with speech. Using newly-coined derived English words as a stimuli, participants rated the loudness of white noise overlaid on portions of spoken words corresponding to prefixes, word-initial roots, or suffixes. Results indicate that participants gave overall higher loudness ratings to noise on prefixes compared to noise on suffixes. Furthermore, as signal-to-noise ratios decreased, participants increased their loudness ratings at greater rates for noise on roots compared to noise on prefixes. These results support the discontinuous hypothesis, and suggest that prefixed words introduce a perceptual bias which could explain the development of certain distinctive prefix characteristics over time.

1. Introduction

Although prefixes and suffixes act as morphological equivalents in many ways, prefixes have several distinctive properties which challenge any unified treatment of affix behavior. For example, prefixes are notably infrequent compared to suffixes, and their occurrence is largely restricted to languages with verb-object word order (Hawkins & Gilligan 1988). Prefixes only rarely trigger progressive phonological alternations on the following root (Hyman 2008), despite the fact that morphological boundaries are generally active sites for such changes; roots, for example, routinely trigger progressive alternations on the following suffix. Finally, the linear ordering of prefixes before roots

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disrupts the temporal alignment between word-initial and root-initial information, despite the fact that such alignment is crucial within most models of word recognition (Hawkins & Cutler 1988). These observations come from very different domains of inquiry, such as typology, theoretical phonology, and cognitive psychology, yet a complete understanding of prefixes – which would derive their distinctive properties from a common source (see Hall 1992) – is still lacking.

One way to address these seemingly disparate properties is to ask a simple question. What is the listener's perceptual experience of a spoken prefix? Is it comparable to his or her experiences of other types of spoken morphemes, or is it different? For example, when listeners hear a word like *pre-pay,* do they perceive the prefix *pre-* in a significantly different manner than the initial root *pay* in *pay-ment?* And, do they perceive *pre-* in a different manner than they perceive the suffix *-ment*? In other words, we can ask if listeners perceive word-initial material differently depending upon its morphological status (prefix versus initial root), and also if listeners perceive affix material differently depending upon its linear order (prefix versus suffix).

If we could answer these questions, we could potentially explain the diverse differences between prefixes and suffixes, and show that they arise from a single set of perceptual facts. Conceivably, of course, we could pose an analogous question in the domain of production: for example, do speakers produce prefixes differently than roots or suffixes? Yet a focus on listeners and perception, which we adopt here, has proven to be a particularly fruitful approach for explaining other seemingly arbitrary patterns that nevertheless recur cross-linguistically. Ohala (1993) and Blevins (2004), among others, have argued extensively that diachronic sound changes – and the resulting synchronic phonological alternations – originate in the mind of listeners as they attempt to interpret the variability inherent in speech (for a different view, see Steriade 2001). They have shown that certain sequences of vowels and consonants encourage perceptual differences (or 'misperceptions') more than other sequences, explaining why some alternations recur while others are only rarely attested. By hypothesis, then, certain sequences of morphemes could also encourage perceptual differences more than other sequences, potentially explaining the cross-linguistic asymmetries in prefixes and suffixes.

There are two components to the question of prefix perception, which are closely related but nevertheless distinct. The first component, which has been investigated extensively by previous researchers, concerns decomposition: do listeners actually parse complex words into constituent morphemes? Parsing of some kind is a pre-requisite for asking further questions about how listeners perceive different morphemes – if no parsing occurs, then the morpheme would not be an independent unit of perception – so we must examine the evidence for it. The second component, which has received less attention, concerns morpheme-specific experiences: if and when listeners have decomposed a complex word, do they perceive its constituent morphemes all in the same way? Or, as we will hypothesize in the current study, do they perceive different types of morphemes in different ways?

This paper focuses on the second component of prefix perception, and investigates these questions with a noise-rating experiment. Participants heard complex English words in which the prefix, root, or suffix was overlaid with white noise, and assigned a rating indicating how loud the noise sounded to them. The data that we analyze thus represent subjective judgments on the part of listeners, indicating the extent to which the noise interfered with their perception of a particular morpheme, and we will use this data to address the question of whether listeners experience spoken prefix material differently than spoken root and suffix material. Before investigating this question in more detail, however, we must first examine the evidence for decomposition, as well as previous work on the recognition of prefixed words.

1.1 Decomposition: Empirical evidence and models of word recognition

Extensive evidence supports the idea that listeners and/or readers can and do decompose derived complex words into constituent morphemes.[2] The vast bulk of this evidence comes from priming studies. The key finding, reported for many languages and for many different types of morphemes, is that exposure to one word (e.g., *prepay*) facilitates subsequent lexical decision to a morphologically related word (*payment*) (see the seminal study by Marslen-Wilson, Tyler, Waksler, & Older 1994, as well as the many citations in Diependaele, Grainger, & Sandra 2012: 321). Presumably, such facilitation can only occur if exposure to a complex word somehow activates the lexical entries associated with its constituent morphemes (such as *pay*). Although the details of this activation remain a matter of debate, its occurrence implies decomposition of some kind.

On the basis of this evidence, almost all models of complex word recognition include a mechanism for decomposition (an exception is the full-listing hypothesis of Butterworth 1983, which nevertheless does assume decomposition in the case of novel forms), as well as a mechanism for processing full word forms. That is, all models include a mechanism for parsing *prepay* into the prefix *pre-* and the root *pay*, as well as a mechanism for processing *prepay* as an unbroken whole. Across models, however, the interaction between these mechanisms differs (for review, see Diependaele et al. 2012). In morpheme-first models, decomposition occurs first: after listeners have identified lexical entries for individual morphemes (and only then), they access representations for the full form (prefix-stripping model of Taft & Forster 1975; Taft, Hambly, & Kinoshita 1986; Taft & Ardasinski 2006). In dual-route models, decomposition and full form processing begin simultaneously and race against one another; the idea is that decomposition offers a better route for recognition of novel or less frequent derived words, while full form processing offers a better route for known derived words (Augmented Addressed Morphology model of Caramazza, Laudanna, & Romani 1988; see also the hybrid model of Diependale, Sandra, & Grainger 2009). Some dual-route models, however, claim that decomposition can also occur with known derived words, depending upon variables such as relative frequency of the base versus derived form (Morphological Race model of Schreuder & Baayen 1995), and more recent proposals argue that decomposition and full form processing crucially interact with one another for most or even all words (Kuperman, Schreuder, Bertram, & Baayen 2009). Finally, in full-form models, processing of the full word form occurs first: after listeners recognize a whole word (and only then), they can access decomposed morphemes through sound and meaning correspondences with related whole words (supralexical model of Giraudo & Grainger 2000; Grainger, Colé & Segui 1991).

In sum, most models agree that listeners parse at least some complex words into constituent morphemes. The issue of *when* listeners decompose – before, during, or after full-form processing – obviously differs quite a bit from model to model, and we do not engage in this debate here. But the issue of *what* listeners decompose – some, all, or no words – has some common ground among the models, and is also directly relevant to our research question.

If only some words get decomposed, then we can only inquire about prefix-specific perception for those words. Most of the models cited above agree that highly frequent derived words are probably very poor candidates for decomposition. For example, existing words like *illegible* and *government* are quite frequent, and also more frequent than their bases, making it more efficient to access them as full forms. On the other hand, the models also agree that novel derived words are probably excellent candidates for decomposition. For example, coinages like *mid-quad* and *moat-ward* lack a full-form lexical entry, so the only route to recognition is via individual morphemes. Furthermore, previous research has demonstrated that novel derived words prime their roots just as effectively as existing derived words (Longtin & Meunier 2005). Because decomposition is a crucial prerequisite for an investigation into morpheme-specific perception, and because the morphological priming evidence appears to be robust for coinages like *mid-quad* and *moat-ward*, the current study uses only such novel derived words, while remaining agnostic about whether existing derived words also undergo decomposition.

Given that listeners can form, through decomposition, perceptual representations for individual prefixes, roots, and suffixes in at least some types of words, we can ask how these representations differ. In other words, we can ask whether listeners perceive prefixes differently than they perceive initial roots (common word position, different morphological status) and/or differently than they perceive suffixes (different word position, common morphological status). One way to approach the question is in terms of linearity, and its role in the process of complex word recognition. Broadly speaking, 'recognition' occurs when listeners successfully map the acoustic signal onto a lexical entry. Complex words have multiple lexical entries, and therefore the mapping process could this could conceivably occur in one of two ways. Listeners could recognize prefixed words in a continuous, left-to-right manner, mapping each constituent morpheme onto a lexical entry in linear order (first *pre-*, then *pay*). Or do they could recognize prefixed words in a discontinuous manner, temporarily skipping the prefix in order to access the root entry first (*pay*, then *pre-*).

The linearity question – that is, the question of continuous versus discontinuous recognition – is important because it raises the possibility that listeners experience spoken prefixes differently than they do other morphemes. Stating the idea somewhat crudely, listeners might actually ignore the acoustic information contained in the prefix while waiting for the acoustic information contained in the root. In other words, if listeners do not map spoken prefixes onto lexical entries in real time, as the discontinuous model suggests, then their perception of the acoustic information contained in the prefix should be decidedly different than their perception of the acoustic information contained in roots and suffixes, which they do map in real time. Many models of complex word recognition remain agnostic as to whether prefixed words are special, and the concept of decomposition – which is simply the idea that listeners exhibit sensitivity to the individual morphemes within a word – is compatible with either scenario. But the empirical evidence is decidedly mixed.

1.2 Prefixed words are special: Evidence for discontinuity

Early empirical evidence in favor of discontinuous recognition of prefixed words was introduced as part of the prefix-stripping model of Taft & Forster (1975). This model, which adheres to the 'morpheme-first' approach discussed above, proposes that readers and listeners accomplish complex word recognition by mentally removing prefixes from the word, searching the lexicon for the isolated root, and then later re-combining the prefix with the accessed root. Initially, the empirical evidence for this model came from reaction-time studies with non-words. In both visual (Taft & Forster 1975) and spoken modalities (Taft, Hambly & Kinoshita 1986), experiments showed that participants took longer to make lexicon decisions to stimuli with actual prefixes (*dejoice, dejouse*) than to stimuli with non-prefixes (*tejoice, tejouse*), supporting the concept of a prefix-stripping mechanism that requires more processing time than simple rejection of a non-complex nonce item. Furthermore, within the prefixed stimulus set, participants took longer to respond to stimuli with actual roots (*dejoice*) than those with nonsense stems (*dejouse*), supporting the idea that accessing the root's lexical entry, plus re-combination of prefix + root, requires more processing time than simple rejection of a nonsense root. More recent evidence comes from a study with real words in the visual modality. Taft & Ardasinski (2006) showed that root frequency effects (e.g., faster recognition of *unreal* compared to the equally frequent *refuel,* due to higher frequency of *real* compared to *fuel*) occur in conditions with nonsense root distractors (*recodge*), where lexical decision requires decomposition of all stimuli, but crucially persist even in conditions with real root distractors (*relodge*). In this latter condition, lexical decision would presumably be most efficient on full forms, but the persistence of root frequency effects, Taft & Ardasinski argue, shows that prefix-stripping nevertheless occurs.

Applied to the spoken modality, the results of Taft and colleagues argue for a scenario in which listeners temporarily ignore prefixes in order to access root entries first; presumably, they retroactively access the prefix entry only after root recognition. Citing Taft and colleagues, Hawkins & Cutler (1988) offer an additional rationale for listeners to prioritize roots. Roots provide information about semantic representations which, they point out, listeners construct relatively early during the overall comprehension of an utterance. Affixes, on the other hand, typically provide information that is either less important for semantic representations (in the case of derivational affixes) or provide information about syntactic representations (in the case of inflectional affixes), which listeners construct relatively late during comprehension. On this basis, Hawkins & Cutler argue that suffixation is more frequent in the world's languages because suffixed words provide temporal alignment between word-initial and root-initial material, which crucially facilitates listeners' preference for processing roots before affixes. One question they do not address, but which is relevant to the current study, is whether listeners still exhibit these preferences when listening to a word that does *not* facilitate it, namely a prefixed word. If listeners still prefer to access the root entry first, this would imply discontinuous recognition.

Combining the arguments of Taft and colleagues with those of Hawkins & Cutler (1988), we have a scenario in which listeners generally treat roots differently than affixes, whether they be prefixes or suffixes. The reason is that roots contain richer semantic content than affixes, and are more informative for word recognition. In this same scenario, though, listeners also treat prefixes differently from suffixes. The reason here is that prefixes interfere with the temporal alignment between word-initial position and root-initial material. Therefore, listeners skip prefixes and recognize them only retroactively; by contrast, listeners recognize suffixes in real time because they occur after roots.

Under such a scenario, we would predict certain perceptual facts about affixes (again, whether prefixes or suffixes) in comparison with initial roots. We would, for example, predict that noise should interfere more with perception of roots than with affixes, because the roots play a more important role in complex word recognition than affixes do. We would also predict that the left-to-right mapping of speech sounds onto lexical entries, which plays a big role in the perception of monomorphemic words and roots (see the discussion of Cohort theory, below), is largely irrelevant for affixes. For prefixes, this is because listeners do not map prefixes as they unfold in time, but retroactively. For suffixes, this is because successful root recognition already provides information about where the root ends and the suffix begins.

Also under this scenario, we would predict certain perceptual facts specifically about prefixes in comparison with suffixes. We would, for example, predict that noise should interfere more with the perception of prefixes than suffixes, again because mapping spoken prefixes to lexical entries occurs retroactively and is therefore plausibly more difficult; by contrast, the mapping of spoken suffixes to lexical entries can occur in real-time, immediately after root access, and is plausibly easier.

1.3 Prefixed words are not special: Evidence for continuity

While experiments conducted under the auspices of the prefix-stripping model support the idea of discontinuous prefix processing, other research points to a different conclusion. Experiments conducted under the auspices of Cohort theory support the notion of continuous, left-to-right mapping (Nooteboom & Van der Vlugt 1988; Grosjean 1980; and others). The key proposal behind Cohort theory, then, is that early segments drive recognition. Upon hearing a fragment processing: the claim is that listeners recognize morphemes in linear order, as they hear them. Under such a scenario, it is highly unlikely that listeners would perceive prefixes differently than roots or suffixes.

Left-to-right processing models, such as Cohort theory (Marslen-Wilson & Welsh 1978, Gaskell & Marslen-Wilson 1997), were originally developed to account for mono-morphemic words, where the experimental evidence strongly suggests that listeners prioritize segments in word-initial positions, even when segments in word-final positions provide just as much information about the word (Nooteboom 1981; Nooteboom & Van der Vlugt 1988; Grosjean 1980; and others). The key proposal behind Cohort theory, then, is that early segments drive recognition. Upon hearing a fragment of speech such as [slæn], all of the words whose initial phonemes match this fragment, such as *slant* and *slander,* get activated and form a cohort. Candidates get de-activated, and eliminated from the cohort, as soon as mis-matching information from the speech stream arrives, ultimately leading to recognition of a single word. Thus, hearing [slæn] followed by [d] eliminates *slant,* leaving only *slander*; as this example demonstrates, we can often recognize entire words based only on their initial segments.

Marslen-Wilson et al. (1994) argue that left-to-right processing is also operative in multi-morphemic words. The motivation for this argument comes from an asymmetry in their experimental findings. As noted earlier, their results showed that prefixed words prime both the root and related prefixed forms. Suffixed words, however, prime the root but INHIBIT related suffixed forms (*government* facilitates *govern,* but inhibits *governor*), a result replicated in different modalities and at different stimulus-onset asynchronies by Feldman & Larabee (2011). Interpreted in light of Cohort theory, such results seem to make sense, because suffixed words which share the same root (*government* and *governor*) crucially also share the same initial segments. Such words, therefore, enter the same cohort and compete with one another for recognition, in the same way that mono-morphemic words which share initial segments do (*slant, slander*); this explains inhibition. On the other hand, prefixed words which share the same root crucially do NOT share the same initial segments. Such words, therefore, enter different cohorts, and do not compete with one another; this explains the lack of inhibition. Overall, then, the scenario proposed by Marslen-Wilson et al. (1994) relies not only on morphological decomposition, but also on continuous, left-to-right processing for all types of words, including prefixed words.

However, studies designed to explicitly test left-to-right versus discontinuous processing models of prefixed words report mixed results. Tyler, Marslen-Wilson, Rentoul & Henney (1988) conducted gating, auditory lexical decision, and naming experiments with related pairs of English words in which the uniqueness point of the root always occurred earlier than the uniqueness point of the prefixed word (for more on the role of uniqueness point, see Wurm & Ross 2001, Bölte & Uhe 2004, Balling & Baayen 2008, 2012). For example, the uniqueness point of *lead* [lid] occurs at [d], while the uniqueness point of *mislead* [mɪslid] occurs earlier, at [i]. If listeners recognize both *lead* and *mislead* at equivalent time points (e.g., at [d]), this would suggest that they stripped off the prefix in order to first access the root *lead*. Results showed, however, that listeners recognized the prefixed words earlier than the isolated root words, suggesting that they in fact used a full-form mechanism to recognize the word as a whole.

Schriefers, Zwitserlood, & Roelofs (1991), who critique the work of Tyler et al. (1988) on methodological grounds, also set out to test the left-to-right versus discontinuous accounts, but report a completely different finding. These authors conducted gating and phoneme identification experiments in which they manipulated the location of the uniqueness point of prefixed Dutch words. For example, in *toe-staan* 'allow' the uniqueness point occurs at [a], while in *op-staan* 'to get up' it occurs at [n], which is also the uniqueness point of the root *staan* 'to stand'. Their results show that in gating, listeners needed significantly more sensory information to identify roots versus prefixed words, regardless of early versus late uniqueness point. Similarly, in phoneme monitoring, listeners responded more slowly in the bare root condition compared to the prefixed condition, again regardless of uniqueness point.

The results of Schriefers et al. (1991) support neither a discontinuous nor a left-to-right model of prefix processing. Instead, they suggest that prefixed words somehow provide a processing advantage over bare roots. Such an advantage would have nothing to do with uniqueness points, but with the fact of prefixation per se. Interestingly, even though their study did not explicitly test this question, Marslen-Wilson et al. (1994: 27) report a compatible result: '[p]refixed pairs prime each other as well as, if not better than, pairs made up of a free stem and a prefixed form'. Specifically, in their Experiment 4, prefixed words (*unfasten*) facilitated lexical decision by an average of 31 milliseconds for roots (*fasten*), but by an average of 60 milliseconds for related prefixed words (*refasten*). Some researchers have suggested that a prefixation advantage could originate from syntactic and semantic functions that prefixes often play. In English, for example, prefixation does not usually change the base's part of speech (*pay* and *prepay* are both verbs), and it produces a relatively constrained set of meaning changes (*prepay* still means 'pay') (Cutler, Hawkins, & Gilligan 1985). This might imply that prefixes provide some predictive value about the root that follows. Whatever the source, a prefixation advantage would seem to be at odds with the greater typological frequency of suffixation. In sum, the jury is still out, and the available empirical evidence does not resolve the question of how listeners recognize prefixed words.

1.4 Methodological approach: The noise-rating task for morphemes

As our literature review has indicated, a basic question about prefixed words remains unresolved: we do not know if listeners recognize them in discontinuous manner, or in a left-to-right manner (or if still other factors – not yet understood – are at play, as the study by Schriefers et al. 1991 suggests). Partly as a consequence, a basic question about prefixes themselves remains unresolved: we do not know if listeners perceive them in a manner that is different from the way they perceive roots and suffixes, or if they perceive similarly. As described earlier, previous empirical work supports the notion of decomposition – given the weight of the evidence, listeners must be sensitive to the presence of individual morphemes within some, if not all, complex words – but it does not present convincing evidence in favor of a either a left-to-right model of prefixed word recognition, or a discontinuous model. Yet such evidence, if it could be found, would have significant consequences for our understanding of spoken prefix perception, which could potentially unify the seemingly disparate properties that prefixes exhibit cross-linguistically.

In this paper, we seek such evidence by focusing not on the recognition process per se, but directly on listeners' perception of prefixes compared to roots and suffixes. Our experiment uses a noise-rating task, in which participants hear words partially overlaid with white noise and assign a rating indicating how loud the noise sounds. For example, participants heard newly-coined English derived words like *~~mid~~-quad* and *~~moat~~-ward*, where strikethrough indicates the presence of noise at various signal-to-noise ratios, and rated the loudness of the noise on a scale from 1 to 5. Noise obviously interferes with the recognition of the word, and the logic is that loudness ratings probe the extent to which listeners actually experience this interference. Previous studies have used this task to explore the effect of prior exposure. Jacoby, Allan, Collins, & Larwill (1988) presented listeners with old and new sentences against a background of white noise at varying signal-to-noise ratios, and found that listeners assigned lower ratings to noise on the sentences they had heard previously – even when they were not required to identify those sentences. Goldinger, Kleider & Shelley (1999) used the same technique with individual words and found that listeners assigned lower ratings to noise on words they had heard previously – even when they failed to correctly recognize those words as old. In both studies, then, listeners misattributed the relative ease with which they could interpret the old spoken stimuli to a difference in noise level – a perceptual illusion.

Apart from these two intriguing studies, the noise-rating task has not been extensively employed in research on word recognition, and never (to our knowledge) to the question of morpheme-specific perception. This gap warrants a detailed presentation of the logic behind our methodological approach. To begin, the noise rating task does not require participants to report or reflect on the words they have heard, making it unlikely that they will use linguistic knowledge to strategically alter their judgments (Jacoby et al. 1988). This is important for the current experiment because we are investigating a process that listeners are not consciously aware of – specifically, whether they map spoken prefixed words onto lexical entries in a left-to-right or discontinuous fashion – but in order to do so, we are obliged to use stimuli that differ in ways which listeners ARE consciously aware of (most people could probably report, or reflect upon, the fact that *mid-quad* is 'prefixed' and *moat-ward* is 'suffixed'). In this respect, the noise rating task distinguishes itself from lexical decision, which requires participants to reflect on the linguistic status of the words they have heard (word or non-word?), and from gating, which requires them to report the identity of words they have heard.

Even more importantly, the outcome variable of the noise-rating task represents a subjective judgment on the part of the participant, which distinguishes it from lexical decision or gating tasks, where the outcome variables are accuracy and reaction time. This is important, because the subjective experience underlying equally accurate or equally fast results may differ significantly (Jacoby et al. 1988). Consider a real-world example of a student who competes in two spelling bees. In the first spelling bee, the student feels intense stress; in the second, she feels calm and cool. But this subjective difference is not reflected in her spelling accuracies, which are the same for both bees. Or consider the example of an athlete who competes in two marathons. In the first marathon, the athlete feels great; in the second, he feels severe joint pain. But this subjective difference is not reflected in his finishing times, which are the same for both marathons. Of course, the equivalent accuracies and finishing times represent meaningful data, and it is useful to know that the student and the athlete perform their respective tasks in a highly consistent manner. But if our real interest lies in what they experienced during these tasks (because, for example, we are testing medications to reduce stress or pain), this data becomes less relevant.

Turning to an example closer to the question at hand, consider Marslen-Wilson et al.'s finding (1994: 27) that prefix-suffix and suffix-prefix pairs facilitate each other equally well in a cross-modal priming task. Specifically, spoken primes like *dis-trust* facilitate lexical decision for printed words like *trust-ful* by an average of 30 milliseconds, while spoken primes like *judg-ment* facilitate lexical decision for printed words like *mis-judge* by an average of 31 milliseconds. What these nearly-equal RT results do not reveal is whether listeners had different perceptual experiences of, for example, listening to the spoken primes *dis-trust* versus *judg-ment*. It is entirely possible that they did; if so, such differences either failed to exert an effect on reaction times, or exerted effects that were masked by additional differences in reaction times later on in the task, such as the time necessary to read the targets *trust-ful* versus *mis-judge*. Either way, the subjective experience of the participants as they encountered these words – a worthy topic of investigation in its own right – remains largely hidden in the RT data. A similar argument could be made for gating studies, which report accuracy data. Crucially, the noise-rating task has the potential to reveal these experiences because it specifically probes listeners for them.

In the current experiment, then, the noise-rating task provided an advantage over other methodologies because it allowed us to collect the types of judgments that were most closely related to the question at hand, namely, do listeners experience spoken prefix material differently than roots and suffixes? In using the task to pursue this question, we are extending it in two ways. First, we are extending it to a smaller linguistic unit. While Jacoby et al. (1988) used noisy sentences and Goldinger et al. (1999) used noisy words, the current study uses noisy morphemes, such as *mid-* and *moat* in the stimuli ~~*mid-*~~*quad* and ~~*moat-*~~*ward*. Extending the task in this way highlights its versatility: we can use noise to 'isolate' one morpheme while keeping the whole word intact, thus addressing a significant methodological challenge in the study of spoken complex words. As a consequence, though, the current experiment uses sequences of noisy and clear speech within the same stimulus, a departure from previous work that should be borne in mind when interpreting the results.

Second, we are extending the noise-rating task to a new predictor variable. Whereas previous work examined the effects of prior exposure (old versus new), the current experiment examines the effects of morphological status (prefix versus root or suffix). As Jacoby et al. (1988) point out, prior exposure is just one of many cognitive variables that affect our subjective perception of a stimulus. If we read the lyrics of a rock song before we listen to it, those lyrics seem clearer. If we talk with a friend at a party, their voice seems louder than that of another person who is equidistant but talking to someone else. If we ace an academic course, the professor seems like a more talented public speaker than another professor who taught a different course that we failed. In all of these instances, the true difference lies in attention or prior experience, but the subjective difference is one of increased clarity. We can characterize the current experiment, then, as a test of the hypothesis that morphological structure acts as a 'cognitive variable' that influences our subjective perception of spoken words.

It is well-established that people often make sensory judgments based on information that is not from that sensory domain. Prior exposure happens to be the most commonly investigated source of such information. Duration judgments, for example, are influenced by prior exposure in the same way that loudness judgments are: people give longer duration estimates (e.g., how long did this object remain on the screen?) to visual objects they have seen previously ('old') compared to objects they have not ('new') (Pariyadath & Eagleman 2007). However, in addition to prior exposure, many other external factors influence duration judgments, including the brightness, visibility, size, and numerosity of the presented objects (Xuan, Zhang, He & Chen 2007; Terao, Watanabe, Yagi & Nishida 2008). Although comparatively fewer studies investigate loudness, at least one additional factor has been shown to influence judgments in this domain, namely perceived vocal effort (Lehiste & Peterson 1959, Rosenblum & Fowler 1991). In principle, given the research on duration judgments, we would expect many additional factors to affect loudness judgments, and the current study investigates one of these factors.

A great deal of previous work has investigated speech in noise, focusing not on loudness judgments but primarily on intelligibility (e.g., when spoken words are overlaid with noise, can listeners correctly identify them?). In general, this work reveals differences between elements that would be equally intelligible in clear conditions. For example, in noisy conditions, differences in intelligibility have been reported for meaningful vs. non-meaningful sentences (Miller & Isard 1963), predictable versus non-predictable words (Kalikow, Stevens, & Elliott 1977, Lieberman 1963), clear versus plain speech (Payton, Uchanski, & Braida 1994), familiar versus unfamiliar talkers (Nygaard, Sommers & Pisoni 1994), and for General American versus Mid-Atlantic dialects of English (Clopper & Bradlow 2008). In speech degraded by other means, differences in intelligibility have also been reported for words versus non-words (Davis, Johnsrude, Hervais-Adelman, Taylor & McGettigan 2005). Given the usefulness of speech-in-noise stimuli for revealing such a heterogeneous set of differences that are not apparent in clear conditions, such stimuli seemed appropriate for the current study, in which we investigated another potential perceptual difference that is not apparent in clear conditions, namely the difference between prefixes as compared to roots and suffixes.

Most previous research with speech-in-noise stimuli has used word identification tasks, which measure accuracy (e.g., did the subject identify the word correctly, or not?). As outlined above, however, the subjective experiences underlying equally accurate identifications can vary significantly. Because of our interest in subjective experience, then, we used a noise-rating task, for which we believe that the logic of speech-in-noise stimuli – namely, that they reveal perceptual differences which might otherwise not be apparent – apply equally well. Just as heterogeneous factors affect the objective identification of words, so might heterogeneous factors – such as morphological constituency – affect subjective judgments for noise overlaid on words.

1.5 Predictions

We use the noise-rating task to address two questions relevant to prefix-specific perception. The first question was whether listeners would assign different ratings to noise occurring on prefixes versus roots, specifically to roots in word-initial position. In other words, does the perception of noise on word-initial segments depend crucially upon the morphological status of those segments (e.g., do the ratings for noise on *~~mid~~-quad* versus *~~moat~~-ward* differ?). In a left-to-right model, we predict no difference in ratings because the listener maps the acoustic signal onto lexical entries in a linear order without regard to morphological affiliation, so noise should interfere with mapping to the same extent across conditions. In a discontinuous model, on the other hand, we predict a difference in ratings because the listener essentially 'skips' the prefix to access the root first, so noise should interfere with prefixes versus roots in different ways. Specifically, we predict that noise overlaid on roots, which contain crucial semantic information, should interfere more, and produce higher ratings for loudness, than noise overlaid on prefixes. Furthermore, we predict that decreases in signal-to-noise ratio (i.e., increases in noise amplitude) should have a comparatively small effect on prefix noise ratings, but a comparatively larger effect on root noise ratings. This is because the greater the amplitude, the more noise interferes with the listener's ability to align speech segments with morphological boundaries in time. For prefixes, this alignment is irrelevant because listeners access the prefix retroactively; for roots, however, this alignment remains crucial because listeners access them in real time, as acoustic information becomes available.

The second question was whether listeners would assign different ratings to noise occurring on prefixes versus suffixes. In other words, does the perception of noise on affixes depend crucially upon the linear order of the affix (e.g., do the ratings for noise on *~~mid~~-quad* versus *moat-~~ward~~* differ?). Here, both models predict that ratings for prefix noise should be greater than ratings for suffix noise, albeit for different reasons. In the left-to-right model, word-initial segments play a bigger role in word recognition than medial or final segments. Noise should therefore interfere more with the perception of prefixes, which occur initially, than with the perception of suffixes, which occur finally. In the discontinuous model, listeners map acoustic information onto prefix entries retroactively, but they map acoustic information onto suffix entries in real time. Therefore, noise would most likely interfere more with the perception of prefixes than of suffixes, because retroactive lexical access is presumably more difficult than real-time access. However, the models make different predictions about the interaction of affix type with signal-to-noise ratio. In left-to-right models, decreases in signal-to-noise ratio (i.e., increases in amplitude) should have a comparatively large effect on prefix noise ratings, but a comparatively smaller effect on suffix noise ratings. Again, the greater the amplitude, the more noise interferes with the listener's ability to align speech segments with morphological boundaries in time. For prefixed words that are recognized continuously, this alignment is crucial because prefix segments occupy the word-initial positions that form the cohort of candidates for word recognition; for suffixes, however, this alignment is less important because suffix segments occupy word-final positions that play only a diminished role in cohort formation. In discontinuous models, on the other hand, decreases in signal-to-noise ratio should affect ratings for noise on prefixes and suffixes in an equivalent manner. This is because the alignment of the speech signal with morphological boundaries is not crucial for either type of affix: for prefixes, this is because listeners access them retroactively; for suffixes, this is because successful root recognition essentially creates this alignment for the following morpheme.

Thus, the two different models of complex word recognition make different predictions for how listeners perceive prefixes, and specifically for how participants should rate the loudness of noise that occurs on prefixes as compared to word-initial roots and suffixes. We can summarize these predictions as follows:

Prefixes versus Word-Initial Roots (~~*mid*~~*-quad* vs. ~~*moat*~~*-ward*)

1. Left-to-right prediction: Equivalent ratings for noise on prefixes and roots. Decreases in signal-to-noise ratio affect prefix and root perception equivalently.
2. Discontinuous prediction: Louder ratings for noise on roots than on prefixes. Decreases in signal-to-noise ratio affect root perception more adversely than prefix perception.

Prefixes versus Suffixes (~~*mid*~~*-quad* vs. *moat-*~~*ward*~~)

1. Left-to-right prediction: Louder ratings for noise on prefixes than on roots. Decreases in signal-to-noise ratio affect prefix perception more adversely than suffix perception.
2. Discontinuous prediction: Louder ratings for noise on prefixes than on roots. Decreases in signal-to-noise ratio affect prefix and suffix perception equivalently.

2. Experiment: English derivational morphology

2.1 Materials and Methods

2.1.1 Stimuli

Table 1 depicts the basic design of the stimuli, which consisted of novel words containing productive derivational prefixes or suffixes (a complete list is in the Appendix). White noise was overlaid on either the initial morpheme in the word, or the final morpheme. The noise occurred at three different signal-to-noise ratios, +24 dB, +17 dB, and +10 dB, which are identical to the ratios used in Goldinger et al. (1999) in their study of the impact of prior exposure on noise ratings.

Table 1. Stimulus design. White noise was overlaid onto either the initial or final morpheme of prefixed words and suffixed words, at three different signal-to-noise ratios.

	+24 dB S/N ratio		**+17 dB S/N ratio**		**+10 dB S/N ratio**	
	Initial	Final	Initial	Final	Initial	Final
Prefixed	*~~mid~~-quad*	*mid-~~quad~~*	*~~mid~~-quad*	*mid-~~quad~~*	*~~mid~~-quad*	*mid-~~quad~~*
Suffixed	*~~moat~~-ward*	*moat-~~ward~~*	*~~moat~~-ward*	*moat-~~ward~~*	*~~moat~~-ward*	*moat-~~ward~~*

The target words were constructed with three goals in mind: 1) to establish a controlled comparison between English derivational prefixes and suffixes, 2) to establish a controlled comparison between roots, 3) to maximize the likelihood that listeners will use a decompositional strategy, rather than whole-word access, during recognition. To the extent possible, we also attempted to control the internal phonotactics of the morphemes.

We used seventeen derivational prefixes and seventeen derivational suffixes that were matched for type parsing ratio, following Hay & Baayen (2002). This ratio indicates, for a given affix, the proportion of words derived with that affix which listeners are likely to parse into component morphemes. The prefix *re-*, for example, has a ratio of 0.68, which means that among the words derived with this affix (*redo, rework, revisit, rehabilitate,* etc.), listeners are likely to parse 68% of them into component morphemes, while accessing the remaining 32% as whole word lexical entries. The matched suffix *-ship* has a ratio of 0.62. Each prefix was matched as closely as possible with a suffix, creating balance across conditions; the mean type parsing ratio was 0.65 for prefixes (ranging from 0.43 to 0.93) and 0.65 for suffixes (ranging from 0.42 to 0.92). As calculated by Hay & Baayen (2002), the type parsing ratio incorporates information about the relative frequency of derived forms (and, by extension, information about absolute frequency of individual affixes) as well as information about the phonotactic transitions in those forms (again, by extension, information about the segmental content of individual affixes). As such, the type parsing ratio provides a relatively rich characterization of each affix's role in the lexicon of English. Matching these ratios across conditions should maximize the possibility that any difference in how listeners treat complex words arises from their prefixed or suffixed status per se, and not from extraneous differences.

Hay & Baayen (2002) provide type parsing ratios for 26 prefixes. To minimize variation in morpheme duration, we aimed to select a set of prefixes that did not vary in syllable count. Because their list included nineteen monosyllabic prefixes, but only seven multi-syllabic prefixes, we restricted ourselves to monosyllables. Of these nineteen prefixes, *em-* was eliminated because it is a phonological variant of *en-*, and *cross-* was eliminated because no suffix with a comparable ratio was available. The remaining seventeen prefixes were matched, based on the criteria above, to seventeen monosyllabic suffixes. No affix was included on the list more than once.

One hundred and two roots were selected, such that each affix could be combined with three different roots (e.g., *mid-quad, mid-keg, mid-pleat*; *moat-ward, stoop-ward,*

Table 2. Mean values (and standard deviations) of lexical statistics for stimulus words. Log frequency is the base-10 log of the overall corpus frequency from Sommers (n.d.). Familiarity ratings represent judgments from a large sample of American English speakers (Nusbaum, Pisoni, & Davis 1984). Probability of transition refers to the two-phoneme phoneme sequence straddling the prefix-root, or suffix-root boundary.

	Prefixed words	**Suffixed words**
Log frequency of root	0.361 (0.364)	0.362 (0.412)
Familiarity of root (on scale from 1 to 7)	6.614 (0.521)	6.375 (0.754)
Probability of transition	$10^{-03} \times 0.220$ ($10^{-03} \times 0.160$)	$10^{-03} \times 0.180$ ($10^{-03} \times 0.200$)

glad-ward). In order to minimize duration differences across morpheme types, all roots were monosyllabic. Roots were matched for log frequency and familiarity (Sommers n.d., Nusbaum, Pisoni & Davis 1984). For example, the roots of *mid-quad* and *moat-ward* have comparable values for these two variables. No root was included more than once. Re-using one root in both a prefix and suffix context would have ensured exact matching, but this was not semantically possible.

As outlined in the introduction, we used novel derived words in order to maximize the likelihood that listeners would use a decompositional strategy, rather than a whole-word access strategy. To further this goal, we also controlled for the relative frequency of root versus derived forms and for phonotactic transition across morpheme boundaries. Although the roots were highly familiar, they had low frequencies. Nevertheless, because the complex words were newly-coined and therefore all had a frequency of zero, each root was more frequent in isolation than in its derived form (e.g., *quad* > *midquad*, *moat* > *moatward*), increasing the likelihood that listeners will parse the word into individual morphemes rather than use a whole-word access strategy (Hay 2001, 2003). Low probability of phonotactic transitions across morpheme boundaries also facilitates decomposition (Hay & Baayen 2002), so these probabilities were kept as close to zero as possible (e.g., 0.0006 for [d-k] transition in *mid-quad,* and 0.006 for [t-w] in *moat-ward,* using data provided by Vitevitch & Luce 2004) and controlled for across prefixed and suffixed conditions. Key lexical statistics for the stimuli are summarized in Table 2.

The segmental content of the roots and affixes obviously differed: *mid-* differs from *moat,* also from *–ward*. To a certain extent, this reflects real differences in the segmental inventory of roots and affixes generally – roots come from an open class and exhibit a greater variety of segment and segment combinations, while affixes come from a closed class and exhibit a more limited inventory of segments and segment combinations. In fact, we could very well expect listeners to make use of these properties in determining the status (root or affix?) of the morpheme they are listening to at any given moment in time. In order to quantify these differences, we calculated the number of phonemes contained in each individual morpheme, as well as the sum of all the position-specific phoneme probabilities (Vitevitch & Luce 2004). These calculations are reported in Table 3.[3]

Table 3. Mean values (and standard deviations) of phoneme statistics for stimulus words. Number of phonemes represents the count within each morpheme (e.g., *mid* [mɪd] = 3). Sum of probabilities represents the sum of phoneme probabilities (for *mid*, probability of [m] in initial position = 0.057, [ɪ] in second position = 0.096, [d] in third position = 0.038, sum = 1.191).

	Prefixes	**Roots (initial position)**	**Suffixes**
Number of phonemes	2.706 (0.849)	3.737 (0.758)	2.765 (0.831)
Sum of position-specific phoneme probabilities	0.146 (0.071)	0.147 (0.058)	0.094 (0.056)

The relatively high number of phonemes in roots reflects the general richness of segmental contrast in these morphemes, as alluded to above. The relatively low probability of suffix phonemes reflects the fact that a given segment is overall less likely to occur in a later word position than in an earlier word position.

In an online survey, thirty-four American English speakers judged the nativeness of each newly-coined complex word. On average for the prefixed words, 35.1% of respondents gave a rating of 'good', 30.0% gave a rating of 'so-so', and 34.0% gave a rating of 'bad'. On average for the suffixed words, 58.4% of respondents gave a rating of 'good', 21.8% gave a rating of 'so-so', and 18.2% gave a rating of 'bad'. Although these ratings suggest that the stimuli differed in their semantic plausibility, previous research has demonstrated that newly derived words prime their roots just as strongly as existing derived words do, and furthermore that the effect is equally strong for semantically plausible and implausible primes (Longtin & Meunier 2005). On the basis of this work, we reasoned that the judged plausibility of our stimuli should not exert a significant effect on judgments of noise overlaid on complex words.

2.1.2 Simplex words

We also selected thirty-four monomorphemic, disyllabic words that contained pseudo-affixes to match each of the real affixes in the target words (*midd-le, awk-ward,* etc). These words served as controls, helping to ensure that any potential effects for ratings of noise overlaid on sequences such as [mɪd-] or [-wɑɹd] were due to their morphological status as prefixes or suffixes, and not to accidents of segmental content. A major constraint is that only a small handful of words in English meet these criteria. In many cases, only a single pseudo-affixed word was available to match a given affixed word. And in a very few cases, no word was available at all, so we substituted the closest phonological match that still met the requirements (e.g., for the pseudo-prefix *non-,* we used *monster* instead of the desired *nonster*). Because of these constraints, only one set of pseudo-affixed words could be selected (versus three different sets for the affixed words), and these words do not match the affixed words in terms of lexical statistics, such as frequency.

2.1.3 Fillers

We also constructed a list of 185 filler words. Of these, 117 were simplex words employed by Goldinger et al. (1999) in their noise-rating experiments. Their list included 120 bi-syllabic words balanced across low, medium, and high frequencies (e.g., *police*, *handle*, *nectar*); almost all were simplex, but we excluded three of them because they were complex. Of the remaining 68 fillers, 34 were complex words that listeners were likely to access as whole words rather than as decomposed forms, either because the derived form occurs more frequently than the root (*pave-ment*) or because the root undergoes significant reduction under affixation (*marri-age*). The 34 complex fillers were balanced by affix type (prefixes versus suffixes), and included 24 two-syllable words and ten four-syllable words. None of the target prefixes or suffixes were used. The remaining 34 fillers were simplex words with pseudo-affixes that matched those used in the complex fillers, such as *comment* and *cabbage*.

2.2 Stimulus preparation

A linguistically-trained speaker of American English, who was not aware of the purpose of the experiment, recorded each word in a sound-proof booth. With the Praat program (Boersma & Weenink 2012), we used waveforms and spectrograms to segment each recorded word into root and affix portions. With the Akustyk program (Plichta 2012), we calculated the average intensity of each root and the affix separately. Based on these calculations, we added white noise to either the root or the affix at one of three signal-to-noise ratios: +24, +17, and +10 dB. Thus, for each word such as *mid-quad*, nine stimuli were created: three with noise on the root, three with noise on the affix, and three with noise on the whole word (e.g., *mid-~~quad~~*, *~~mid~~-quad,* and *~~mid-quad~~* at 24, +17, and +10 dB S/N ratios). For simplex controls, we added white noise to the pseudo-root, the pseudo-affix, or the whole word (*midd~~le~~*, *~~midd~~le,* *~~middle~~*). For fillers, we added white noise to the first half (as defined by duration measurement), the second half, or the whole word.

2.3 Design

Three lists of thirty-four target complex words were constructed: Lists One, Two, and Three. Each list contained seventeen matched pairs of prefixed and suffixed words, and the roots differed across the lists.

Participants were randomly assigned to one of three groups, each of whom heard 219 words at test, presented in three blocks: a) 34 target complex words (*mid-quad, moat-ward*), b) 34 target simplex words with pseudo-affixes (*middle, awkward*), and c) 117 filler words from Goldinger et al.'s (1999) experiment (*police, handle, nectar*). The other 68 filler words were interspersed at regular intervals throughout these three blocks. Group One (n = 34) listened to test blocks in the order a, b, c and listened to List One of complex words; Group Two (n = 33) listened in the order a, c, b and listened to List Two of complex words; while Group Three (n = 34) listened in the order b, c, a and listened to List Three of complex words.

A study phase preceded the test phase, because previous research had indicated that prior exposure to a spoken sentence or word could affect the loudness ratings that listeners assign (Jacoby et al. 1988, Goldinger et al. 1999). At study, participants heard half of the 219 words, presented in the clear. The study words were randomly selected for each participant, and balanced among complex targets, simplex targets, Goldinger fillers, and plain fillers, which were blocked in the same order as occurred later at test. For each word, participants saw two buttons on the screen (e.g., *moat-ward* and a foil such as *basis*), and they identified the word they heard by clicking on the appropriate button.

At test, participants heard a single repetition of all 219 words, again spoken over headphones and by the same speaker. They were instructed to attend carefully to each word, because the experimenter would ask about the words later. Each word was partly or fully overlaid with noise. After a 500 ms delay from the offset of the word, participants rated the loudness of the noise by clicking on a value ranging from 1 (softest) to 5 (loudest). The order of words within each block was randomized for each participant. The placement of noise on a given word's root, affix, or entirety was counter-balanced across participants, as was the S/N ratio (soft = +24 dB, medium = +17 dB, loud = +10 dB).

2.4 Participants

One hundred and one adult members of the University of Wisconsin, Milwaukee community participated in the experiment, which lasted approximately 30 minutes, and received either course credit or $7 as compensation. Sixty of the participants were female, and forty-one were male. Their ages ranged from 18 to 34. All were native speakers of English and none reported any diagnosed problems with speech, language, or hearing.

3. Results

Two separate analyses were conducted. The first analysis compared ratings to noise on prefixes versus on initial roots, and the second compared ratings to noise on prefixes versus suffixes. In both cases, the outcome variable is an ordered categorical variable (i.e., a noise level rating from 1 to 5), suitable for analysis with a proportional odds logistic regression model (Agresti 2010). And in both cases, three predictor variables and their interactions were evaluated (within each set of parentheses, the first condition listed served as the reference point in the model): Morpheme type (Analysis 1: prefix versus root, Analysis 2: prefix versus suffix), Signal-to-Noise ratio (+24 dB, +17 dB, +10 dB), and Word status (old versus new).

3.1 Prefixes vs. Roots

Figure 1 and Table 4 depict the mean ratings and standard errors for noise on prefixes (~~*mid*~~-*quad*) and for noise on roots (~~*moat*~~-*ward*), across the three signal-to-noise ratios. Two patterns are evident. First, as the noise became objectively louder (i.e., as the signal-to-noise ratio decreased), loudness ratings increased for both morpheme types. This simply indicates that participants' judgments followed the actual noise levels

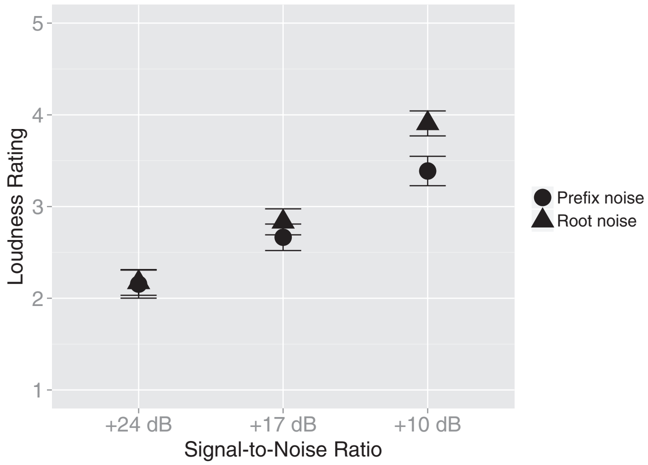

Figure 1. Mean loudness ratings (1 = softest, 5 = loudest) and standard errors for noise occurring on prefixes (~~*mid*~~-*quad*) versus noise occurring on roots (~~*moat*~~-*ward*), across three signal-to-noise ratios.

Table 4. Mean loudness ratings (1 = softest, 5 = loudest) and standard errors for noise occurring on prefixes versus noise occurring on roots, across three signal-to-noise ratios.

	+24 dB	**+17 dB**	**+10 dB**
Prefix noise (~~*mid*~~-*quad*)	2.154 (0.077)	2.665 (0.073)	3.388 (0.072)
Root noise (~~*moat*~~-*ward*)	2.173 (0.071)	2.833 (0.072)	3.907 (0.069)

present in the stimuli. Second, as the noise became objectively louder, loudness ratings increased more for root noise than for prefix noise (that is, in Figure 1, the triangles rise at a steeper slope than the circles do). This suggests that increasingly louder noise affected listeners' experience more when it occurred on roots than on prefixes.

Table 5 displays the statistical analysis, which confirms the patterns that are visually evident in Figure 1.

This analysis reveals a main effect of Signal-to-Noise ratio, which includes a change in Signal-to-Noise ratio from +24 to +17 dB as well as a change from +17 to +10 dB. Main effects of Signal-to-Noise ratio were also found in a random-intercept mixed model with subject as a random effect (change from +24 to +17 dB: $\beta = 1.288$, std. error = 0.193, z = 6.664, $p = 10^{-10} \times 0.267$; change from +17 to +10 dB: $\beta = 2.503$, std. error = 0.266, z = 9.408, $p = 10^{-15} \times 0.200$) and in a model with item as a random effect (change from +24 to +17 dB: $\beta = 1.087$, std. error = 0.286, z = 3.800 $p = 10^{-03} \times 0.144$; change from +17 to +10 dB: $\beta = 2.495$, std. error = 0.304, z = 8.210, $p = 10^{-15} \times 0.200$).

The analysis also reveals a significant interaction between Signal-to-Noise ratio and Morpheme Type. As the positive coefficient indicates ($\beta = 1.000$), ratings increased

Table 5. Results of probabilistic odds logistic regression analysis, for loudness ratings for noise occurring on prefixes (~~*mid*~~-*quad*) versus on roots (~~*moat*~~-*ward*).

Predictor	Estimate	Std. error	z value	P (>|z|)	
S/N ratio (+17 dB)	1.130	0.273	4.141	$10^{-04} \times 0.346$	*
S/N ratio (+10 dB)	2.215	0.290	7.632	$10^{-13} \times 0.230$	*
Word status (old)	−0.088	0.282	−0.314	0.753	
Morpheme type (root)	−0.212	0.279	−0.757	0.449	
S/N ratio (+17 dB):Word status (old)	−0.319	0.379	−0.841	0.400	
S/N ratio (+10 dB):Word status (old)	0.041	0.389	0.104	0.917	
S/N ratio (+17 dB):Morpheme type (root)	0.108	0.387	0.279	0.780	
S/N ratio (+10 dB):Morpheme type (root)	1.000	0.397	2.530	0.011	*
Word status:Morpheme type (root)	0.527	0.390	1.353	0.176	
S/N ratio (+17 dB):Word status:Morpheme type	0.236	0.535	0.442	0.659	
S/N ratio (+10 dB):Word status Morpheme type	−0.347	0.543	−0.639	0.523	

more for roots compared to prefixes as S/N decreased from +17 to +10 dB. This interaction was also significant in a random-intercept mixed model with subject as a random effect ($\beta = 1.103$, std. error = 0.364, z = 3.033, p = x $10^{-02} \times 0.242$) and in a model with item as a random effect ($\beta = 1.090$, std. error = 0.415, z = 2.628, p = $10^{-02} \times 0.859$).

No other effects were significant, except that the model with subject as a random effect revealed one additional significant interaction, between Word Status and Morpheme Type ($\beta = 0.808$, std. error = 0.226, z = 3.570, p = $10^{-03} \times 0.357$). However, because this interaction did not reach significance in the main model, nor in the model with item as a random effect, we do not discuss it further here.

For comparison, an analysis of the ratings given to pseudo-prefixes (~~*mid*~~*dle*) and pseudo-roots (~~*awk*~~*ward*) was also conducted. Results revealed main effects of Signal-to-Noise ratio (change from +24 to +17 dB: $\beta = 1.313$, std. error = 0.274, z = 4.794 p = $10^{-05} \times 0.164$; change from +17 to +10 dB: $\beta = 2.449$, std. error = 0.278, z = 8.802, p = $10^{-15} \times 0.200$). No other effects were significant.

3.2 Prefixes vs. Suffixes

Figure 2 and Table 6 depict the ratings for noise on prefixes (~~*mid*~~-*quad*) and for noise on suffixes (*moat*-~~*ward*~~), across the three signal-to-noise ratios. Two patterns are evident. First, as the noise became objectively louder (i.e., as the signal-to-noise ratio decreased), loudness ratings increased for both morpheme types. Again, this simply indicates that participants' judgments followed the actual noise levels present in the stimuli. Second, loudness ratings are greater for prefix noise compared to suffix noise, in a virtually equivalent manner across all three S/N ratios (that is, in Figure 2, the circles are always higher than the squares, but they rise at essentially equal slopes).

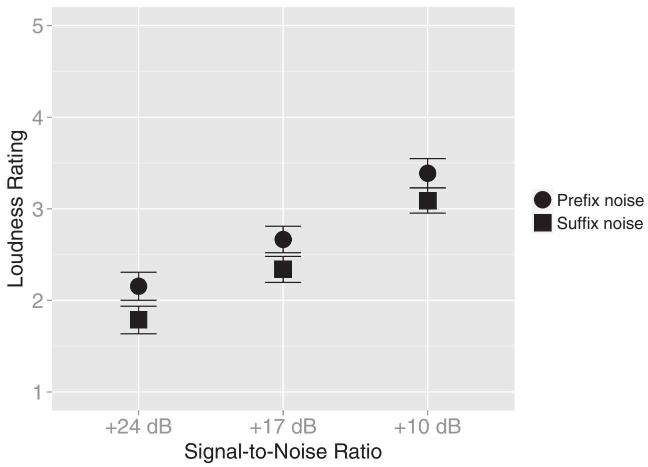

Figure 2. Mean loudness ratings (1 = softest, 5 = loudest) and standard errors for noise occurring on prefixes (*~~mid~~-quad*) versus noise occurring on suffixes (*moat-~~ward~~*).

Table 6. Mean loudness ratings (1 = softest, 5 = loudest) and standard errors for noise occurring on prefixes versus noise occurring on suffixes, across three signal-to-noise ratios.

	+24 dB	**+17 dB**	**+10 dB**
Prefix noise (*~~mid~~-quad*)	2.154 (0.077)	2.665 (0.073)	3.388 (0.072)
Suffix noise (*moat-~~ward~~*)	1.786 (0.076)	2.339 (0.072)	3.090 (0.070)

This suggests that noise affected listeners' experience more when it occurred on prefixes than on suffixes, but that the amplitude of the noise did not affect this difference.

Table 7 displays the statistical analysis, which confirms the patterns that are visually evident in Figure 2.

This analysis reveals a main effect of Signal-to-Noise ratio, which includes a change in Signal-to-Noise ratio from +24 to +17 dB as well as a change from +17 to +10 dB. Main effects of Signal-to-Noise ratio were also found in a random-intercept mixed model with subject as a random effect (change from +24 to +17 dB: $\beta = 1.316$, std. error = 0.282, $z = 4.671$, $p = 10^{-05} \times 0.300$; change from +17 to +10 dB: $\beta = 2.347$, std. error = 0.303, $z = 7.743$, $p = 10^{-14} \times 0.970$) and in a model with item as a random effect (change from +24 to +17 dB: $\beta = 1.041$, std. error = 0.283, $z = 3.680$ $p = 10^{-03} \times 0.233$; change from +17 to +10 dB: $\beta = 2.372$, std. error = 0.300, $z = 7.911$, $p = 10^{-14} \times 0.256$).

The analysis also reveals a main effect of Morpheme Type. As the negative coefficient indicates ($\beta = -1.039$), ratings decreased for noise on suffixes compared to noise on prefixes. This main effect was also significant in a random-intercept mixed model with subject as a random effect ($\beta = -1.147$, std. error = 0.297, $z = -3.864$,

Table 7. Results of probabilistic odds logistic regression analysis, for loudness ratings for noise occurring on prefixes (~~*mid*~~-*quad*) versus on suffixes (*moat*-~~*ward*~~).

Predictor	Estimate	Std. error	z value	P (> |z|)
S/N ratio (+17 dB)	1.085	0.270	4.024	$10^{-04} \times 0.571$ *
S/N ratio (+10 dB)	2.096	0.286	7.332	$10^{-12} \times 0.227$ *
Word status (old)	−0.090	0.280	−0.323	0.747
Morpheme type (suffix)	−1.039	0.280	−3.711	$10^{-03} \times 0.206$ *
S/N ratio (+17 dB):Word status (old)	−0.295	0.375	−0.785	0.432
S/N ratio (+10 dB):Word status (old)	0.054	0.385	0.140	0.889
S/N ratio (+17 dB):Morpheme type (suffix)	0.414	0.384	1.078	0.281
S/N ratio (+10 dB):Morpheme type (suffix)	0.408	0.390	1.047	0.295
Word status:Morpheme type (root)	0.278	0.402	0.693	0.488
S/N ratio (+17 dB):Word status: Morpheme type	−0.166	0.540	−0.308	0.758
S/N ratio (+10 dB):Word status Morpheme type	−0.062	0.545	−0.113	0.910

$p = 10^{-03} \times 0.112$) and in a model with item as a random effect ($\beta = -1.119$, std. error = 0.334, $z = -3.353$, $p = 10^{-03} \times 0.798$). No other effects were significant.

For comparison, an analysis of the ratings given to pseudo-prefixes (~~*mid*~~*dle*) and pseudo-suffixes (*awk*~~*ward*~~) was also conducted. Results revealed main effects of Signal-to-Noise ratio (change from +24 to +17 dB: $\beta = 1.276$, std. error = 0.272, $z = 4.700$, $p = 10^{-05} \times 0.261$; change from +17 to +10 dB: $\beta = 2.379$, std. error = 0.276, $z = 8.627$, $p = 10^{-15} \times 0.200$). No other effects were significant.

4. Discussion

4.1 Key results

The results of this experiment suggest that people have different subjective experiences when listening to a prefix versus when listening to a root, and when listening to a prefix versus when listening to a suffix. The pattern of results supports, to a large extent, the predictions of a discontinuous model of prefixed word recognition. We suggest that listeners do not experience all types of morphemes equally, and that the asymmetric perceptual experiences for prefixes, compared to roots and suffixes, could account for their asymmetric typological patterns.

A comparison of the ratings assigned to noise on prefixes (~~*mid*~~-*quad*) versus noise on roots (~~*moat*~~-*ward*) revealed that signal-to-noise ratio interacted significantly with morpheme type. Decreases in S/N ratio (that is, objectively louder noise) led to increases in subjective loudness ratings for both morpheme types, as expected under any model, but exerted a significantly greater effect on ratings for noise on roots. In other words, the loudest levels of noise apparently interfered more with root perception than with prefix perception. This result fits with the predictions of the discontinuous model, which claims that listeners recognize prefixed words by skipping ahead to the root. If that is the case, objective increases in noise loudness at the beginning of the word should not fundamentally affect listeners' attempts to correctly align information from the speech stream with stored representations of the root. Of course, in the discontinuous model, the recognition strategy differs for words in which the root is word-initial. For root-initial words, objective increases in noise loudness on the root SHOULD affect listeners' attempts to correctly align information from the speech stream with stored representations of the root. Stated succinctly, the discontinuous model predicts that listeners employ different recognition strategies for words that begin with a prefix versus those that begin with a root, and the results of the current experiment clearly support this idea. Furthermore, the failure to find this pattern for pseudo-prefix noise (*~~midd~~le*) versus pseudo-root noise (*~~awk~~ward*) in the control words suggests that it represents a genuine effect of morpheme type on word recognition.

A comparison of the ratings assigned to noise on prefixes (*~~mid~~-quad*) versus noise on suffixes (*moat-~~ward~~*) revealed a main effect of morpheme type. That is, listeners gave overall higher loudness ratings to prefix noise than to suffix noise. Either model can provide an account for the finding that prefix noise interferes more with recognition than suffix noise. Under a left-to-right model, this could occur because prefixes occupy the word-initial positions that are crucial for cohort formation, whereas suffixes occupy word-final positions that play a relatively minor role. Under a discontinuous model, such a result could occur because mapping the acoustic signal to prefix lexical entries occurs retroactively, whereas mapping the signal to suffix lexical entries occurs in real time; the retroactive requirement could lead to decreased perceptual clarity of prefixes and higher susceptibility to noise. Although the main effect of prefix versus suffix noise ratings is therefore not diagnostic for either model, note that the failure to find any difference in ratings for pseudo-prefix noise (*~~midd~~le*) versus pseudo-suffix noise (*awk~~ward~~*) in the control words undermines the predictions of the left-to-right model, which predicts that initial noise should always be more detrimental than final noise, regardless of morphological affiliation.

More tellingly, in the comparison of noise on prefixes (*~~mid~~-quad*) versus noise on suffixes (*moat-~~ward~~*), signal-to-noise ratio did not interact with morpheme type. That is, the higher loudness ratings for prefix noise compared to suffix noise remained statistically equivalent across objective increases in loudness. This is what we would expect if the task of temporal alignment is highly relevant for roots, but less relevant for either prefixes or suffixes, a scenario consistent with discontinuous models. Put another way, the predictions of the left-to-right model – namely, that increasingly louder noise should exhibit greater interference on word-initial segments (and hence prefixes) than it does on word-final segments (hence suffixes) – failed to be confirmed by our results.

Overall, then, results of the key comparisons investigated in this study – between prefixes and roots, and between prefixes and suffixes – are consistent with the predictions of a discontinuous model of prefixed word recognition. We suggest that listeners recognize prefixed words differently from isolated roots and suffixed words, and that this difference has direct consequences for listeners' subjective perceptual experience of prefixes.

4.2 Prior exposure

Recall that in addition to the test phase, the current experiment included a study phase in which participants heard half of the stimuli presented in the clear. The test phase followed the designs of previous experiments, which employed the noise-rating task as a way to investigate the effects of prior exposure (Jacoby et al. 1988, Goldinger et al. 1999). Our statistical models showed no significant difference between old and new words, a somewhat surprising result given the robust differences reported by previous researchers. A possible explanation is that words which are only partially, rather than fully, overlaid with noise do not really pose a difficult perceptual challenge for listeners, and so they do not need to rely on information stored from previous exposures in order to aid real-time processing. However, the current results largely exclude this possibility, because even in a separate analysis of the condition where complex words were fully overlaid with noise, no effect of old versus new occurred ($\beta = -0.141$, std. error $= 0.275$, $z = -0.511$, $p = 0.609$). Furthermore, a separate analysis of the filler words that were drawn directly from the work of Goldinger et al. (1999) also showed no effect, suggesting a more general failure to replicate the effects of previous exposure, which will require further work to understand.

4.3 Task limitations

The noise-rating task has several limitations worth noting. First, it is possible that participants attended only to the white noise and not to the words themselves, which would negate the effect of all of the experimental conditions except S/N ratio. We tried to avoid this scenario by giving participants explicit instructions to listen to the words, and also by making each experiment relatively short so as to avoid fatigue. The results of the current experiment, which shows significant effects of predictors besides S/N ratio, suggest that this effort succeeded. Second, it is possible that participants mistakenly rated the loudness of the speech signal, not the white noise. Again, we tried to avoid this scenario with explicit instructions and practice trials. Results show that participants gave increasingly louder ratings as S/N ratio decreased, suggesting that listeners did indeed rate the loudness of noise, not the speech. Third, intensity does not remain constant across a single word, but can fluctuate. For example, informal inspection showed that in some stimuli, intensities were somewhat lower for morphemes in word-final position. We did not normalize the intensities of individual morphemes, preferring to retain the characteristics of natural speech, but we did control for these natural fluctuations by calculating average intensity separately for each morpheme before adding noise at a particular S/N ratio. Finally, we overlaid the stimuli with white noise, which masks certain speech sounds more effectively than others (Phatak, Lovitt, & Allen 2008), and in a way that interacts with the intensity of the speech signal (Pollack 1948). If the prefixes, roots, or suffixes used as stimuli contained a disproportionate number of segments that are exceptionally poorly (or exceptionally well) masked by white noise, this could have affected the results in unintended ways.

5. Conclusion

The results of the current perceptual study offer some insight into the distinctive typological properties of prefixes, even if only speculatively at this point. As noted in the introduction, there is a puzzling cross-linguistic lack of alternations in which prefixes trigger changes on roots (Hyman 2008). The nasal assimilation process in Luganda is an example of this otherwise rare occurrence: *m-báànj-a* → *m-máànj-a* 'I demand payment', Hyman & Katamba (1999: 397). Meanwhile, alternations in which roots trigger changes on prefixes, as seen in English words like *ir-relevant, il-legible, im-possible,* are well-attested. Complicating matters, this alternation asymmetry holds for a heterogeneous set of alternations, including local assimilations, long-distance assimilations such as consonant harmony (Hansson 2001) and vowel harmony (Walker 2011), and vowel elision (Casali 1997), suggesting the need for a very general explanation.

As proposed by Ohala (1993) and others (Blevins 2004, Beddor 2009, Yu 2010, and articles in Yu 2013), one way to approach such a problem – that is, to understand why some phonological patterns occur frequently while others do not – is to analyze the conditions under which listeners are likely to misinterpret what the speaker intends to say, because these conditions can lead to phonologization over time. We suggest that prefixed words may represent one such condition. The results of the current study suggest that listeners prefer to map acoustic information onto root entries first, even when roots do not occur first in the linear order of the word. Essentially, this might mean that listeners partially ignore prefixes, at least temporarily. This renders the prefix perceptually less clear, and highly subject to interference by noise. Listeners would thus seem quite likely to misinterpret prefixes, moreso than other types of morphemes.

Ohala (1993) and others develop the logic of perceptual 'misinterpretation' and apply it to situations in which listeners must interpret context-induced variation in the speech stream. Yu (2010) uses the straightforward example of voiceless sibilants in English: when the consonant /s/ occurs in the context of the vowel [u], as in the word *sue,* speakers tend to pronounce it more like [ʃ]. Listeners must then interpret this variation between [s] and [ʃ], and there are two basic strategies for doing so. They can attend to the surface details of the consonant, attributing the variation to the consonant itself, a scenario that can potentially lead to reanalysis of /s/ as underlying /ʃ/. Or they can attend to the surface details of the vowel, attributing the variation to the vowel, a scenario that can lead to phonologization of the rule whereby /s/ alternates to [ʃ] before [u]. As Yu (2010) shows, different people exhibit different biases toward one scenario or the other.

If we extend this logic to complex words, we might say that different types of morphemes also introduce different perceptual biases toward one scenario or the other. Suppose, for example, that /s/ and /u/ straddle a prefix-root boundary,

$[...s]_{Prefix}$ – $[u...]_{Root.}$ If listeners recognize prefixed words discontinuously, as the current experiment suggests, they may be biased to ignore the surface [s]~[ʃ], which is contained within the prefix, but to attend to the surface [u], which is contained within the root. This is exactly the scenario which can lead to phonologization of the rule whereby /s/ alternates to [ʃ] before [u], and it is also an instance of the well-attested pattern in which a root triggers an alternation on a prefix. Discontinuous processing largely excludes the opposite scenario in which listeners are biased to attend to surface [s]~[ʃ], because these segments occur in the skipped prefix; if this is the case, it would mitigate against the development of alternations in which prefixes trigger alternations on roots.

Further work on English words, on words in other languages, and on other morphological domains, is certainly required in order to pursue the ideas that we have sketched here. The current study is limited to English and also to derivational prefixes; furthermore, participants heard newly-coined words, rather than existing words. As outlined earlier, the motivation for using newly-coined words was to maximize the likelihood that participants would use a decompositional strategy during processing, but the drawback is that the current results become more difficult to compare to existing results in the literature. A follow-up study would need to determine if the current results obtain for existing complex words.

To confirm the idea of discontinuous processing, it will also be crucial to investigate inflectional prefixes. While previous research suggests that decomposition occurs in equivalent ways for derived versus inflected words (Fowler, Napps & Feldman 1985, Sánchez-Casas, Igoa, & García-Albea 2003), it does not necessarily follow that prefix-specific processing also occurs in equivalent ways. Indeed, Hawkins & Cutler (1988) implicitly suggest a difference between derivation and inflection in their account of typological asymmetries in affixes. Derivational affixes contain semantic information, they point out, although less than the root does, while inflectional affixes contain primarily syntactic information. If the driving force behind a 'root-first' processing strategy is to build a semantic representation before a syntactic one, as they argue, then this suggests that, if listeners do engage in discontinuous processing for inflectional prefixes, such processing may have a somewhat different motivation – and thus different manifestations – than it does for derivational prefixes. An investigation of proclitics, which behave phonologically like prefixes but syntactically and semantically like independent constituents, could also help disentangle the motivations for discontinuous processing, and shed more light on Hawkins & Cutler's proposal.

Even with its limitations, the current study represents one step toward the goal of understanding morphological asymmetries in perception, and their consequences for typology. The noise-rating task, and the focus on subjective experience more generally, bring key advantages to the table as we investigate the processing and recognition of complex words. Accuracy and reaction times, while useful in their own right, can mask underlying differences in subjective perceptual clarity. Yet, in examining the potential origins of word patterns, it is often precisely these differences that we are most interested in.

Appendix.

Stimulus lists for target complex words

Note that the word *nullfold* occurs in all three lists because *null* is the only English root that met the criteria for the experiment.

Prefixed words			Suffixed words		
List 1	**List 2**	**List 3**	**List 1**	**List 2**	**List 3**
bewhirl	beshrub	beshrink	bleakish	punkish	rogueish
conbroil	conthieve	congroove	skunkette	grouchette	hulkette
deshroud	dewad	dewedge	drabness	sparseness	glibness
disdredge	dis-hem	dis-hoop	belchy	slouchy	beigey
unchalk	unchurn	unweed	babedom	scribedom	snobdom
enzest	enmead	enwand	slicken	meeken	starken
inmute	inmauve	inmild	oozer	snoozer	jeerer
nonlame	nonglum	nongruff	nullfold	nullfold	nullfold
forehoist	forehinge	forehitch	fudgeless	yamless	bounceless
trans-chunk	trans-mall	trans-hip	blightful	farceful	sleetful
subvent	subvault	subtab	gnomehood	elkhood	tykehood
imweb	imfake	imweird	suavize	briskize	lushize
prehem	prehose	prehoe	phlegmlike	quartzlike	swoonlike
midquad	midkeg	midpleat	gladeward	moatward	stoopward
outquack	outjoust	outquilt	gauchemost	stalemost	gravemost
selfprimp	selfcloak	selfswab	grouchproof	chokeproof	muttproof
reshred	resheathe	reweave	clownship	dameship	czarship

Stimulus list for simplex words

Pseudo-prefixed	Pseudo-suffixed
belief	polish
confide	cassette
device	witness
disturb	clergy
until	random
envy	kitchen
index	brother
monster	scaffold
fortune	atlas
transcend	waffle
subject	yahoo
impede	baptize
precinct	polite
middle	awkward
outfit	cosmos
welfare	culprit
regret	worship

Notes

1. For assistance and insights on this project, I am indebted to Christian DiCanio, Sabine Heuer, Sharon Inkelas, John Kingston, Jenny Lederer, Alan Yu, Carolyn Zafra, and three anonymous reviewers. Flaws in the paper are mine.
2. Much of the previous work on complex word recognition actually consists of reading studies with orthographic stimuli. It is not always clear when and how the conclusions of such studies apply to spoken word recognition, which is our concern in this paper. Nevertheless, because studies in both visual and auditory domains have contributed significantly to theories of complex word recognition, we review both types of studies here (for further discussion on the implications of modality, see Feldman & Larabee 2001, Allen & Badecker 2002).
3. Because neither prefixes nor initial roots are preceded by any segments, their position-specific phoneme probabilities can be calculated in isolation. However, because suffixes are by definition preceded by root segments, their probabilities must be calculated relative to a specific root. To do this, we arbitrarily chose the roots from List One (see Appendix).

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