Examining the morphological decomposition of complex words in native and non-native speakers of English

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ABSTRACT

Word knowledge is an essential component of second language acquisition. For many second language learners of English, acquiring new words can be a difficult task. Understanding the structure of words may be a valuable strategy for vocabulary development. This study examines the processing of morphologically complex English words by native and non-native speakers of English in a word typing task. The evaluation of the stimuli through word typing is also explored as a possible measure of functional ability in English in non-native speakers. A total of 270 complex affixed words were used as stimuli with true and pseudo-affixed words making up the real word-stimuli and novel-possible and novel-impossible stimuli. A total of 33 native speakers completed the lexical decision task in Experiment One that provided a validity check on the stimuli. Experiment Two had 52 native and 55 non-native speakers complete a typing task. Results indicated that complex real affixed words were typed more quickly than complex novel affixed words. Of particular interest were changes in typing speed at the morpheme boundary within a word. Native speakers displayed a greater slowing at the morpheme boundary than the non-native speakers, indicating a greater sensitivity to the internal structure of words. With respect to functional ability, the results suggest that typing sensitivity to morpheme boundaries relates to more general functional ability.

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INTRODUCTION

A large and sound knowledge of vocabulary is vital for both ESL (English as a second language) and EFL (English as a foreign language) students. Second language learners enter ESL classroom with various levels of English proficiency. One area of this proficiency that may be highly varied is vocabulary. It has generally been accepted that vocabulary size affects a student's ability to read in ESL in a second language learning setting (Schmitt, 2008; Stæhr, 2008). Many institutions of higher learning require individuals to have a basic level of English proficiency before they can attend their school. Having a high level of academic vocabulary knowledge is said to help with a student's ability to perform in school (Csomay & Prades, 2018; Huang, 2006; Nagy & Townsend, 2012). For example, students in an ESL setting depend on passing English proficiency standards to advance their education or even to obtain permanent residential status in a foreign country, which would require a significant amount of vocabulary knowledge. Students in an EFL setting face the issue of reading and studying textbooks created in English speaking countries, which were intended for native speakers and not students starting to learn the language (Huang, 2006). This undoubtedly creates an issue for those students who do not excel in reading and understanding written text.

If vocabulary levels of ESL students are important, how can one measure the levels of the students? In one study it was suggested that the number of word lemmas can be used to establish vocabulary levels (Brysbaert, Stevens, Mandera, & Keuleers, 2016). A lemma is the base form of a word that does not include any inflection, and from which multiple forms can be derived (Brysbaert et al., 2016). An example of a lemma is the word *walk*, while *walked*, *walking*, and *walker* represent derived forms that make up a word family for the word *walk*. Researchers suggest that the average number of lemmas a young adult native speaker of English knows is approximately 42000, with this number increasing as one gets older (Brysbaert et al., 2016). In another study, this time using data from the British National Corpus, found that knowledge of approximately 8000 to 9000 word families were required in order read texts such as newspapers (Nation, 2006). The number of lemmas and word families in a student's vocabulary prior to enrolling in an ESL classroom may be nowhere near these figures. Furthermore, trying to acquire this amount of word knowledge could take a very long time. As well, students learning English as a foreign language in a country where their first language is predominantly spoken may be at an even greater disadvantage. This could be due to the lack of ability to practice and have exposure to the English language outside of the classroom.

As will be discussed below, many new words learned by new learners are structurally complex in that they contain more than one meaningful unit (morphemes). This fact needs to be considered when trying to assess and understand vocabulary in both native and non-native speakers. The comparison of native and non-native speakers is important because it provides insight in how different non-native speakers may be from the fluent native speaker word production level. The following study seeks to better understand vocabulary acquisition by examining native and non-native speakers' ability to produce different kinds of structurally complex words from many different word families.

Vocabulary Acquisition in Non-Native Speakers

To develop reading and writing skills, one will require a substantial amount of vocabulary knowledge (Schmitt, 2008). In an English-for-academic-purposes (EAP) setting, students are learning the language to prepare for higher education (e.g., college/university). Here, students need to focus heavily on reading and writing. In this academic setting, much research has been conducted looking at the impact of vocabulary knowledge on student ability.

Researchers have found a significant correlation between vocabulary size and the performance of students on reading comprehension tests (Aidinlou & Vaskehmahalleh, 2017; Qian, 1999; Sen & Kuleli, 2015; Stæhr, 2008). This has led to the claim that vocabulary size plays a pivotal role in determining the success of reading ability in a student's second language (Stæhr, 2008). The amount of vocabulary a student should know for optimum reading ability has been debated. This debate has centered on the amount of text coverage that is required for successful reading comprehension (Aidinlou & Vaskehmahalleh, 2017; Nation, 2006). Text coverage means how many words a reader knows in a given piece of text, where higher percentage of coverage refers to more words known (Nation, 2006). In one study, researchers measured text coverage and reading comprehension in non-native English speakers (Hu & Nation, 2000). The researchers examined 66 high vocabulary scoring non-native speakers from an EAP course on two measures of reading comprehension, a multiple choice and written cued recall test. The researchers found that when 80% of the words in the text were known, learners' comprehension scores were low on the two measures, and when 90 to 95% of the words were known, comprehension scores increased somewhat. It was found that a minimum of 98% of the text had to be known in order for there to be a high level of reading comprehension (Hu & Nation, 2000). The 98% figure means that in a text with 100 words, only two would be unknown. Additionally, Nation's (2006) estimate of 8000-9000 word families is based around the 98% text coverage as well (Nation, 2006; Schmitt, 2008).

Another study, which examined Arabic and Greek EFL learners, found only 4000-5000 word families were needed in order to have adequate reading comprehension (Milton & Hopkins, 2006). While second language learners may be able to comprehend some text with a smaller number of word families known, the researchers suggest at minimum 8000-9000 word families would cover enough words in order to read a variety of different texts (Nation, 2006; Schmitt, 2008).

In addition to reading, there is also a link between vocabulary size and writing ability. Researchers in Malaysia found that students with a low level of vocabulary knowledge performed poorly on writing short stories (approximately 200 words long) even after completing a four week intervention (Mukundan, Mahvelati, Din, & Nimehchisalem, 2013). This link between vocabulary size and writing ability is demonstrated in Laufer and Nation's Lexical Frequency Profile, which uses student's writing samples to assess their performance on a vocabulary test (Laufer & Nation, 1995). The profile provided a measure of the number of high and low frequency words, as well as academic words that were used in student writing samples. The researchers found a correlation between the kinds of words students used in their writing samples and their vocabulary size, where larger vocabulary sizes used more low frequency and academic words compared to high frequency words. The findings of the lexical frequency profile are evident in studies that examine teachers' ratings about the quality of ESL and EFL learner writing samples (Astika, 1984; Engber, 1995; Lee, 2003; Stæhr, 2008).

Importance of Morphology

When it comes to vocabulary acquisition for ESL learners, multimorphemic words are very important. The reason for this is that the majority of words in the English language are multimorphemic, as opposed to monomorphemic (Libben, Curtiss, & Weber, 2014). An example of a monomorphemic word is the word *play*. If prefixes and suffixes are attached to the word, multiple different forms are produced (e.g., *playful, player, replay*). By possessing the morphological knowledge of word stems and the relationships with affixes, many more words can be understood**.** As the learners progress into learning EAP, attend university/college and work in the real world, they will constantly encounter new vocabulary (Libben et al., 2014). As a result of having the morphological knowledge of word decomposition as well how prefixes and suffixes change the form or meaning of the stem of a word, new vocabulary can be acquired without the need for memorization and increasing the learner's knowledge of word families. This is important because the research discussed previously suggested approximately 8000-9000 word families should be known in order to read a variety of texts (Nation, 2006). In addition to possessing morphological knowledge, it is also important to have some lexical knowledge. While morphological knowledge examines word structure, lexical knowledge addresses whether a word is a real English word (Archibald & Libben, 2018). The combination of using morphology to help break down a word and having the knowledge of real or nonwords complement each other. Knowing this information about lexical and morphological word processing, it is clear that these two processes play a critical role in reading, understanding language and expanding vocabulary.

Derivational Morphology

As discussed so far, vocabulary acquisition is important for the development of reading and writing skills. One aspect of vocabulary acquisition that tends to be overlooked in favour of word meaning is morphology or word form (Schmitt, 2008). When teaching vocabulary, the focus of the activities and lessons is often about the meaning of the word (Saigh & Schmitt, 2012; Schmitt, 2008). When morphology is disregarded, second language learners can lack the ability to develop skills related to the morphological processing of words. Here learners decompose words into smaller meaningful units known as morphemes to help them understand the meaning of words (Archibald & Libben, 2019; Carlisle, 2003; Kuperman, Bertram, & Baayen, 2008; Velan & Frost, 2011). This process of morphological word decomposition is a critical skill needed for reading, as most English words are made up of two or more morphemes (Carlisle, 2003).

Many different word types can be decomposed into morphemes, for example, roots, stems, prefixes and suffixes (Carlisle, 2003; Velan & Frost, 2011). Sometimes, however, words may not be broken down more than to a single morpheme. In this case, a word would be called a simple word. An example of a simple word is *build*, as it cannot be broken down into any further meaningful units. Simple words are also known as monomorphemic words and some examples can be as short as *dog*, *cat*, and *job* or as long as *elephant*, *alligator*, or *umbrella*. Conversely, words that can be broken into two or more morphemes are called complex words. An example of a complex word is *builder*, which contains the root morpheme *build* and the bound morpheme –*er*. This example highlights the presence of free and bound morphemes. The free morpheme *build* is able to stand alone and make sense (Archibald & Libben, 2019), while the bound morpheme –*er* needs to be attached to the end of *build* in order to make sense. Multimorphemic words can consist of compound and complex words which include prefixed and suffixed words. Some examples of multimorphemic words include *aircraft, eggshell, staircase, blueprint, unicorn, fixable* and *unlawful*. Linguists suggest there is a morphological characteristic of multimorphemic words, where these word types contain boundaries between the morphemes within the word. For example, the morphemic boundary for the word *grapefruit* occurs between the last letter of *grape* – *e* and the first letter of *fruit* – *f*. The morphemic boundary will create parts to a word, which can be decomposed and create understanding and meaning of a word.

Production of True and Pseudo Affixed Words

In the psycholinguistic literature, there has been some work done on the properties of morphologically complex words (Lewis, Solomyak, & Marantz, 2011; Rastle, Davis, & New, 2004; Rueckl & Aicher, 2008). In particular, the examination of true and pseudo-affixed words has shown up a few times. In the field of morphology, this examination came in the form of masked priming effects and what is commonly referred to the ‘corn-corner’ effect, that is asking whether the stem ‘corn’ is processed inside the whole word ‘corner’ (Archibald & Libben, 2019; Carlisle, 2003; Rastle et al., 2004; Rueckl & Aicher, 2008). This example sets the stage for examining words that share morphological structure without any semantic structure.

In one study, researchers examined masked priming effects in a lexical decision task for the stems of true and pseudo-affixed words that were semantically, morphologically and orthographically related to whole word primes (Rastle et al., 2004). The term ‘true affixed words’ was used to refer to the stems of these words being semantically and morphologically related to the whole word (e.g., worker-work). The term pseudo-affixed words were used to refer to the stems that were only pseudo-morphologically related to their whole words (e.g., brother-broth). In the third condition, the stems of the affixed words were only orthographically related the whole word and not semantically or morphologically related (e.g., brothel-broth). The researchers found that the true and pseudo-affixed word conditions had similar priming effects, but the orthographically similar stem-words did not. The researchers concluded that the decomposition of the true affixed words occurs with morphological structure of the words into stems and affixes, while decomposition based on orthographic similarity alone did not occur (Rastle et al., 2004). In a similar study, researchers examined long term priming effects of semantic transparency for the same types of stimuli as those used by Rastle and colleagues

(Rueckl & Aicher, 2008). The major difference in this study as compared to the previous one is that the researchers increased the time between the presentation of the prime and the target by two seconds and, as a result, measured the long-term priming effect. Contrary to the findings of the previous study, the researchers found that only the true affixed stem-word primes that were semantically related to each other facilitated the priming effect (Rueckl & Aicher, 2008). Neither the pseudo-affixed with the semantically unrelated nor the orthographically similar stem-word prime pairs showed significant priming effects. Another study examined the neural basis of morphological complex word decomposition (Lewis et al., 2011). The researchers conducted a visual lexical decision task using pseudo-affixed words as targets and non-words as fillers. To get a representation of the neural underpinnings of target word decomposition, the researchers recorded magnetoencephalography (MEG) throughout the experiment. The researchers found evidence for automatic decomposition of the pseudo-affixed words by the visual word form area (VWFA) early on in the process of word recognition (Lewis et al., 2011).

The three studies discussed above provide evidence of morphological decomposition for various levels of complex words early on in word processing and reading. The results of these studies provide a clear picture of words that decompose and assist in the process of word recognition as evidenced through the priming and lexical decision tasks. It is important to note that the three studies discussed above, like the majority in this psycholinguistic literature focus on the recognition/comprehension of words. Considerably less research has addressed morphological processing in production with native and non-native speakers of English as the focus (Zwitserlood, 2018). Furthermore, these studies only looked at native speakers of English, so the question remains how non-native speakers would process these kinds of words and in comparison, to native speakers.

Production of Novel-Possible and Impossible Affixed Words

The big difference between the novel and real affixed words is that the latter are valid words that exist in the English language while the former do not. The interest in these novel word types is regarding the morphological decomposition by native and non-native speakers. In the true affixed words, a clear stem and affix are defined, which should make for easy decomposition by the native speakers and should depend on skill level by the non-native speakers. The process may change when the word does not exist but looks like it does, as in the case of novel-possible words (i.e., *vibrantness*). In one study, researchers examined the morphological decomposition of complex nonwords in a lexical decision task, and found that native speakers of English had taken longer to make a lexical decision about the nonwords (ex. gasful) compared to words that were orthographically similar to the nonword (ex. gasfil) (Crepaldi, Rastle, & Davis, 2010). Although this study was conducted in a word recognition paradigm, the results show the complexity of novel words. Even though novel words were compared to other novel words with similar orthographic features, they were still responded to slowly by native speakers of English. In a similar study, researchers examined the processing of nonwords relative to the two languages of German-English bilinguals (Lemhöfer & Radach, 2009). In this study, researchers conducted a lexical decision task three times, with each version targeting nonwords in German, nonwords in English and a mix of nonwords in both languages. The researchers found the nonwords in English resulted in longer decision times, as English was the non-dominant language of the participants and similar findings when the nonword was related to the language of the particular task as well. This study provides evidence for the difficulty of nonword processing in non-native speakers of English. In these two studies, while the processing of the nonwords occurred, it remained in a visual word recognition domain. What the current study contributes to the literature is the examination of the writing-production of true, pseudo, novel-possible and novel-impossible affixed English words. This aspect goes beyond just simple word recognition through decomposition, and targets word production, which would assess real time morphological word decomposition. Additionally, it is beneficial to compare a study that uses the word recognition approach from a lexical decision task with the word production approach of the current typing task. From the examination of the literature, the combination of these two approaches has not been seen, and thus the current study would benefit from including both to help build a clearer picture of the morphological decomposition of structurally complex real and novel words.

Stem-Affix Restrictions

The expansiveness of the English vocabulary may pose a challenge to new learners of the language. Additionally, within certain word types there are restrictions to which word stems can attach to which affixes. These restrictions refer to which word classification can validly go with an affix, as suffixes can change the meaning of the word and the lexical category of the base, while prefixes only change word meaning (Libben, 1993). For example, the suffix –*er* takes a verb and creates a noun and the prefix *re-* takes a verb and creates a new verb. A word like *teacher* would be considered a true affixed word because its stem *teach* can take the –*er* suffix. In contrast, a word like *brother* would be classified as a pseudo affixed word, because it looks like there is the suffix –*er* attached to it. However, if –*er* is removed the remaining letters *broth-* cannot stand alone as a real word with the same context. Both true and pseudo affixed word types consist of real English words and thus would require lexical knowledge to help process the words. If an affix was attached to real stem words where there was a stem-affix restriction, then a new nonword would be created (i.e., not a real English word). This could lead to the creation of novel-possible words if there are no stem-affix restrictions, but the resulting word does not exist already (i.e., *vibrantness*). Or it may create novel-impossible words where there is a stem-affix restriction and results in a word that cannot morphologically exist (i.e., *agenter*). These two examples both represent nonwords, which would require morphological word knowledge to help in their decomposition. For the specific restrictions in each word condition, refer to Appendix Table C3 (Archibald & Libben, 2018). If a native or non-native speaker encounters these four types of affixed words, they will likely need both lexical and morphological knowledge to decompose the words.

Psycholinguistic Tasks

Many different techniques could be used to measure morphological processing in word recognition. Some of the common techniques used in psycholinguistics research include lexical decision, priming and typing tasks. In the lexical decision task, judgements about real or non-words are made, while response times and word judgement accuracy are used to determine any lexicality effects of the stimuli (Archibald & Libben, 2019; Brysbaert, Lagrou, & Stevens, 2017; Keuleers, Diependaele, & Brysbaert, 2010; Lehtonen & Laine, 2003). The application of this methodology is vast as it has been used in multiple languages: Finnish (Lehtonen & Laine, 2003), Dutch and French (Keuleers et al., 2010), and English (Brysbaert et al., 2017; Diependaele, Lemhöfer, & Brysbaert, 2013; Kuperman & Van Dyke, 2013). In addition to various language contexts, it can be used in studies related to morphological processing (Lehtonen & Laine, 2003), vocabulary size and word frequency (Brysbaert et al., 2017), and eye-tracking (Kuperman & Van Dyke, 2013). Similarly, the priming method has also been used psycholinguistic research. In a priming task, a prime word is presented briefly to the participant and is followed by the target word, and participants are instructed to respond based on the task requirements (Archibald & Libben, 2019). Researchers can compare the response times and accuracy of related prime – target trials to unrelated prime-target trials (Archibald & Libben, 2019; Guldenoğlu & Miller, 2012; Rastle et al., 2004; Rueckl & Aicher, 2008; Schmidtke, Kuperman, Gagné, & Spalding, 2016; Silva & Clahsen, 2008). In one priming study, researchers were able to demonstrate that non-native speakers of English were slower to respond to target words that were preceded by an unrelated prime compared to the morphologically related prime (Silva & Clahsen, 2008).

While the use of these two methodologies has been extremely valuable, their use is limited to the domain of word recognition and comprehension. In the current study, to understand how morphological processing of true, pseudo, novel-possible and novel-impossible affixed words occurs in production, a different technique needed to be employed. A fairly recent development to psycholinguistic research is the ability to use typed responses to measure morphological aspects of lexical processing (Libben et al., 2014). The use of a typing task allows the examination of the process an individual goes through as they read a word and begin to type it from start to finish. The exact letter timing, stoppages, errors/backspaces are recorded throughout the typing of a single word or a string of words, which provides data that are naturally occurring in everyday language production (Libben et al., 2014). Typing onset, letter typing, and whole word typing times, as well as typing times before and after morphemic and syllable boundaries are typical measures recorded in the typing production paradigms (Bertram, Tønnessen, Strömqvist, Hyönä, & Niemi, 2015; Libben et al., 2014).

As described earlier, morphemic boundaries are supposed pauses between each morpheme in a multimorphemic word. For example, in the word *grapefruit*, the morphemic boundary would occur between *grape* and *fruit* (Libben et al., 2014). Using letter typing times and positioning of the letters preceding and following the boundary, the boundary pause time can be measured (Libben et al., 2014). In the example of *grapefruit*, the letter '*f*' would be considered at the plus one position and the letter typing time that would be used to determine the pause time at the morphemic boundary. Various typing time measures with morphemic boundaries will be useful in the current study in examining the morphological processing of structurally complex affixed words. Previous studies examining typing latencies in compound words have yielded interesting results. One study found that typing times of English compounds was influenced by the number of morphemic boundaries as well as the semantic transparency of the constituents (parts) of the compound words (Libben et al., 2014). More specifically, the researchers found the pause at the morphemic boundary was largest when the two parts of the compound were both semantically related to the meaning of the whole word (e.g., *grapefruit*), while the smallest pause occurred for compound words whose parts were not semantically related to the meaning of the whole word (e.g., *deadline*). Another study examining the typing of Finnish compounds determined through writing onset time that the compounds were processed as whole words before they were typed (Bertram et al., 2015). Additionally, the researchers found that inter-keystroke typing times were longer when individuals encountered syllable and morphemic boundaries. One possible explanation the researchers suggested was that more resources were needed when processing these two kinds of boundaries. In terms of the target populations, these studies focused on either bilinguals/multilinguals (Libben et al., 2014) or native speakers (Bertram et al., 2015) separately. The current study will compare native and non-native English speakers to each other using structurally complex affixed stimuli.

When a word is typed, pauses at the morphemic boundary (or boundaries) signify the processing of morphological structure within the word. Pauses made at correct and incorrect boundaries within a word can also provide insight into how letters are chunked during word production (Libben et al., 2014). To understand what is happening leading up to and during a typing response, Bertram and colleagues (2015) suggest different typing measures can be used. For example, to measure the planning stages leading up to a typed response, researchers can utilize writing onset latency (WOT). To measure what is happening during typing, inter-keystroke intervals (IKIs) can be utilized to measure the time taken at each morpheme boundary. First, using WOT, these researchers determined that whole word representation of complex words (i.e., compounds) occurs during the language planning stage before word typing begins. Second, the results from the IKIs indicate that longer interval pauses occurred at morphemic boundaries within words, suggesting that additional language planning occurs during word typing. The researchers in this study followed up previous work with monomorphemic stimuli and used complex multimorphemic Finnish compounds instead (Bertram et al., 2015). The current study will utilize the measures of WOT or per letter reaction times (PLRT) and IKI to examine complex word decomposition in a typing task.

Stimulus Design

In the current study, two experiments that utilize the same set of stimuli are reported. In this section the features of each word type will be described. The detailed process in which the words were obtained and created is outlined in the Methods section below. Refer to Table 1 at the end of this section for word examples for each word type.

True Affixed words. These complex words consist of a real stem and real affix to form a real word. These words can be morphologically decomposed into two morphemes. Therefore, these words test the lexical knowledge of the native and non-native participants. A prime example is the word *teacher*. It contains the real word stem *teach* and real affix *–er*.

Pseudo Affixed words. These simple words do not consist of a real stem and real affix. These words cannot be morphologically decomposed into two morphemes. Therefore, these words test the lexical knowledge of the native and non-native participants. An example is the word *affable*, which does not contain a real word stem that can standalone because it is not a valid word, but it does contain a real bound affix –*able*.

Novel-possible Affixed words. These complex words consist of a real stem and real affix which could form a real word in the English language. These words look like they could morphologically decompose into two morphemes if they existed. Therefore, these words test the morphological knowledge of the native and non-native participants. An example is the word *scuffer*. The word does not exist in the English language but could because it contains a real stem *scuff* and a real affix –*er*.

Novel-impossible Affixed words. These complex words consist of a real stem and real affix which could not form a word due to stem-affix restrictions. These words look like they could morphologically decompose into two morphemes. Therefore, these words test the morphological knowledge of the native and non-native participants. An example is the word *packeter*. The word does not exist in the English language and cannot occur because the real stem *packet* and the real affix –*er* violate stem-affix restrictions and would create a non-valid word.

Table 1

Stimuli table. Stimuli breakdown by word type and subtype with examples and total number of each.

Word Type	Subtype	Example	Total Number of Each Subtype
Existing	True Affixed	Teacher	70
	Pseudo Affixed	Affable	60
Novel	Novel-Possible	Vibrantness	70
	Novel-Impossible	Agenter	70

Current Study

The core research questions that will be addressed in this study build upon recent findings that the typing of multimorphemic words shows effects of morphological structuring and that this morphological structuring takes the form of elevated typing times at morpheme boundary positions. Furthermore, the use of real and non-word multimorphemic words allows for the examination of lexical and morphological knowledge. A secondary goal of the project is to test whether the typing methodology used in Experiment Two could be used as a measure of fluency in non-native speakers of English. With this as background, an initial first experiment will validate the stimulus set to be used in the second experiment, which will address the following research questions:

1. Does the pattern of typing response times differ in magnitude of morphological structuring among true, pseudo, novel-possible and novel-impossible affixed English multimorphemic words?

2. Does the pattern of typing response times differ in magnitude of morphological structuring between native speakers and non-native speakers of English?

3. Can the typing methodology be used as a measure of fluency in non-native speakers of English?

The independent variables include language group (native and non-native speakers of English), and multimorphemic word types (true, pseudo, novel-possible and novel-impossible affixed English words). As in the previous typing studies (Bertram et al., 2015; Libben et al., 2014), the dependent variables will include first letter typing onset, per letter typing times, and whole word typing times, as well as typing times before and after morphemic boundaries.

Experiment One

The purpose of this lexical decision experiment was to make sure the words included in the true, pseudo, novel-possible, and novel-impossible affixed word types were classified correctly by online native speakers from the same potential population for the typing task in Experiment Two. The lexical decision task was chosen as the four-word types were comprised of two real word types (i.e., true and pseudo words) and two novel word types (i.e., novel-possible, and novel-impossible words). It was thought that the novel-possible and impossible word types would yield more incorrect responses and longer reaction times, and the lexical decision task would provide the best measure to capture accuracy and speed.

Methods

Participants

In the first experiment, only native speakers of English were recruited. A total of 60 participants completed the stimuli check lexical decision task. From this population, the data of only 33 participants (21 Males, 11 Females, and one other) were used in the analyses of Experiment One. Participants who had an accuracy level below 75% on the lexical decision task were removed, including those who made random button presses, pressed the same key as the only response or just did not complete the task in its entirety. The participants age ranged from 24 to 71 years of age, with various levels of education completed (high school, college, bachelors, masters, and PhD). Refer to Appendix Table A1 for the complete participant information. All participants were recruited from Amazon's Mechanical Turk (Mturk) and completed the experiment on an external online hosting site. Each participant was allotted 30 minutes to complete the experiment. All participants received two dollars upon completion of the experiment.

Pre-Task Activities

Before the start of every experiment, participants completed a short demographic questionnaire. The questionnaire was designed to gather some non-identifying pieces of information from the participants. This included general information like their Mturk worker ID, age, gender, and their highest level of education completed. Additionally, language specific information was also collected through the following two questions: 1) "what is your first language" and 2) "please list any other languages that you may know". Please refer to Appendix Table B1 for the full questionnaire. The language information was used to rule out any individuals whose first language was not English.

Following the demographic questionnaire, participants completed a short typing task. This task is designed to warm participants up before they began the main experiment. Refer to Appendix figure B1, for an image of the sample paragraph the participants typed. Participants were instructed to type out the exact sample paragraph that was displayed on the center of the screen. If an error was made, the participant had to correct it before moving forward because the colour of the text would change from a green (correct) to red (error) and not move forward until the correct key was pressed. Upon completion of the typing task, participants were presented with a summary screen that displayed their word typing time and accuracy rate.

Stimuli

The stimuli for this experiment were selected using the CELEX word database (Baayen, Piepenbrock, & Gulikers, 1995), the English Lexicon Project (ELP) web word database (Balota et al., 2007), from word lists used in other studies (Lewis et al., 2011; Rastle et al., 2004; Rueckl & Aicher, 2008), and online dictionary/word databases (ex. www.merriam-webster.com, www.7esl.com and www.wordmom.com). The stimuli consisted of words that were true affixed, pseudo affixed and novel-possible affixed and novel-impossible affixed. Refer to Appendix Table C1 for exact numbers of words per affix and word type and to Table C2 for the full word list used in the experiment, as well as Table C1 for specific examples. For all word conditions, the affixes included the same suffixes (i.e., *-able, -er, -ity, -ize,* and *-ness*) and the same prefixes (i.e., *re-*, and *un-*). All inflectional affixes (for example: *-ing,* and *-ed*) were excluded from selection because they are infinitely productive, meaning they can attach to many stems regardless of the lexical category of the stem. The number of each affix type differed across the word conditions due to stem-affix restrictions. The methods used to select words are described below.

True affixed words. The process of word selection started with selecting the true affixed words from the CELEX word database in Microsoft Office Excel. This was done by first filtering the database by the column header ‘MorphStatus’, which reflected the morphological word class of the word. For the true affixed word types, only the ‘C’ or complex word types were chosen under the MorphStatus heading. Then the column header ‘TransDer’ was filtered to only ‘#’ because this setting found words where the letters did not change before or after a morpheme (ex. hunt & hunter vs get & getter). Next, the ‘Imm’ column header was filtered by ‘*+suffix*’ or ‘*prefix+*’ to find words that ended with a specific suffix or started with a prefix. The ‘FlatSA’ column header was set to ‘SA’ (S = stem & A = affix) when looking for suffixed words and ‘AS’ when looking for prefixed words. Then the filtered list of words was examined, and words that had a minimum word length of six were selected. Upon selection, words were verified that they did not already exist in the stimuli list using the find and replace feature in Excel.

Pseudo affixed words. Due to the rarity of pseudo affixed words, a different word selection process was used. An online resource called *WordMom* (www.wordmom.com) was used to search for words that started or ended with a specific affix. The site displayed the words in alphabetical order, and then all the listed words were highlighted and inputted into the ELP online database. From the ELP, only the words that were listed as one morpheme and a word length of six were included for the pseudo affix word type. Similarly, the CELEX database was also used to search for a particular affix, and the selected words were run through the ELP database and chosen based on the morpheme and word length requirements. Finally, all the selected words were double checked in the final list to make sure they did not appear more than once.

Novel-possible affixed words. To obtain these words, the CELEX word database was used. First, the 'FlatSA' column header was set to 'S' (S = stem) when looking for both the suffixed and prefixed words. This step listed words without any affixes attached to them. Then the 'Struclab' column header was filtered by the lexical category that was needed (e.g., *[V]* for verbs, *[N]* for nouns, and *[A]* for adjectives). From there, only words that ended in two consonants were chosen and were checked by adding the corresponding suffix. The double consonant prevented the stem from being spelled or pronounced differently when the suffix was attached (e.g., the word *swimmer* without the suffix is *swim*, so this would mean the affix addition changed the spelling of the word). This step was not necessary for stems that went with the prefixes. The stems were verified in the final list to avoid multiple entries. The possible words were typed into an online dictionary to check whether they already existed. If they did not exist, then the word was kept in the final list, otherwise a new word selection was made. For all words, the Merriam-Webster dictionary was used (www.merriam-webster.com). The stems were also checked on the dictionary to make sure their lexical category was limited to only one-word class. For the *-ity* suffix, words had to be more than one syllable in length. All words had a minimum word length of six letters.

Novel-impossible affixed words. Following the process of the novel-possible affixed words, the 'FlatSA' column header was set to 'S' for both the suffixed and prefixed words. This time the 'Struclab' column header was filtered by the lexical category that violated the stem-affix restrictions. For example, *-er* affix takes a verb, so when searching for these stems nouns or adjectives were chosen. The stem was then checked to see if it was present in the list or not. The selected words were checked via the online Merriam-Webster dictionary for validity. Only words that were not valid or real were kept in the final list. Once again, the online dictionary was used to make sure the word stems belonged to a single lexical category, as well having more than one syllable and being a minimum of six letters in the length.

Equipment

In Experiment One, the stimuli check lexical decision task was created using a cognitive psychological experimental program known as PsychoPy (Peirce, 2007). Once the task programming was finished, it was uploaded to an online repository known as Gitlab. This online repository allowed for version control of the experiment. Any changes made to the task on the local machine were synced with the study on the Gitlab repository. The online repository on Gitlab was also connected to Pavlovia, which was the host server that stored the experiment online. Every time a local synchronisation of the experiment occurred; the study structure was automatically updated on the repository as well as on the Pavlovia server. Finally, Mturk was used to allow participants to access the experiment online and linked through Pavlovia. To run the experiment, credits were needed to be purchased on Pavlovia with a corresponding amount being purchased on Mturk to run the experiment batch. Upon completion of the experiment, a comma delimited (CSV) file was saved with the data. The data were cleaned using Excel and analysed in R. Since the study was completely online, participants completed the study on their own computers. Participants responded to each word using a keyboard and moved onto the next trial after every button press; thus, an optical mouse was not needed for navigation. The experiment was opened through the participant's internet browser, so no additional software was needed to complete the experiment.

Procedure

Participants accessed the online experiment via a link once they accepted the experiment's consent form on Mturk. When the experiment began, the demographic questionnaire was filled out (refer to Appendix Table B1). As mentioned before, this questionnaire asked for participants' worker ID, age, gender, highest level of education completed and a couple questions about language background. Upon completion of the questionnaire, an experiment welcome prompt appeared along with the instructions for the short typing task and the stimuli check lexical decision task. Then, the participant was instructed to complete a short paragraph typing task (refer to Figure B1 in Appendix B), in which they copied word for word what was displayed on the screen. As the letters were typed, the colour of the letter would change to green if typed correctly, otherwise the letter would turn red. The red colour would remain until the error was corrected using the backspace key. Upon completion of this short typing task, a summary slide would appear providing overall accuracy and words per minute statistics for the participant. Following the statistics slide, an instruction slide for the stimuli checking lexical decision task appeared on screen. Participants were asked to judge 270 English words that were presented in the middle of the screen. Participants were asked to press the 'A' key to respond 'YES, I have seen or heard this English word before' and press the 'L' key to respond 'NO, I have not seen or heard this word before'. Participants were asked to respond as accurately as possible. Before the start of the main experiment, participants completed eight practice trials. The button choice instructions remained on screen for each practice trial. After the practice was complete, the instructions were presented once more to reassure the objective of the task. Participants completed two blocks of 135-word judgement trials. Between the two blocks, a rest break was provided. It was at the discretion of the participant how long of a break they would take. Upon completion of the second block of trials, a thank you message appeared in a green box thanking participants for completion of the experiment and the experiment results were saved.

Results

As mentioned earlier, there were 33 native speakers with an age range of 24 to 71 years of age. Of the 270 total words in the experiment, 10 words were removed for having an accuracy value below 60%. Of these 10 words, eight were true affixed (i.e., reduplicate, hybridize, craftable, proudness, absentness, elegantness, pointness and mutuality) and two were pseudo affixed (i.e., paucity and regatta). After removal of low accurate responses, the accuracy of the remaining trials was 89%. Trimming reaction times below 300 milliseconds resulted in the removal of 33 observations and trimming reaction times above 2000 milliseconds resulted in the removal of 337 observations. As a result of this data cleaning, only 4.8% of data was removed. All data cleaning utilized Microsoft Office Excel and R statistical software. All data cleaning procedures were conducted only once and before the statistical analyses. The results were analyzed in three ways. First an overall measure of accuracy and reaction time was computed for each word type, then a linear mixed effects regression (LMER) analysis was conducted for real words (true & pseudo affixed) and nonwords (novel-possible & novel-impossible affixed) separately with RTs as the dependent variable.

Accuracy Analysis

First, an overall measure of accuracy was computed. This was done by removing the 10 words with low accuracy from the overall dataset. This resulted in an overall accuracy measure of 89.3%. The rest of the analyses that follow are based on this correct-trials dataset. Refer to Table 2 below for the accuracy values and standard deviations per word type category.

Table 2

Average lexical decision accuracy for each word type category with standard deviations

Word Type	Correct LD Response	Average Accuracy	Standard Deviation
True Affixed	Yes	0.89	0.31
Pseudo Affixed	Yes	0.94	0.25
Novel-Possible Affixed	No	0.82	0.38
Novel-Impossible Affixed	No	0.93	0.26

Reaction time analysis

Next the dataset was trimmed to remove reaction time (RT) outliers at both ends of the distribution. The limit was set to 0.3 seconds for the lower end, and 2.0 seconds for the upper end. Only five percent of the trials from the dataset were removed as a result. The first analysis examined the average RTs by-word type with total number of trials and standard deviations (see Table 3).

Table 3

Average reaction times (RTs) for each word type category with standard deviations.

Word Type	Average RT	Standard Deviation
True Affixed	945 ms	558 ms
Pseudo Affixed	893 ms	721 ms
Novel-Possible Affixed	1100 ms	667 ms
Novel-Impossible Affixed	1080 ms	1020 ms

From the RT analysis in Table 3, it was evident that the words and nonwords need to be separated for further analyses. The four-word categories were split into real word (true-affixed and pseudo-affixed) and non-word (novel-possible affixed and novel-impossible affixed) groups. This allowed for a comparison of these 2 groups separately (as seen in table 4 and 5 below).

Table 4 displays a RT linear mixed effects regression (LMER) for the real words. This model is based on the results of 125 words, as eight true affixed and two pseudo affixed were removed due to low accuracy. In this model, the RT was the independent variable (IV), the word type, affix, and word length were predictors and participants as well as words were included as random effects. As seen in Table 5, only the re- and –er affixes were significantly different from the intercept value -able. A visual representation of these significant effects can be seen in Figure 1 below.

Table 4

Reaction time linear mixed effects regression analysis for real words.

Random Effects				
Group name	Variance	SD		
Participant	0.048	0.220		
Word	0.011	0.103		
Fixed Effects	Estimate	SE	t	p
(Intercept)	8.464E-01	6.747E-02	12.544	< .001
Word Type				
Pseudo Affixed	-3.264E-02	1.841E-02	-1.773	n.s.
Affix				
-er	-7.968E-02	3.283E-02	-2.427	< .05
-ity	-3.318E-02	3.107E-02	-1.068	n.s.
-ize	-1.063E-02	3.358E-02	-0.317	n.s.
-ness	-3.527E-02	3.468E-02	-1.017	n.s.
re-	-5.858E-02	2.948E-02	-1.987	< .05
un-	-2.636E-02	3.509E-02	-0.751	n.s.
Word Length	9.311E-03	6.858E-03	1.358	n.s.

Figure 1

Bar graph of the main effect of affix with RTs for real words, where re- and –er affixes were significantly (p<0.05) different from the –able affix. The x-axis represents each affix, while the y-axis represents the reaction time (seconds).

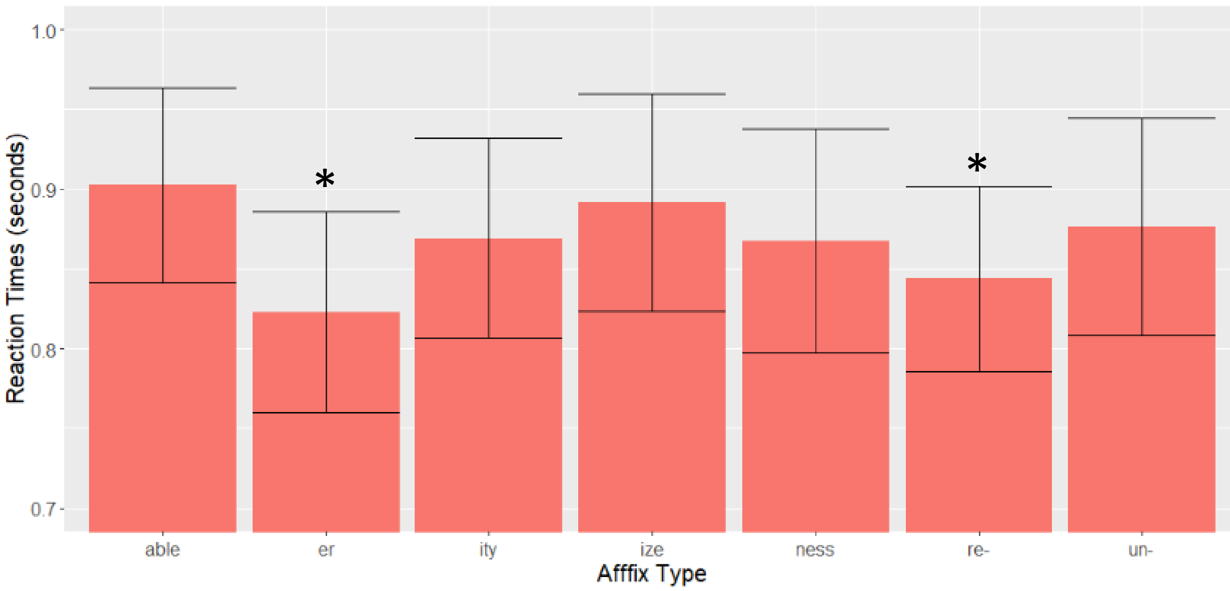


Table 5 displays a RT linear mixed effects regression (LMER) for the nonwords. Just like the model in Table 4, the nonwords model had the same IV, predictors and random effects. This model is based on 135 words, as no words were removed due to inaccuracies from the novel-possible affixed or novel-impossible affixed word types. As seen in Table 5, there was a significant main effect of word, word type where only the affix -ize was significantly different from the intercept value, and main effect of word length. A visual representation of these significant effects can be seen in Figures 2 and 3.

Table 5

Reaction time linear mixed effects regression analysis for nonwords with the various affixes. The "intercept" against which the other word types are compared are the Novel-Impossible words. Novel-Possible Affixed is the main effect of all the possible affixed items. They are given individually below the main effect. Similarly, the intercept against which the other affixes are compared are the –able affixed words.

Random Effects				
Group name	Variance	SD		
Participant	0.031	0.177		
Word	0.004	0.066		
Fixed Effects	Estimate	SE	t	p
(Intercept)	7.421e-01	7.325e-02	10.131	< .001
Word Type				
Novel-Possible Affixed	3.739e-02	1.390e-02	2.690	< .01
Affix				
-er	-7.455e-03	2.724e-02	-0.274	n.s.
-ity	-3.439e-02	2.575e-02	-1.335	n.s.
-ize	-6.824e-02	2.567e-02	-2.658	< .01
-ness	-1.075e-02	2.761e-02	-0.389	n.s.
re-	-5.205e-02	2.728e-02	-1.908	n.s.
un-	-6.053e-03	2.787e-02	-0.217	n.s.
Word Length	3.066e-02	7.465e-03	4.107	< .001

Figure 2

Bar graph of the significant main effect of word type with RTs for nonwords, where the novel-possible affixed words were significantly (p<0.01) slower from the novel-impossible affixed words. The x-axis represents each word type, while the y-axis represents the reaction time (seconds).

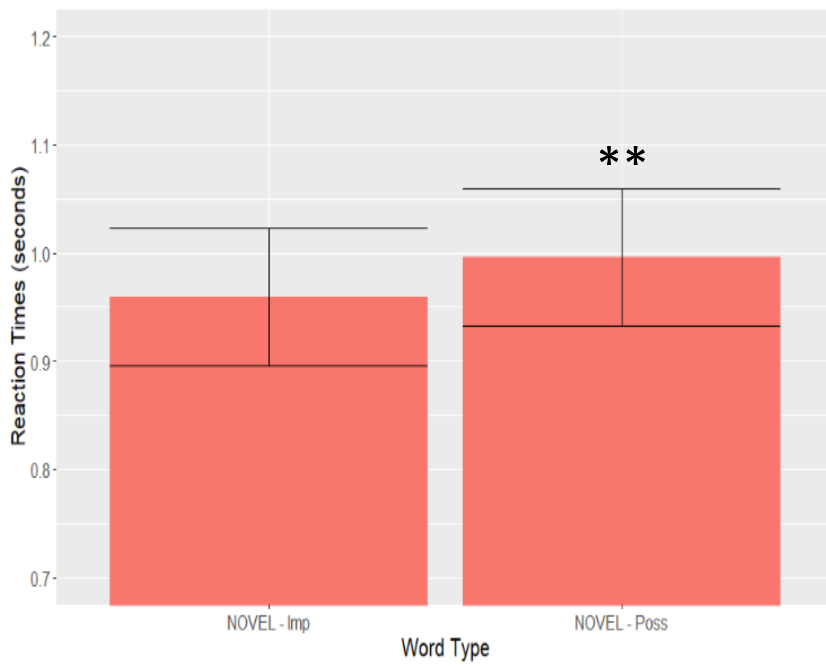
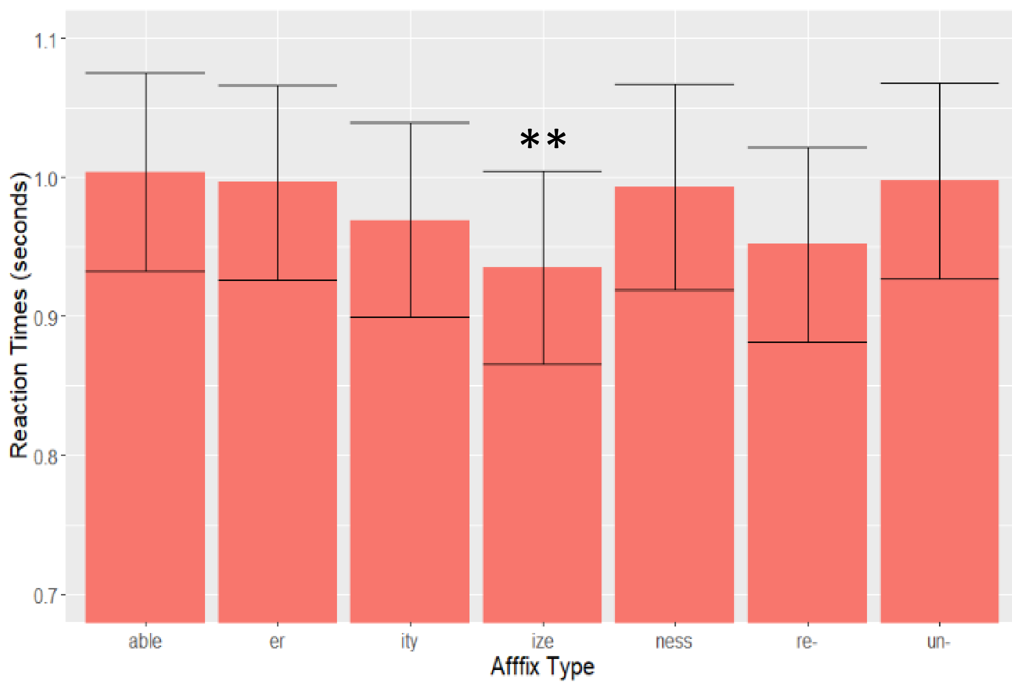


Figure 3

Bar graph of the significant main effect of affix with RTs for nonwords, where responses to the –ize affix was significantly (p<0.01) faster than the –able affix. The x-axis represents each affix, while the y-axis represents the reaction time (seconds).



Discussion

The purpose of experiment one was to serve as a stimulus check and validate the four word type conditions. To examine this, a set of 270 English affixed words were created based on four different affix types (i.e., true, pseudo, novel-possible & novel-impossible affixed). The words were put through a lexical decision task and only words with a high level of accuracy (or agreeableness) were included in the analyses of Experiment Two.

The results of lexical decision task in Experiment One provided evidence of low accuracy on 10 words (eight – true and two pseudo-affixed). The chosen accuracy cut-off was 60%, as anything higher would have removed too many trials and anything lower would have dropped accuracy to chance. The interesting part is that most words with low accuracy were from the true affixed word type. This is surprising considering all the participants in this experiment were native speakers of English. Specifically, for this language group, true affixed words, which consist of real word stems and affixes, should easily be recognized. The reaction time analysis was conducted for the real words (true and pseudo affixed) and nonwords (novel-possible and novel-impossible) separately. This was done because comparing both types together would be problematic since one set exists in the language while the other does not. For the real words, only a significant main effect of affix type was present. RTs were significantly faster for *–er* and *re-* affixed words compared to the *–able* affixed words (refer to Figure 1 in Results). This is an expected result because it would make sense that words with shorter affixes are responded to faster than words with longer affixes. The nonwords on the other hand showed significant effects of word type, affix type and word length. RTs were longer for novel-possible words compared to novel-impossible (refer to Figure 2 in Results). This is also an expected result because it shows that native speakers spent more time deciding whether the novel-possible words were real or not.

This result was expected when creating these word types, as they were created so that they would look like they can morphologically go together (i.e., no stem-affix restriction) but do not exist in the current English lexicon. While this result reflects a lexical decision, it does provide some insight in how native speakers may approach these words when encountering them in a typing production task. Overall, the results contribute to the goals of the study, by providing an evaluation of the stimuli by a similar Mturk worker population that was used in Experiment Two analyses. The result of this experiment shows the usefulness of the lexical decision task in evaluating the stimuli. The lexical decision task provides a single measurement (latency or accuracy) for the recognition of a whole word. In comparison, a typing task is based on production of language and is not commonly used in psycholinguistic research. The typing task in Experiment Two provides the opportunity to measure word production as it is happening and provides an inside look into specific parts of a word.

Experiment Two

The purpose of this typing experiment was to examine the difference in morphological processing between native and non-native speakers of English using a typing task. These differences would also be examined with respect to four-word types: true affixed, pseudo affixed, novel-possible affixed and novel-impossible words. The experiment also tested whether the typing methodology used in Experiment Two could be used as a measure of fluency in non-native speakers of English.

Methods

Participants

In the second experiment, native (NS) and non-native speakers (NNS) of English were recruited. A total of 138 participants completed the word typing task. From this population, the data of only 107 participants with 52 NS (35 males, 16 females, and 1 other) and 55 NNS (38 males, 17 females) were used in the analyses of Experiment Two. Participants were excluded due to incomplete tasks either during the pre-task activities or during the main experiment. The NS age ranged from 23 to 62 years of age, while the NNS age ranged from 21 to 66 years of age. Both groups had various levels of education completed (high school, college, bachelors, masters, and PhD). Refer to Appendix Table A2 for the complete participant information. All participants were recruited from Mturk and completed the experiment on an external online hosting site. Each participant was allotted 60 minutes to complete the experiment. All participants received four dollars upon completion of the experiment. To help limit bad responses, some Mturk worker qualifications were set in place. For example, workers task (or HIT) completion percentage was set at 90% and their total number of HITs completed was set at 500.

Pre-Task Activities

As in Experiment One, participants completed a short demographic questionnaire. The questionnaire was designed to gather some non-identifying pieces of information from the participants. This included general information like their Mturk worker ID, age, gender, and their highest level of education completed. Additionally, language specific information was also collected through the following four questions: 1) "what is your first language", 2) "what is your second language?", 3) "please list any other languages you may know (e.g., French, German etc.)", and 4) "at what age did you learn all your languages? (e.g., Spanish - age 4, English - age

6)". Please refer to Appendix Table B2 for the full questionnaire. The language information was used to make sure there was no discrepancy between the first languages learned and what was stated for each language group.

Following the demographic questionnaire, participants completed two more short questionnaires. The first was a single item typing style questionnaire (refer to Appendix Table B3 for full questionnaire). This provided the chance to examine participants natural typing style, i.e., whether they used one or two hands, or how many fingers they used to type with. Unfortunately, this was only included for half the participants, so it did not get used in the data analyses. The second was a 20-item English language fluency questionnaire (refer to Appendix Table B4 for full questionnaire). This questionnaire was used to establish some sort of English fluency score for both NS and NNS. The questions asked for self-reports on English-speaking ability in various real-life situations.

Once again before the start of the main experiment, a short typing task was presented to the participants. This was the same task as presented in Experiment One. Refer to Appendix Figure B1, for an image of the sample paragraph that participants typed.

Stimuli

The same 270 words and four types used in Experiment One were used again in Experiment Two.

Equipment

The same process of accessing the experiment was used as Experiment One and once again participants completed the experiment on their own computers and internet browsers.

Procedures

The procedure is roughly the same as Experiment One for the pre-task activities but differs for the main experiment. After completing the demographic, typing style, English language fluency questionnaires and the paragraph typing task, participants were directed to the instruction slide of the main experiment. Participants were asked to type English words as quickly and accurately as possible as they appeared on screen. The word would appear in the center of screen prompted by three triangle brackets “>>>”. Like the paragraph typing pre-task, the typed letters of a word would turn green when the correct letter was typed and red when an error was made. Participants were instructed to correct any errors by using the backspace key. A typing trial could not be completed until the word was typed correctly. This feature was added to ensure participants completed the experiment properly. Once the word was typed correctly, participants pressed “enter/return” to move onto the next trial. Eight practice trials were presented in the practice block with the instructions listed at the top of the screen. Upon completion of the practice block, the instructions were presented again. Like Experiment One, the typing task was split into two blocks of 135 words each. Between the blocks, participants received a self-controlled break. Participants pressed the space key to end the break and continue to the second block. A thank-you message appeared at the end of the completion of block two.

After removal of incomplete data and further cleaning using Excel and R, only 107 of the 138 total participants remained. In addition to participant removal, the 10 words with low accuracy ratings as a result from Experiment One were removed from the dataset. An additional word was removed due to stimulus design violations (i.e., having both a prefix and suffix), leaving 259 words in the analyses. All data cleaning procedures were conducted only once and before the statistical analyses. The results were analyzed in two sets; the first set examined the morpheme boundary effects pertaining to the hypotheses for the prefixes and the second set for the suffixes.

(1) The first analysis involved the morpheme boundary. This analysis allowed for the examination of how native and non-native speakers morphologically process the four-word types before, at and after a morpheme boundary in prefixed words. The analysis covered the overall prefix morphemic boundary analysis, along with several follow-up analyses.

(2) The second analysis examined how native and non-native speakers morphologically process the four-word types before, at and after a morpheme boundary in suffixed words. Some follow-up analyses were also included.

Results

All analyses below are based on a total sample size of 107 participants. Unless otherwise stated, each reaction time analysis has a sample distribution that removes any word that had a per-letter reaction time (PLRT) greater than two seconds. This was done so that only words included had letters typed in a sequential manner without very long pauses/breaks while typing. Times that are recorded greater than two seconds pose the threat of turning typing into a conscious process. Additionally, the PLRT values were converted to milliseconds (ms) and then further converted natural log ms PLRT values. This was done to normalize the distribution of values, as reaction time data are always heavily skewed. The Results section below will present the morphemic boundary analyses which pertain directly to the three research questions with the prefixed and suffixed words separately for each question.

Question One – Morphological Structuring of Word Types

Prefix Results

The purpose of the morphemic boundary analysis was to examine how native and non-speakers process the four-word types based on time spent before, at and after the morpheme boundary in prefixed and suffixed words. The typing times before and after the morphemic boundary utilized the minus one and plus one notation as in the previous typing study (Libben et al., 2014). The results are below starting with the prefixes, followed by the suffixes.

Research question one asked whether the magnitude of morphological decomposition would differ among true, pseudo, novel-possible and novel-impossible affixed English words. In order to test this, a log reaction time linear mixed effects regression (LMER) analysis was conducted with boundary position and word type as the independent variables (IVs), fluency score and language as participant variables, log stem/whole word frequency as the control variable and participant and word typed as random effects in the model. With the boundary position on the intercept, there was a significant main effect of boundary position, where the minus one (M = 154 ms, t = -16.971, $p < 0.001$) and the plus one (M = 182 ms, t = -4.012, $p < 0.001$) boundary positions had significantly faster RTs compared to the boundary (M = 233ms). With the pseudo word type on the intercept, there was a significant main effect of word type, where novel-impossible prefixed words (M = 195 ms, t = 4.643, $p < 0.001$) had significantly longer reaction times (RTs) overall compared to the pseudo words (M = 174 ms). There was a significant interaction of boundary position and word type, where the novel-possible (M = 254 ms, $p < 0.001$) and novel-impossible (M = 248 ms, $p < 0.001$) prefixed words had significantly longer RTs at the boundary position compared to the pseudo (M = 202 ms) prefixed words at the boundary position. A follow up lmer analysis removing either the minus_1 or plus_1 position found the same significant differences in RTs in word types at the boundary position, suggesting the difference occurs only at the boundary position. Refer to Table 6 for the model summary and Figure 4 for the interaction bar graph.

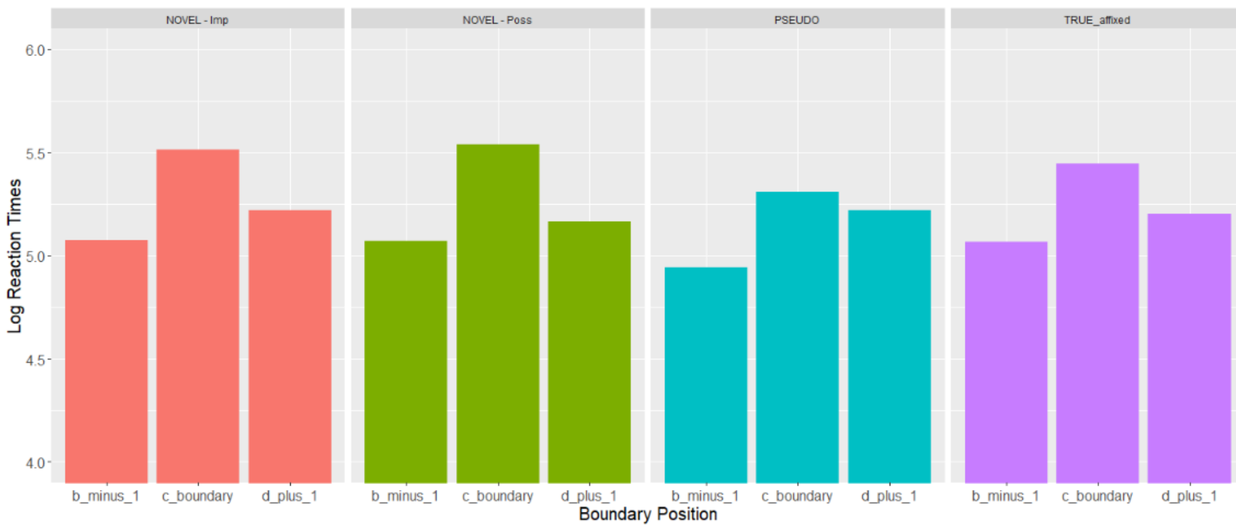
Table 6

Morphemic boundary by word type LMER analysis for prefixes with effects, variances, standard deviations, estimates, standard errors, t-scores, and p-values

Random Effects				
Group name	Variance	SD		
Participant	0.129	0.360		
Target Word	0.016	0.126		
Fixed Effects	Estimate	SE	t	p
(Intercept)	5.86E+00	2.13E-01	27.446	< .001
Boundary Position	-3.67E-01	2.16E-02	-16.971	
Boundary				< .001
Plus_1	-8.67E-02	2.16E-02	-4.012	< .001
Word Type				
Novel-Impossible Affixed	2.04E-01	4.39E-02	4.643	< .001
Novel-Possible Affixed	2.29E-01	4.39E-02	5.216	< .001
True Affixed	1.36E-01	4.39E-02	3.111	< .01
Fluency Score	-5.66E-03	2.40E-03	-2.359	< .05
Language Group	-7.57E-03	7.15E-02	-0.106	n.s.
Log Stem/Whole Word Frequency	-5.19E-02	2.01E-02	-2.578	< .05
Boundary Position x Word Type				
Minus_1 x Novel-Impossible	-6.90E-02	3.06E-02	-2.254	< .05
Plus_1 x Novel-Impossible	-2.04E-01	3.06E-02	-6.658	< .001
Minus_1 x Novel-Possible	-9.84E-02	3.10E-02	-3.174	< .01
Plus_1 x Novel-Possible	-2.87E-01	3.10E-02	-9.254	< .001
Minus_1 x True	-1.31E-02	3.10E-02	-0.423	n.s.
Plus_1 x True	-1.57E-01	3.10E-02	-5.052	< .001

Figure 4

Bar graph representing the significant two-way interaction of boundary position by word type for LRTs of prefixed words, where both the novel-possible and novel-impossible prefixed words had significantly longer LRTs at the boundary position compared to the pseudo prefixed words at the boundary position. The x axis represents the boundary positions, while the y-axis represents the LRTs and the grouping factor is word type.



As a result of this LMER, a secondary LMER analysis was conducted this time examining the same model but only for pseudo and true prefixed words (i.e., the real words). This analysis revealed a significant interaction of boundary position by word type, where true prefixed words were typed significantly slower at the boundary (M = 233 ms, $p < 0.01$) and minus one (M = 159 ms, $p < 0.05$) positions compared to pseudo prefixed words at the same positions (M = 202 ms & M = 140 ms). There was no significant difference between the two-word types at the plus one position. Only when this analysis was run again but with the minus one or boundary position removed from the model data, this significant interaction disappeared, suggesting that the difference between the pseudo and true prefixed words occurs at the minus one position before the morphemic boundary and at the boundary itself, but not at the plus one position.

Suffix Results

The same LMER analysis for prefixes was conducted for the suffixes. There was a significant main effect of boundary position, where the boundary position (M = 190 ms) had significantly shorter typing times compared to the minus one (M = 206 ms, $p < 0.001$), but significantly longer typing times compared to the plus one (M = 160 ms, $p < 0.001$) position. The model found a significant main effect of word type, but post-hoc pairwise comparisons between the four-word types revealed no significant differences. Like the prefix analysis, the model revealed a significant interaction between boundary position and word type. Post-hoc pairwise comparisons found significant differences at the boundary position, where pseudo suffixed words (M = 170 ms) were typed significantly faster compared to novel-impossible (M = 203 ms, $p < 0.001$), novel-possible (M = 193 ms, $p < 0.05$), and true (M = 195 ms, $p < 0.05$) suffixed words. Refer to Table 7 for the model summary and to Figure 5 for the interaction bar graph.

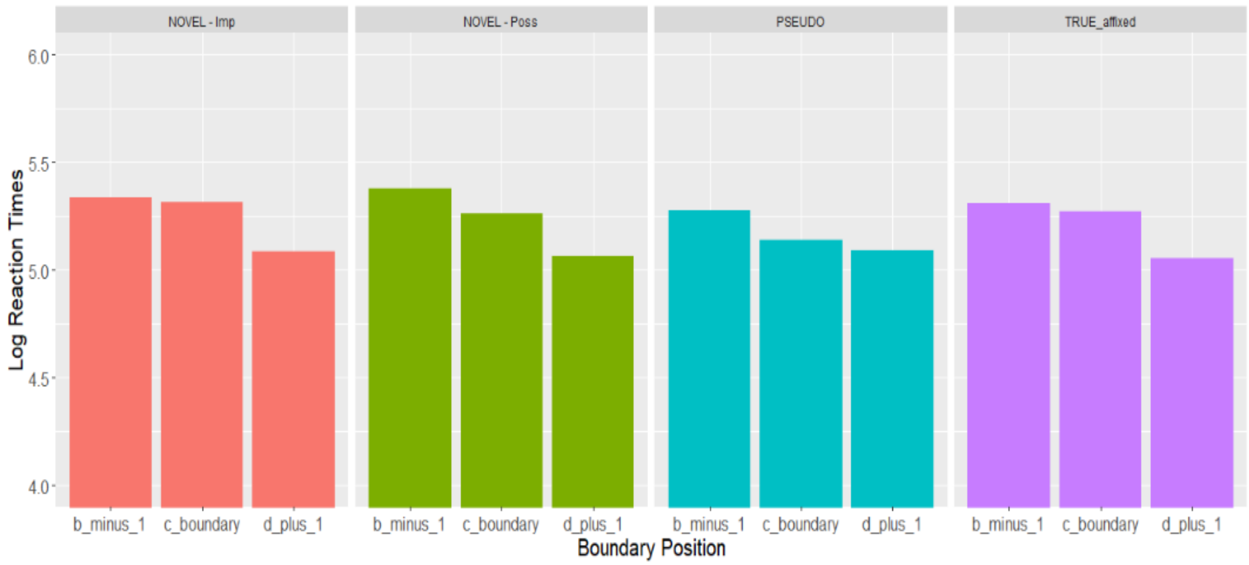
Table 7

Morphemic boundary by word type LMER analysis for suffixes with effects, variances, standard deviations, estimates, standard errors, t-scores, and p-values

Random Effects				
Group name	Variance	SD		
Participant	0.148	0.384		
Target Word	0.028	0.169		
Fixed Effects	Estimate	SE	t	p
(Intercept)	5.75E+00	2.26E-01	25.42	< .001
Boundary Position	1.42E-01	1.70E-02	8.344	
Boundary				< .001
Plus_1	-4.72E-02	1.70E-02	-2.782	< .01
Word Type				
Novel-Impossible Affixed	1.75E-01	3.71E-02	4.728	< .001
Novel-Possible Affixed	1.25E-01	3.71E-02	3.38	< .001
True Affixed	1.37E-01	3.93E-02	3.484	< .001
Fluency Score	-6.85E-03	2.55E-03	-2.684	< .01
Language Group	2.06E-02	7.60E-02	0.271	n.s.
Log Stem/Whole Word Frequency	-1.70E-02	1.95E-02	-0.872	n.s.
Boundary Position x Word Type				
Minus_1 x Novel-Impossible	-1.20E-01	2.28E-02	-5.267	< .001
Plus_1 x Novel-Impossible	-1.77E-01	2.28E-02	-7.776	< .001
Minus_1 x Novel-Possible	-2.40E-02	2.33E-02	-1.03	n.s.
Plus_1 x Novel-Possible	-1.53E-01	2.33E-02	-6.57	< .001
Minus_1 x True	-1.06E-01	2.30E-02	-4.627	< .001
Plus_1 x True	-1.75E-01	2.30E-02	-7.635	< .001

Figure 5

Bar graph representing the significant two-way interaction of boundary position by word type for LRTs of suffixed words, where the true, novel-possible, and novel-impossible suffixed words had significantly longer LRTs at the boundary position compared to the pseudo suffixed words at the boundary position. The x axis represents the boundary positions, while the y-axis represents the LRTs and the grouping factor is word type.



A secondary LMER analysis was conducted for the suffixed real words. The boundary position by word type interaction remained significant, where the true suffixed words were typed significantly slower at the boundary position compared to the pseudo suffixed words. If the analysis was run again removing the boundary position, the significant boundary by word type interaction disappeared. This suggests that the difference between the pseudo and true suffixed words occurs at the morpheme boundary, with the true suffixed words typed slower than the pseudo suffixed words.

Question Two – Morphological Structuring of Language Groups

Prefix Results

Research question two asked whether the magnitude of morphological decomposition would differ between native and non-native speakers of English. To test this a log reaction time LMER analysis was conducted with boundary position and language group as the independent variables (IVs), fluency score and word type as participant variables, log stem/whole word frequency as the control variable and participant as well as word typed as the random effects in the model. There was no significant main effect of language group. There was a significant interaction of boundary position and language group, where the NNS had significantly longer RTs at the boundary position (M = 229 ms) compared to the minus one (M = 157ms, $p < 0.001$) and plus one (M = 179ms, $p < 0.001$) positions. This same pattern was also observed for the NS, where NS had significantly longer RTs at the boundary position (M = 237 ms) compared to the minus one (M = 149 ms, $p < 0.001$) and plus one (M = 179 ms) (refer to Figure 6). A follow up lmer analysis removing the plus one boundary position confirmed that the significant interaction between boundary positions and language group does remain. Refer to Table 8 for the model summary table.

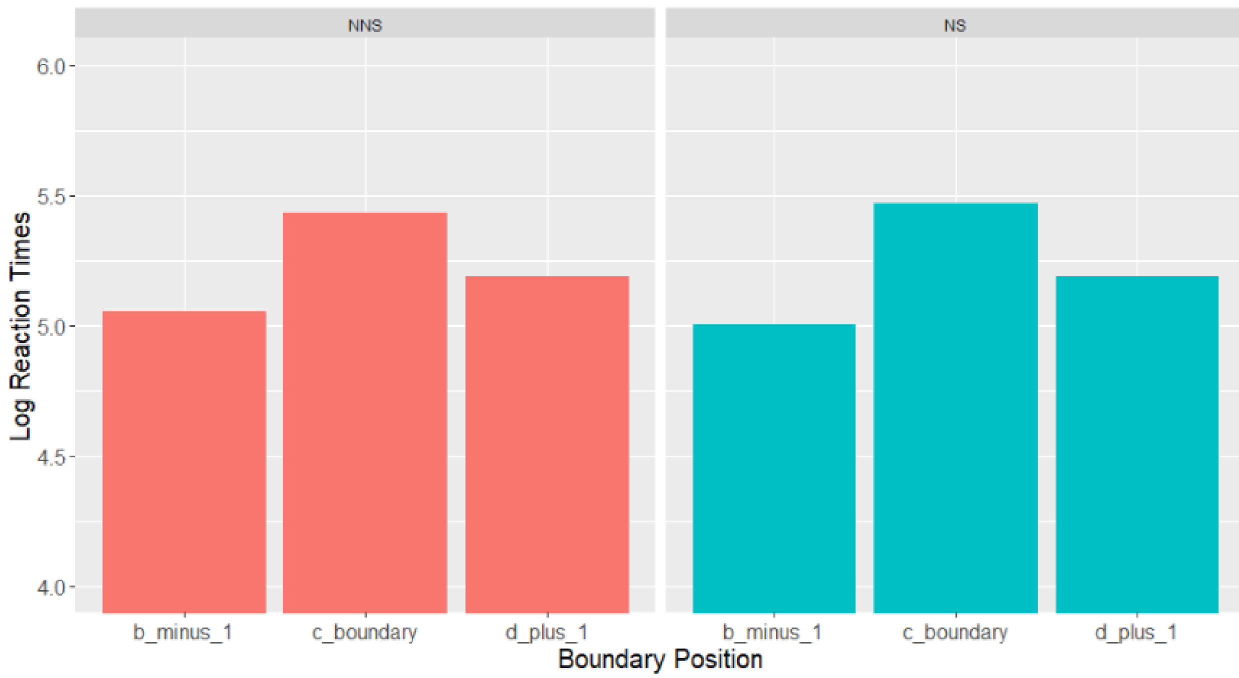
Table 8

Morphemic boundary by language group LMER analysis for prefixes with effects, variances, standard deviations, estimates, standard errors, t-scores, and p-values

Random Effects				
Group name	Variance	SD		
Participant	0.132	0.363		
Target Word	0.016	0.128		
Fixed Effects	Estimate	SE	t	p
(Intercept)	5.91E+00	2.16E-01	27.379	< .001
Boundary Position				
Boundary	-3.80E-01	1.70E-02	-22.309	< .001
Plus_1	-2.47E-01	1.70E-02	-14.486	< .001
Word Type				
Novel-Impossible Affixed	1.24E-01	4.17E-02	2.973	< .01
Novel-Possible Affixed	1.25E-01	4.18E-02	2.99	< .01
True Affixed	8.64E-02	4.16E-02	2.077	< .05
Fluency Score	-5.80E-03	2.43E-03	-2.39	< .05
Language Group	3.06E-02	7.36E-02	0.416	n.s.
Log Stem/Whole Word Frequency	-5.55E-02	2.07E-02	-2.686	< .01
Boundary Position x Language Group				
Minus_1 x NS	-8.11E-02	2.40E-02	-3.384	< .001
Plus_1 x NS	-3.25E-02	2.40E-02	-1.357	n.s.

Figure 6

Bar graph representing the significant two-way interaction of boundary position by language group for LRTs of prefixed words, where both the NNS and NS had significantly longer LRTs at the boundary position compared to the minus one and plus one positions. The x axis represents the boundary positions, while the y-axis represents the LRTs and the grouping factor is language group.



A follow-up analysis was conducted looking at the real prefixed words and novel prefixed words separately to each other. The significant boundary by language group interaction remained for only the prefixed real words but not for the prefixed novel words, suggesting that the real words may be driving the significant interaction.

Suffix Results

The same LMER looking at language group in the model was conducted for suffixed words. The results revealed no significant main effects of language group, but there was a significant interaction of boundary position by language group. NNS had significantly longer RTs at the minus one position (M = 205 ms) compared to the boundary (M = 184 ms, $p < 0.001$) and from the boundary compared to the plus one (M = 160 ms, $p < 0.001$) position. This same pattern was also observed for the NS, where NS had significantly longer RTs at the minus one position (M = 206 ms) compared to the boundary (M = 197 ms, $p < 0.01$) and from the boundary compared to plus one (M = 159 ms, $p < 0.001$) position. (refer to Figure 7). Importantly, the difference between the two language groups is largely observed when moving from the minus one to boundary position. The NNS typing speed decreases much faster than the NS. Refer to Table 9 for the model summary. A follow-up LMER analysis looking at the same model but for real words only, found the same significant boundary by language group interaction as before, with the same patterns observed for both language groups. NS are sensitive to the boundary effect for real word suffixes, while the NNS are not.

Table 9

LRTs of morphemic boundary by language group LMER for suffixes with effects, variances, standard deviations, estimates, standard errors, t-scores, and p-values

Random Effects				
Group name	Variance	SD		
Participant	0.148	0.384		
Target Word	0.028	0.169		
Fixed Effects	Estimate	SE	t	p
(Intercept)	5.79E+00	2.26E-01	25.620	< .001
Boundary Position				
Minus_1	1.09E-01	1.13E-02	9.664	< .001
Plus_1	-1.42E-01	1.13E-02	-12.559	< .001
Word Type				
Novel-Impossible Affixed	7.63E-02	3.47E-02	2.203	< .05
Novel-Possible Affixed	6.65E-02	3.46E-02	1.924	n.s.
True Affixed	4.32E-02	3.70E-02	1.166	n.s.
Fluency Score	-6.85E-03	2.55E-03	-2.684	< .01
Language Group	6.76E-02	7.66E-02	0.883	n.s.
Log Stem/Whole Word Frequency	-1.70E-02	1.95E-02	-0.872	n.s.
Boundary Position x Language Group				
Minus_1 x NS	-6.68E-02	1.59E-02	-4.216	< .001
Plus_1 x NS	-7.42E-02	1.59E-02	-4.679	< .001

Figure 7

Bar graph representing the significant two-way interaction of boundary position by language group for LRTs of suffixed words, where both NS and NNS had significantly longer LRTs at the minus one position compared to the boundary and from the boundary compared to the plus one position. The x axis represents the boundary positions, while the y-axis represents the LRTs, and the grouping factor is language group.

Question Three – Language fluency and typing latencies

Prefix Results

Research question three asked whether the typing paradigm used in this study could be used as an assessment tool to measure fluency in non-native speakers of English. To test this, a log reaction time LMER analysis was conducted with boundary position, word type and fluency score as the independent variables (IVs), log stem/whole word frequency, trial order and word length as the control variables and participant as well as stimulus item as the random effects in the model. The analysis yielded a significant main effect of boundary position, where the boundary position (M = 234 ms) was typed significantly slower compared to the minus one (M = 160 ms, $p < 0.001$) and plus one (M = 183 ms, $p < 0.001$) positions. There was also a significant main effect of word type, where pseudo prefixed words (M = 173 ms) were typed faster compared to the novel-impossible (M = 202 ms, $p < 0.001$) and novel-possible (M = 195 ms, $p < 0.05$) prefixed words. However, for the effects related to the research question, there were no significant main effects of fluency or any interactions involving boundary position, word type and fluency. Despite the removal of various variables and predictors in subsequent models, no fluency effects were observed for non-native speakers typing prefixed words. Refer to Table 10 below for the model summary.

Table 10

LRTs of morphemic boundary by word type by fluency score LMER for prefixes with effects, variances, standard deviations, estimates, standard errors, t-scores, and p-values

Random Effects				
Group name	Variance	SD		
Participant	0.133	0.365		
Target Word	0.014	0.118		
Fixed Effects	Estimate	SE	t	p
(Intercept)	5.91E+00	3.30E-01	17.896	< .001
Boundary Position				
Minus_1	-4.23E-01	1.59E-01	-2.656	< .01
Plus_1	-2.40E-01	1.59E-01	-1.505	n.s.
Word Type				
Novel-Impossible Affixed	3.33E-01	1.64E-01	2.034	< .05
Novel-Possible Affixed	1.86E-01	1.66E-01	1.12	n.s.
True Affixed	8.18E-02	1.66E-01	0.493	n.s.
Fluency Score	-6.85E-03	3.63E-03	-1.888	n.s.
Log Stem/Whole Word Frequency	-5.76E-02	1.97E-02	-2.92	< .01
Trial Order	-2.43E-04	1.22E-04	-1.992	< .05
Word Length	5.99E-03	1.33E-02	0.45	n.s.
Boundary Position x Word Type				
Minus_1 x Novel-Impossible	-9.99E-02	2.25E-01	-0.444	n.s.
Plus_1 x Novel-Impossible	-1.70E-01	2.25E-01	-0.753	n.s.
Minus_1 x Novel-Possible	-1.50E-01	2.29E-01	-0.656	n.s.
Plus_1 x Novel-Possible	-1.09E-01	2.29E-01	-0.477	n.s.
Minus_1 x True	1.00E-02	2.29E-01	0.044	n.s.
Plus_1 x True	1.16E-01	2.29E-01	0.509	n.s.
Boundary Position x Fluency Score				
Minus_1 x Fluency	1.48E-03	1.85E-03	0.802	n.s.
Plus_1 x Fluency	1.52E-03	1.85E-03	0.821	n.s.
Word Type x Fluency Score				
Novel-Impossible x Fluency	-8.87E-04	1.85E-03	-0.479	n.s.
Novel-Possible x Fluency	7.96E-04	1.87E-03	0.426	n.s.
True x Fluency	8.18E-04	1.87E-03	0.437	n.s.
Boundary Position x Word Type X Fluency Score				
Minus_1 x Novel-Impossible x Fluency	-3.06E-04	2.62E-03	-0.117	n.s.
Plus_1 x Novel-Impossible x Fluency	-1.05E-04	2.62E-03	-0.04	n.s.
Minus_1 x Novel-Possible x Fluency	-1.88E-05	2.64E-03	-0.007	n.s.
Plus_1 x Novel-Possible x Fluency	-1.66E-03	2.64E-03	-0.629	n.s.
Minus_1 x True x Fluency	-7.80E-04	2.64E-03	-0.295	n.s.
Plus_1 x True x Fluency	-2.76E-03	2.64E-03	-1.046	n.s.

Suffix Results

The suffix LMER analysis to test fluency in non-native speakers used the same model setup as the prefixes. Unlike the prefix analysis, the suffix LMER analysis yielded some significant findings. There was a significant three-way interaction of boundary position by word type by fluency score, where non-native speakers with a high fluency score (85) typed true (M = 156 ms, $p < 0.001$), novel-impossible (M = 169 ms, $p < 0.001$) and novel-possible (M = 162 ms, $p < 0.001$) suffixed words significantly faster at the plus one compared to boundary position (M = 190 ms, M = 201 ms, M = 191 ms) of each word type respectively (refer to Figure 8). Importantly, there was no significant difference in the typing times of pseudo suffixed words at the boundary (M = 169 ms) compared to the plus one position (M = 167 ms), unlike the other three-word types. Refer to Table 11 below for the model summary.

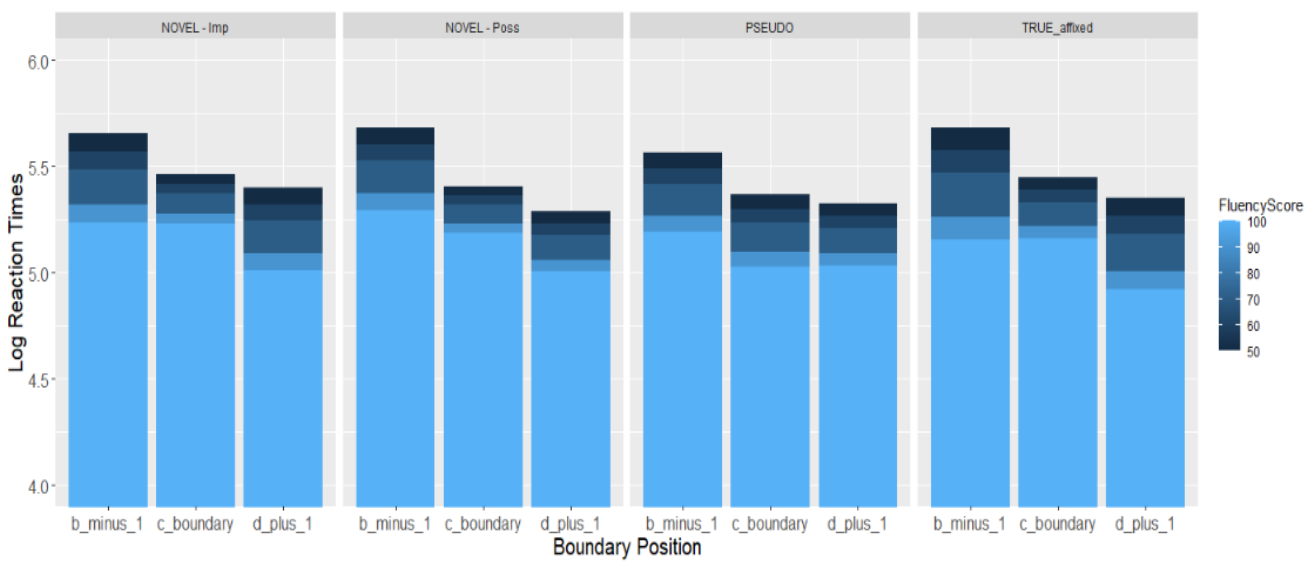
Table 11

LRTs of morphemic boundary by word type by fluency score LMER for suffixes with effects, variances, standard deviations, estimates, standard errors, t-scores, and p-values

Random Effects				
Group name	Variance	SD		
Participant	0.167	0.409		
Target Word	0.023	0.153		
Fixed Effects	Estimate	SE	t	p
(Intercept)	5.36E+00	3.48E-01	15.383	< .001
Boundary Position				
Minus_1	2.26E-01	1.24E-01	1.824	n.s.
Plus_1	-8.89E-02	1.24E-01	-0.719	n.s.
Word Type				
Novel-Impossible Affixed	-1.19E-02	1.23E-01	-0.097	n.s.
Novel-Possible Affixed	-8.84E-02	1.25E-01	-0.710	n.s.
True Affixed	2.49E-02	1.25E-01	0.199	n.s.
Fluency Score	-6.79E-03	3.93E-03	-1.729	n.s.
Log Stem/Whole Word Frequency	-2.45E-02	1.85E-02	-1.320	n.s.
Trial Order	-2.01E-04	9.06E-05	-2.221	< .05
Word Length	4.99E-02	9.31E-03	5.357	< .001
Boundary Position x Word Type				
Minus_1 x Novel-Impossible	1.59E-01	1.67E-01	0.948	n.s.
Plus_1 x Novel-Impossible	1.76E-01	1.67E-01	1.052	n.s.
Minus_1 x Novel-Possible	2.22E-01	1.70E-01	1.311	n.s.
Plus_1 x Novel-Possible	3.34E-02	1.70E-01	0.197	n.s.
Minus_1 x True	2.45E-01	1.69E-01	1.452	n.s.
Plus_1 x True	1.33E-01	1.69E-01	0.787	n.s.
Boundary Position x Fluency Score				
Minus_1 x Fluency	-6.40E-04	1.43E-03	-0.447	n.s.
Plus_1 x Fluency	9.22E-04	1.43E-03	0.643	n.s.
Word Type x Fluency Score				
Novel-Impossible x Fluency	2.14E-03	1.37E-03	1.564	n.s.
Novel-Possible x Fluency	2.47E-03	1.39E-03	1.776	n.s.
True x Fluency	1.07E-03	1.38E-03	0.773	n.s.
Boundary Position x Word Type X Fluency Score				
Minus_1 x Novel-Impossible x Fluency	-3.19E-03	1.94E-03	-1.648	n.s.
Plus_1 x Novel-Impossible x Fluency	-3.99E-03	1.94E-03	-2.058	< .05
Minus_1 x Novel-Possible x Fluency	-2.79E-03	1.97E-03	-1.419	n.s.
Plus_1 x Novel-Possible x Fluency	-2.19E-03	1.97E-03	-1.115	n.s.
Minus_1 x True x Fluency	-4.11E-03	1.95E-03	-2.104	< .05
Plus_1 x True x Fluency	-3.74E-03	1.95E-03	-1.915	n.s.

Figure 8

Bar graph representing the significant three-way interaction of boundary position by word type by fluency score for LRTs of suffixed words, where non-native speakers with a high fluency score (85) typed true, novel-impossible, and novel-possible suffixed words significantly faster at the plus one compared to boundary position of each word type respectively. There were no significant differences between the boundary and plus one positions in pseudo suffixed words for high fluency NNS. The x-axis represents the boundary positions, while the y-axis represents the LRTs, and the grouping factor is word type. The light blue bars represent the NNS with high fluency scores, while the dark blue bars represent the NNS with low fluency scores.



Discussion

The purpose of Experiment Two was two-fold. First, the study was designed to examine the morphological processing of various complex word types, as well as a comparison of morphological processing between native and non-native speakers. Second, we wanted to determine whether the typing methodology could be used to measure English language fluency in non-native speakers. To examine these issues, a set of 270 English affixed words were put through a word-typing task in Experiment Two. The results are discussed below based on each research question from the study.

Question One – Morphological Structuring of Word Types

The first research question asked whether the magnitude of morphological decomposition would differ among true, pseudo, novel-possible and novel-impossible affixed English words. The reason for separating the prefixed from the suffixed words is that they are unbalanced groups, as there are more suffixed types and words overall. So, for the analyses, a linear mixed effects regression was conducted for boundary position by word type for the prefixed and suffixed words separately. For the prefixes but not the suffixes, there was a significant main effect of word type, where the novel-impossible prefixed words had significantly longer LRTs compared to the pseudo prefixed words, suggesting that between these two-word types, pseudo prefixed words are processed more easily. The similarities between the prefixes and suffixes come in the form of the boundary position by word type interactions.

For prefixes, both the novel prefixed word conditions were typed significantly slower at the boundary position compared to the pseudo prefixed words at the boundary (refer to Table 6). This same pattern was observed for the suffixed words, where the novel suffixed words were typed significantly slower at the boundary compared to the pseudo suffixed words (refer to Table 7). This evidence helps address research question one, as the novel affixed words were typed more slowly than the real affixed words. In addition to the novel words, the true suffixed words were also typed significantly slower at the boundary position compared to the pseudo suffixed words. A follow-up LMER analysis with only real words (i.e., true and pseudo) confirmed that the true suffixed words at the boundary were typed significantly slower than the pseudo words.

This is an expected result as the presence of a real suffix should slow down typing times compared to when there is no suffix (as in the pseudo words).

Although the initial LMER did not reveal a boundary by word interaction between the prefixed real words, a follow-up analysis was still conducted examining the boundary by word type effect for only real prefixed words. The analysis revealed a significant boundary by word interaction true prefixed words were typed slower at the boundary and minus one position compared to the pseudo prefixed words. For the true prefixed words this means that the presence of a real prefix in the true words slows down the typing at the beginning of the word and at the boundary. In addition to this, generally the typing times at the beginning of a word are slower, so words with the presence of real prefix may disrupt processing further. Again, like the results of the real suffixes, this is expected where there is more slowing down to process the real prefixes and less slowing with the recognition of no prefix in the pseudo words.

In both instances, follow-up analyses looking specifically at the true and pseudo affixed words revealed that the removal of a particular boundary position would also remove the significant interactions, which would suggest that those positions are where the LRTs are truly different. It is clear from these prefix and suffix analyses that the pseudo words stand out from the others, and in particular from the true affixed words. The results of these analyses provide support for the claim that the morphological structure of the word types differs as seen from the significant interactions between morpheme boundary positions and word types. As for the research question, the results show differences in RTs between the novel and real words and within the real words as well. This would be expected as the real words are presumably the ones the participants would have had the most experience with in the past, compared to the completely made-up novel words (regardless of whether stem-affix violations occurred or not).

Question Two – Morphological Structuring of Language Groups

Research question two asked whether the magnitude of morphological decomposition would differ between native and non-native speakers of English. When typing suffix words, native speakers would have shorter RTs for the boundary position compared to the minus one but longer compared to the plus one position, and for prefixes the boundary position would have longer RTs compared to both the minus one and plus one positions. This would differ for non-native speakers as they would have longer RTs for suffixed words at the boundary position, but for prefixed words the RTs would be shorter. To test this, the language group variable was added to the LMER models. The differences came out in an interaction of boundary position and language group. Here native speakers had significantly longer typing times for the prefixed words when moving from the minus to the boundary position in comparison to the non-native speakers going from minus one to boundary (refer to Figure 6). A further follow-up analysis was conducted to compare the real and novel prefixed words separately to each other. The boundary by language group interaction remained significant for the pseudo vs true comparison but came out as non-significant in the novel word comparison. This suggests that it is the real prefixed words that are driving the significant interaction, particularly for the NS as they show the greatest sensitivity in typing times for the morpheme boundary.

This same exact model setup for the suffixed words yielded similar results. The NNS had significantly longer RTs at the minus one compare to boundary, and longer at the boundary compared to the plus one position. The NS followed this same pattern; however, the difference is that when moving from minus one to boundary, the NNS typing times decreased much faster than the NS (refer to Table 9). The follow-up analysis looking at just the real words, found that the boundary by language group interaction remained significant. This suggests that the NS are sensitive to the boundary effect for real word suffixes as they are slower when moving from the minus one to boundary position, while the NNS do not show this distinct slowing.

The findings from both the prefixes and suffixes provide evidence for a difference in morphological processing between native and non-native speakers. However, both the prefix and suffix findings show no support for NSs having slower typing times for the novel affixed words. Instead, the native speakers had slower typing times for the real affixed words compared to the novel affixed words. This is a surprising finding, in that one would think that the native speakers would have the most experience with the real words at least and would then out-perform the non-native speakers. One thing that could be taken from this result is that maybe the typing production task allowed for the non-native speakers to perform well on the real words. The reason for this could be that a typical language production setting would require speaking ability, social interaction, and a host of other factors (i.e., stress), but here the typing is able to strip all that away and almost create a level playing field with the native speakers. This idea is the basis of the following research question.

Question Three – Language fluency and typing latencies

The third and final research question furthered question two about differences between the language groups with the idea that the typing methodology used in experiment two might be useful as a measure of English language fluency in non-native speakers. First the dataset was selected only for the non-native speakers and from there the fluency score variable replaced the language group variable from model two. If there were to be any effects of fluency either on boundary position or word type it would be seen in this model. For the prefixes this was not the case. There were no significant effects of fluency in the analysis. Even after removing the word type variable, no effects were found. This clearly rules out the use of the typing methodology to test for fluency in this specific set of prefixed words for the current study. The suffix words analysis yielded several significant effects. The critical finding was a significant three-way interaction of boundary position, word type and fluency score. Non-native speakers with high fluency (score of 85) typed true, novel-impossible, and novel-possible suffixed words significantly faster at the plus one position compared to the boundary position of each one of those words. It's important to note there were no significant differences in typing times of pseudo suffixed words at the plus one compared to the boundary position. This suggests that as the NNS become more fluent (or more nativelike) they use more morphology as evinced by the slowing down going from boundary to plus one positions in pseudo suffixed words. While the result seems expected like previously, one thing stands out; just like the NS, the NNS were able to make a distinction in the processing of real and novel words. In a follow-up analysis, where the novel suffixed words were removed from the model, the boundary by fluency interactions remained significant.

One thing to consider when it comes to the results of the fluency question is the language fluency questionnaire. The questionnaire was 20 items that related to some aspect of English language usage on a daily basis (refer to Appendix Table B4). This style of questionnaire was chosen to avoid any general and vague self-assessment on language ability. The questions about daily use would probe the participant's ability to perform a particular action (i.e., they can tell the date or time, or can provide directions to a specific location). There are two problems with this questionnaire, the first being it measures speaking ability. This is not a bad thing, but this experiment measured typing production, as opposed to verbal production. So, to generalize results from one domain to the other may be problematic, especially as many non-native speakers learn abroad to deal with English in the written mode without much speaking practice, and others come here and learn to speak without having as much literacy training. The second issue is about how someone may approach the items in the questionnaire. To answer the question, the non-native speaker may have to consider several extrinsic factors such as speaking ability, confidence, form, accent, or even social skills. Thus, in terms of face validity, the questionnaire may be confounded with other factors that prevent the measurement of fluency in the non-native speakers.

Lastly, the overall ability to generalize the results of this study and specifically for the use of the typing task as a measure of fluency in ESL students is very limiting. The reason for this is that the population of Mturk workers in both Experiment One and Two had an average age of about 40 (refer to Appendix Table A1 and A2 for more participant information for Experiments One & Two). This age is much older than what most ESL/EFL students would have in the classroom. The youngest person in either experiment was 21 years of age, and even that age is most likely older than eldest student in the ESL/EFL classroom, unless it was an adult ESL/EFL classroom. As a result, it would be difficult to say whether the methodology could be useful as a tool to measure fluency for EAP or by teachers in the classroom.

Limitations

Having the ability to run experiments online has huge benefits, but it comes with its own set of problems. One such issue revolves around controlling who gets to participate in the study. For the current study, two experiments were created on Mturk, one for native speakers of English and the other for both native and non-native speakers. This was done to help separate results for the two groups and to help control who was eligible for which group. The non-native speakers were assigned a qualification of ESL if they had completed a language experience questionnaire previously. So, for a non-native speaker to participate they had to have the ESL qualification. For native speakers no such qualification was a given. So, it is possible that non-native speakers participated in the native speaker group experiment and stated they were native speaker when they may not have been. This could have been the contributing factor to why some native speakers had low English fluency scores on the fluency questionnaire. Another possible issue with the platform is that participants were mostly limited to North America because of the way Mturk pays workers. Since the payout is only in USD, it limits the population to who can have a US Amazon account.

Other limitations are related to the stimuli that were used in the experiment. Both the language groups (55 non-native, 52 native) and the word types (70 true, novel-possible & impossible, 60 pseudo) were quite balanced in terms of numbers of each. So, this means that the expected effects and their correct directions came out, and the groups were balanced, which suggests that the study worked. However, since the criteria for each word type was very specific (i.e., minimum six letters in length, only certain affixes used, all the stem-affix restrictions, stimuli being more than one syllable), it made it difficult to completely balance all the word types and the affix types. Furthermore, certain affix types just had more available options to choose from compared to others. This applied more to the word types in general. True-affixed are real words with real stems and no violations of stem-affixes. Even the two novel-affixed types were easy to construct because it was a matter of creating mismatches with stems and affixes to make up new words. But the pseudo affixed words were a problem because they required finding words that started or ended with one of the seven affixes and had to be a single morpheme. This brings up the other problem with pseudo affixed words in that they are single morpheme words, which are quite difficult to find but are even more difficult when having to be paired with specific affixes.

Lastly, a brief attempt was made to measure typing ability and style (i.e., how many fingers/hands are used, how many words can be typed per minute, able to type without looking at the keyboard etc.). However, it was unfortunately not included for all subjects and thus was unusable. Some measure of this needs to be included or developed to get a better understanding of how someone types in general, which can influence greatly the results of any typing study including this one.

Implications/Future Directions

As described in the introduction, morphology plays an important role in understanding language and obtaining vocabulary knowledge. One of the main goals of this study was to examine whether the typing methodology employed in Experiment Two could be used as a measure of morphological ability and fluency in non-native speakers of English. While the results did not provide any evidence for the methodology to be used as a measure of fluency, it did demonstrate morphological sensitivity. The results from research question two suggest that native speakers are more sensitive to the morpheme boundary in real suffixed words compared to the non-native speakers. A distinct slowing down at the boundary by the native but not non-native speakers demonstrates the recognition of the affix and thus morphological ability. Since the non-native speakers performed differently and sometimes very similarly to the native speakers, it shows the methodology can be used to compare these two groups. Furthermore, it adds credibility to the use of this typing methodology to investigate other morphological processes or be used in different linguistic domains. For instance, by substituting the stimuli for words with high valence or arousal ratings, one could compare how these two language groups differ in their ability to process highly emotional word content or stories in a block of text.

Another benefit from using this typing methodology is due to its inherent ability to have the words and participants as their own controls. There are multiple word entries from each person, and thus allowing for comparison to themselves. This adds statistical power to the study and helps to address the problem of homogenous samples. Non-native speakers often vary considerably in their language processing abilities and to have a group of speakers of the same level is quite difficult. By having each person be their own control, this problem can be circumvented.

Lastly, it may be that enhancing applicability of findings such as these to a classroom setting would require greater focus on particular age groups (for example those most characteristic of particular ESL populations). However, from the basis of this study alone, the ability to provide instant feedback to students using the typing methodology could be very valuable. Furthermore, future experiments may benefit from using better measures of fluency and typing ability/style to help clarify the findings from the current study.

Conclusions

The main goals of this study were to examine the morphological processing of native and non-native speakers of English and of true, pseudo, novel-possible and novel-impossible affixed words. A secondary goal was to determine whether this typing methodology could be used to measure fluency in non-native English speakers. Taking the results from the three research questions together, three take home messages persist.

First, there is a difference in the morphological processing of the four complex word types, and more so between the true and pseudo affixed real words. Second, both language groups showed evidence for morphological processing of the real affixed words over the novel words, and there were differences between the two language groups in this regard.

Lastly, the typing methodology may be useful for measuring fluency in non-native speakers but as seen from the results only for real suffixed words, and probably not in a way that allows the method (so far) to be used as a psychometric test of fluency in English. The methodology does provide a good comparison of the native and non-native language groups and thus could be used in a wide variety of linguistic contexts.

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Appendix A

Table A1

Participant Information for Experiment One.

Gender	N	Age (min to max)	Education Counts
Male	21	28 – 71	4 – Highschool 2 – College 10 – Bachelors 4 – Masters 1 – NA
Female	11	24 – 60	1 – Highschool 6 – Bachelors 4 – Masters
Other	1	35	1 – Bachelors
Overall Total:	33	24 – 71	5 – Highschool 2 – College 17 – Bachelors 8 – Masters 1 – NA

Table A2

Participant Information for Experiment Two.

Gender	N	Language Counts	Age (min to max)	Education Counts
Male	73	35 – Native Speakers 38 – Non-Native Speakers	21 – 66	8 – Highschool 4 – College 43 – Bachelors 17 – Masters 1 – NA
Female	33	16 – Native Speakers 17 – Non-Native Speakers	22 – 62	1 – Highschool 24 – Bachelors 7 – Masters 1 - PhD
NA	1	1 – Native Speaker	32	1 – NA
Overall Total:	107	52 – Native Speakers 55 – Non-Native Speakers	24 – 71	9 – Highschool 4 – College 67 – Bachelors 24 – Masters 1 – PhD 2 – NA

Appendix B

Table B1

Short demographic questionnaire that is presented at the beginning of the stimuli check lexical decision experiment (Experiment One)

Mturk Identification Number	
Age	
What is your gender? (e.g. M = Male, F = Female, O = Other, NA = Prefer not to say)	
Highest level of education completed?	
What is your First language?	
Please list any other languages that you may know.	

Table B2

Short demographic questionnaire that is presented at the beginning of the word typing task experiment (Experiment Two)

Mturk Identification Number	
Age	
What is your gender? (e.g. M = Male, F = Female, O = Other, NA = Prefer not to say)	
Highest level of education completed? (e.g. High School, Diploma, Bachelors, Masters, PhD)	
What is your First language?	
What is your Second language?	
Please list any other languages you may know. (ex. French, German etc.)	
At what age did you learn all your languages? (ex. Spanish - Age 4, English - Age 6)	

Table B3

Short typing style questionnaire that is presented during the pre-task activities prior to the word typing task (Experiment Two)

Please answer the question below using one of the four options.	
Press the number key associated with your answer.	
Which statement best describes your normal typing behaviour?	1 = I generally use all fingers of both hands 2 = I generally use about three fingers of each hand 3 = I generally use two fingers, one on each hand 4 = I generally type with one finger only

Table B4

20 item English language fluency questionnaire that is presented during the pre-task activities prior to the word typing task (Experiment Two)

Please answer the question below using one of the four options.	
Press the number key associated with your answer.	
I can introduce myself and say what my job is.	1 = I cannot do this 2 = Poorly 3 = With Difficulty 4 = Reasonably Well 5 = I can do this fluently
I can tell the date and time.	
If someone calls and speaks English on the phone, I can take and communicate basic messages.	
I can provide directions to a location (for example, to a store).	
I can say what I plan to do during the weekend.	
I can describe a foreign city that I have visited.	
I can explain why a certain location is my favourite vacation spot by providing three reasons.	
I can refuse an invitation to go to somewhere (for example, to a restaurant) and provide reasons for my refusal.	
I can say what I did yesterday.	
I can start a conversation when I meet someone.	
I can return an item to a store and explain why I am returning that item.	
I can phone a doctor's office to make an appointment and explain my medical issue in general terms.	
I can praise or criticize a film, a play or a person.	
I can contrast two cities in the world on the basis of lifestyle and culture.	
At a restaurant, I can complain about a dish and express my displeasure.	
After a presentation, I can ask a question.	
I can formulate a suggestion at a formal meeting.	
If I do not share someone's opinion on a	

serious matter, I can argue and express my opinion.	
I can talk about the pros and cons of a particular situation.	
I can provide a detailed account of a speech given by the head of the organization for which I work.	

Figure B1

The sample paragraph typed in the pre-task typing activity.

>>> Hunt and peck, i.e., typing with only two fingers, also known as Eagle Finger, is a common form of typing in which the typist presses each key individually. Instead of relying on the memorized position of keys, the typist must find each key by sight. Use of this method may also prevent the typist from being able to see what has been typed without glancing away from the keys. Although good accuracy may be achieved, any typing errors that are made may not be noticed immediately due to the user not looking at the screen. There is also the disadvantage that because fewer fingers are used, those that are used are forced to move a much greater distance.

Appendix C

Table C1

Stimuli information table. True-affixed are real words that can be decomposed into 2 or more morphemes. Pseudo-affixed are real words that look like they can decompose into 2 morphemes but cannot. Novel-affixed possible words are non-words with a real stem and affix that satisfy stem-affix restrictions. Novel-affixed impossible words are non-words with a real stem and affix but cannot go together due to stem-affix restrictions.

Affix	Type	True	Pseudo	Novel - Possible	Novel - Impossible	Total Number of Words/Affix
un-	Prefix	unlock	unison	unflat	unboat	34
re-	Prefix	reborn	retail	rechock	replush	47
-er	Suffix	hunter	brother	gummer	blimper	40
-ity	Suffix	humidity	varsity	exactity	inventity	40
-ize	Suffix	hospitalize	capsize	silentize	eruptize	35
-able	Suffix	fixable	affable	meldable	crookable	41
-ness	Suffix	kindness	business	proudness	bowness	33
Total Number of Words/Word Type		70	60	70	70	270

Table C2

Full word list per word type.

True Affixed	Pseudo Affixed	Novel-Possible Affixed	Novel-Impossible Affixed
teacher	affable	scuffer	packeter
fighter	liable	smircher	organer
hunter	capable	trender	blimper
catcher	constable	allower	gunker
golfer	formidable	failer	agenter
holder	palpable	yanker	nickeler
builder	amiable	convicter	instincter
walker	vulnerable	needer	eventer
breeder	despicable	combuster	jacketer
wrecker	potable	threater	glitcher
legality	viable	reyearn	unmiddle
mutuality	wicker	rehold	unlizard
humidity	drawer	rebungle	unpekoe
fluidity	whisker	repester	unsheep
stupidity	beaker	rechuck	unstilt
complexity	ponder	resnitch	uncheek
morbidity	mutter	repluck	unboat
tonality	brother	retickle	unbasket
practicality	flicker	redowse	unlamp
locality	wander	reavert	untangent
hospitalize	bother	unmild	periodable
winterize	amenity	unweird	clefable
capitalize	vicinity	unfake	crookable
normalize	celebrity	unpassive	glassable
burglarize	cavity	unprompt	skillable
moralize	humility	unsimple	wristable
hybridize	paucity	unplump	loyalable
vitalize	propensity	unflat	barnable
itemize	entity	unlarge	plightable
terrorize	varsity	unthick	pathable
singable	acuity	adeptity	broilness
filmable	iodize	foreignity	debutness
thinkable	cauterize	callowity	pointness
contestable	pulverize	horridity	fraudness
spreadable	tantalize	compactity	beatness
employable	understand	piousity	mightness
wearable	capsize	corruptity	bowness
rentable	unique	robustity	sleetness
fixable	unison	exactity	crashness

printable	remnant	occultity	boastness
realign	underneath	facetize	inventity
reinsure	remorse	timidize	soapity
reboot	rescue	pepperize	riskity
reacquire	rendition	silentize	warpity
reissue	realtor	riverize	mournity
reduplicate	repertoire	honestize	wringity
review	remember	shovelize	gullity
retread	reptile	discreetize	alarmity
rebind	repeal	razorize	smashity
reassemble	reservoir	quietize	drugity
unclog	regimen	jiltable	eruptize
unbend	residue	pretendable	grindize
uncover	recipe	snipable	bumpize
unseal	response	coughable	keepize
uncork	regatta	meldable	throwize
unlock	retina	charable	listenize
unbutton	region	craftable	cleanize
unleash	witness	dingable	meltize
unplug	business	peekable	acceptize
untangle	harness	digable	paintize
kindness		lateralness	retrunk
positiveness		centerness	reomelet
cruelness		proudness	replush
harshness		linearness	rechild
whiteness		lastness	redaisy
weakness		absentness	rethroat
frigidness		tealness	replasma
loudness		vibrantness	reking
moistness		elegantness	repalace
distinctness		worstness	redonkey

Table C3

Stimulus-affix restrictions table.

Affix	Affix Name	Stem Lexical Category	Stem + Affix = Change	Example
Prefix	un-	Adjective or Verb	Adjective → New Adjective Verb → New Verb	Kind → Unkind
Prefix	re-	Verb	Verb → New Verb	Think → Rethink
Suffix	-er	Verb	Verb → Noun	Build → Builder
Suffix	-ity	Adjective	Adjective → Noun	Stupid → Stupidity
Suffix	-ize	Noun or Adjective	Noun → Verb Adjective → Verb	Hospital → Hospitalize
Suffix	-able	Verb	Verb → Adjective	Fix → Fixable
Suffix	-ness	Adjective	Adjective → Noun	Sad → Sadness