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6-month-olds' segmentation and representation of morphologically complex words

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ABSTRACT OF THE DISSERTATION

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by

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Professor Megha Sundara, Chair

One of the issues in infants' language acquisition is - how do infants find word-like forms from fluent speech. Previous literature on infants word segmentation has mostly focused on understanding the bottom-up cues, i.e., cues in the input such as acoustic/prosodic cues, that infants utilize in pulling out nouns. This dissertation asks whether infants can use **top-down** cues in pulling out **verbs**. Verb segmentation has been reported to be delayed as compared to noun segmentation and these results have been used to explain the delay in its acquisition of verbs. This dissertation argues otherwise, demonstrating that in fact at the beginning of word segmentation, i.e., at 6-months, infants can pull out verbs with the help of a known word *mommy* (a paradigm used in Bortfeld, Morgan, Golinkoff, & Rathbun, 2005).

The current dissertation goes further and asks how these verbs are represented. To be specific, this dissertation looks at 6-month-olds' segmentation of morphologically complex verbs, such as *walking*, *walks*, and *walked*, and asks whether preverbal infants can relate these forms to the root form *walk*. The main focus of this research is to understand how prelexical infants, who cannot rely on semantics, relate complex forms to the root forms.

This dissertation expands our understanding of the role of the functional morphemes (such as *-ing, -ed, -s*) in this process by conducting a corpus analysis as well as behavioral experiments. In this dissertation, I locate the beginning stage of this complex form acquisition and show that at 6-months, infants start segmenting complex verbs, and based on the frequency and the characteristics of the functional morphemes, infants begin to relate complex forms to root forms. The findings of this dissertation highlight the importance of top-down cues in early language development and have crucial implications for verb acquisition. Also, these results provide evidence for morpheme-based processing models and acquisition models such as prosody-functor models, arguing for early representation of functional elements and their facilitatory influence on word segmentation and representation.

The dissertation of Yun Jung Kim is approved.

Toben Mintz

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2015

To my families, especially my husband and my daughter,

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Sundara, M., **Kim, Y. J.**, White, J., & Chong, A. J. (under revision). There is not *pat* in *patting*: Phonetic similarity biases infants learning of phonological alternations.

Kim, Y. J. (in press). Do learners prefer transparent rule ordering? An artificial language learning study. *47thProceedings in Chicago Linguistic Society*, 2011, The University of Chicago

Kim, Y. J. & Sundara, M. (2014). Segmentation of word-initial words is facilitated by function words. *Journal of Child Language*, available on CJO2014. doi:10.1017/S0305000914000269

Kim, Y. J. (2012). Function words facilitate vowel-initial word segmentation, Unpublished thesis. UCLA

Oh, M. & **Kim, Y. J.** (2011). The production of Korean Stops and Intonation by English Speakers. *Teaching Korean as a Foreign Language*, 36, pp. 139-158. (KCI)

Kim, Y. J. (2008). Advice-giving in EFL writing tutorial sessions: the initiation and the reception of advice in the interaction between the nonnative tutor and the nonnative tutee Unpublished thesis, SNU

Kim, Y. J. (2007). A Discourse Analysis of Writing Tutorials: with Reference to the Dominance in Nonnative Tutees. *SNU working papers in English Language and Linguistics*, 6, pp. 14-34

CHAPTER 1

Introduction

1.1 Overview of the dissertation

This first chapter serves to explain some of the mechanisms that infants may use to find word-like forms from fluent speech. First, I illustrate the segmentation problem and review previous research on constraints or strategies used to tackle this segmentation problem. I also cite studies on the role of functional elements, especially the role of function words in solving the segmentation problem as well as in the general language acquisition process. While doing that, I lay out my hypothesis that functional morphemes can be "known words" for infants based on the similarities between function words and functional morphemes. In Chapter 2, I focus more specifically on the research on the representation of morphologically complex forms by adults, and summarize different acquisition theories and models that explain and predict the representation of complex forms for young language learners. In Chapter 3, I conduct a corpus analysis on functional elements in children's input from the CHILDES database (MacWhinney, 2000) to understand the frequency and transitional probability of the English functional elements. In Chapter 4, I describe the experiments conducted for this research. The Headturn Preference Procedure (Kemler-Nelson et al., 1995) was used for all seven experiments. The experiments were designed to ask whether infants at the beginning stage of the word segmentation (i.e., 6-month-olds) can segment complex verbs from sentences, and whether they can relate those complex forms to the root forms. I was particularly interested in figuring out the factors that affect verb segmentation and representation, such as a) phonological similarity, b) morpheme frequency, and c) the characteristics of the morpheme (such as consonant vs. vowel onsets). In Chapter 5, I will include a summary of the outstanding questions raised by these experiments, as well as discussion of how these results complement existing research on word segmentation. The implications of these results for theories of morphologically complex word representation and models of language acquisition will also be discussed, followed by a conclusion section.

1.2 Finding words from speech: The segmentation problem

In everyday conversation, we encounter a continuous speech stream. Successful communication thus depends on recognizing words from the continuous stream of speech. However, speech input often lacks clear word boundaries due to the absence of audible pauses and coarticulation effects between adjacent sounds. Also, there is no one reliable cue that consistently signals word boundaries. Therefore, finding and recognizing words from fluent speech is a complicated task.

Despite these difficulties, adults succeed in communicating with each other with little effort. How do adults detect word boundaries so easily? One approach is to look at the cues in the signal itself, i.e., bottom-up cues, that may suggest possible boundaries. These bottom-up cues can be language-general, such as distributional cues (e.g., transitional probability, i.e., the co-occurrence probability between syllables, and frequency), or language-specific such as segmental cues and prosodic cues (McQueen, 2007). Adults are known to be sensitive to these bottom-up cues in tackling the segmentation problem.

Similar to adults, infants also face the segmentation problem. This is because infants hear sentences or phrases, not isolated words, more than 90% of the times (Brent & Siskind, 2001; van de Weijer, 1998). Therefore, one of the first tasks that infants need to succeed in, in order to acquire language, is segmenting words from fluent speech. Despite the fact that this problem is complicated, it has been shown that infants are able to segment and identify word forms at a very young age, long before they produce their first words. This segmentation ability emerges between 6-7.5 months of age for English-learning infants (Bortfeld et al., 2005; Jusczyk & Aslin, 1995). To figure out how infants manage to do this, the literature on infants' word segmentation has focused on the cues that infants may use in finding words from speech. It has been shown that infants really early on can utilize bottom-up cues in tackling the segmentation problem. The next section summaries the bottom-up cues that both adults and infants use.

1.3 Bottom-up cues

1.3.1 Language-general: Distributional cues

Some of the cues in the input are language-general, such as distributional cues. Previous literature on the use of distributional cues in word segmentation can be broadly divided into two types. One type focuses on identifying word boundaries using measures of predictability, i.e., transitional probability, between small units, such as phonemes or syllables. The other type attempts to recognize entire words by storing chunks of speech that recur frequently (see Brent (1999), for an overview).

Transitional probability that is used in the first type of research considers the probability of an event given that another event has occurred, as shown in 1.1.

$$TP = P(Y \mid X) = \frac{\text{Frequency of XY}}{\text{Frequency of X}}$$

Figure 1.1: Transitional Probability

The equation in Figure 1.1 computes the probability of Y given X (denoted as P (Y | X)), which is equal to the probability of the co-occurrence of XY (i.e., frequency of XY) over the probability of the occurrence X (i.e., frequency of X). Previous studies have demonstrated that listeners are sensitive to the transitional probability of a sub-word unit, such as the syllable, in finding word-like units (Saffran, Aslin, & Newport, 1996; Saffran, Newport, & Aslin, 1996). The intuition behind using the transitional probability between syllables is that frequently occurring sound sequences[1] in various contexts are better candidates as possible words than those occur rarely in just a few contexts (Brent & Cartwright, 1996). That is, when the first syllable of a disyllable word is given, the probability of the occurrence of the second syllable of the word is higher than the probability of the occurrence of any other syllable. For instance, for the word *pretty*, the occurrence of *ty* given *pre* would be higher than that of *pre* followed by *ny*. Therefore, if *pre* is followed by random syllables that do not normally combine with it such as *ky, sy* or *fy*, listeners assume a word boundary between *pre* and those rarely occurring syllables due to lower transitional probabilities between those syllables.

Not only the forward transitional probability, but also backward transitional probability can be useful in figuring out possible word boundaries.

The equation in Figure 1.2 computes the probability that Y has been preceded by X, and it has been shown that these backward transitional probabili-

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[1] This does not mean that sequences have to occur frequently to have a high transitional probability. The transitional probability of a sequence can be high (even 1.0) but the sequence can be very infrequent at the same time. However, in most cases, frequently occurring sound sequences are more likely to be possible words than sequences that occur less frequently in less variable contexts.

$$BTP = P(X \mid Y) = \frac{\text{Frequency of XY}}{\text{Frequency of Y}}$$

Figure 1.2: Backward Transitional Probability

ties are equally informative about word structure especially in languages that have multiple suffixes attached (Pelucchi, Hay, & Saffran, 2009a).

Adults are sensitive to transitional probability information and use it to segment words from speech. A study done with English-speaking adults demonstrated that subjects were able to segment nonsense trisyllabic words (CVCVCV) from speech based only on transitional probabilities (Saffran, Newport, & Aslin, 1996). Since the stimuli used were synthetic, lacking any other acoustic or prosodic cues, these results strongly suggest that transitional probability alone can assist listeners to extract words from speech input.

Experimental results demonstrate that infants can also utilize transitional probability information to segment words. English-learning 8-month-olds were able to differentiate sequences with high transitional probability and low transitional probability, and only treat the sequences with high transitional probability as coherent word units (Saffran, Aslin, & Newport, 1996). Infants in their study were able to infer that syllables that occur together frequently, that is have a high transitional probability, are possible words. Evidence that infants utilize transitional probability in a word segmentation task has been shown with both artificial languages and natural languages by infants learning languages such as English (Aslin, Saffran, & Newport, 1998; Pelucchi et al., 2009a), Dutch (Johnson & Tyler, 2010), and French (Mersad & Nazzi, 2012). Also, Saffran (2001) demonstrated that infants treat the output of this statistical learning process as a possible "word" and only recognize it when the possible word is embedded in their native language (e.g., "I like my *tibudo*"), but not when it is embedded in nonsense sequences (e.g., "zy like ny *tibudo*").

Infants at later stages of language acquisition can also use the output of this statistical learning process in acquiring the meaning of new object labels. They learn to map the labels for the high transitional probability sequences to visual referents, fail to do so for low transitional probability part word labels or nonword labels (Graf Estes, Evans, Alibali, & Saffran, 2007; Mirman, Magnuson, Graf Estes, & Dixon, 2008).

Frequency alone, though weaker than the transitional probability cue, can also facilitate word segmentation. The effect of frequency in word recognition and segmentation has been widely shown for adults (Grainger, 1990). Adults recognize and segment words that are frequent in the input more easily compared to the less frequent items.

The role of word frequency in infants' word segmentation has been studied as well. For example, Ngon et al. (2013) investigated French learning 11-month-olds' "protolexicon" and demonstrated that infants treated highly frequent sequences from their native language as possible words, failing to distinguish words and nonwords among those sequences. However, infants did not treat low-frequency sequences as words, highlighting the role of frequency in word segmentation and representation. All of the words and nonword sequences in Ngon et al.'s study were selected from French infant-directed corpora based on their frequencies in the infants' input.

So far we have seen that adults and infants both utilize transitional probability and frequency, two language-general distributional cues, in segmenting words from fluent speech. In the next section, I will summarise language-specific cues, both segmental and prosodic, that facilitate word segmentation.

1.3.2 Language-specific: Segmental cues

The language-general distributional cues described above can also help learners detect segmental cues that are present in their native language. For example, one such cue is a phonotactic constraint about their native language. Phonotactics restricts the possible sound sequences and syllable structures in a language. For example, /vn/ is not a legal sequence in English, therefore a sequence of these two sounds will be considered as belonging to two different words as in [faɪvnɛts] "five nets". Adults are sensitive to this type of information and use it to segment words when it is an absolute cue to mark word boundaries (Dumay, Frauenfelder, & Content, 2002; McQueen, 1998; Warner, Kim, Davis, & Cutler, 2005; Weber & Cutler, 2006). For example, French-learning adults heavily rely on syllable onsets to locate the beginning of words. When a word onset and the syllable onset are misaligned, adults have a harder time detecting the target words (Dumay et al., 2002). *Lac* "lake" is easier to spot in *zunlac*, where its edge is aligned with a phonotactically obligatory syllable boundary (that is, <u>nl</u> is not a possible onset), than in *zuglac*, where this is not the case.

Adults are also sensitive to gradient phonotactic knowledge in finding words (van der Lugt, 2001). Dutch listeners showed that words with common beginnings are easier to find than words with rare beginnings. For example, it was easier to find *galg* "gallows" in *piengalg* than *geur* "aroma" in *piengeur*. Both *ga-* and *geu-* are possible beginnings in Dutch, but more words begin with *ga-* than with *geu-*. Dutch listeners were, thus, able to use this gradient knowledge to segment words.

Warner et al. (2005) used Korean listeners to show that they can use both absolute and gradient phonotactic knowledge to find words from speech. In Korean, word boundaries are illegal in the sequence [dʒi], it is legal but not likely in the sequence [di], and very likely in the sequence [nni]. The sensitivity to these different degrees of phonotactic knowledge was shown in word spotting experiments. Korean listeners find words such as *imin* "migration" more easily in [pjodimin] than in [pjodʒimin], and fastest in [pjonnimin].

Another type of segmental cue that adults utilize is coarticulation information (Suomi, McQueen, & Cutler, 1997; Vroomen, Tuomainen, & de Gelder, 1998; Mattys, 2004; Mattys, White, & Melhorn, 2005). For example, in Finnish, vowel harmony provides word-boundary information (Suomi et al., 1997). There are restrictions on which vowels can co-occur within a word; effectively two distinct sets of vowels exist that never both occur within the same word. Listeners appear to have learned to use the knowledge that, if a sequence of speech contains vowels from these two sets, there must be a word boundary between those vowels.

Allophonic information is another type of segmental information that learners can utilize. Allophones are phonetic realizations of phonemes that differ depending on their location within a word. For instance, English voiceless stops are aspirated in word-initial position (e.g., $\underline{\text{p}}$ie [p^h]), but not, for example, after the consonant /s/ (e.g., s$\underline{\text{p}}$y [p]). Such allophonic variation can be used to recognize words in ambiguous speech sequences (Nakatani & Dukes, 1977). Nakatani and Dukes (1977) show that the allophonic variation of syllable-initial and -final /l/ and /r/ can be used for recognizing words. For example, adults successfully segmented *loan* from "we loan" but not from "we'll own" based on the different allophones of /l/ in two cases (dark /ɫ/ vs. light /l/).

Lastly, adults are sensitive to syllable structures of language and use it to distinguish possible and impossible word-like units. For example, in English, a single consonant cannot be a word. Therefore, English-learning adults strongly disfavor any segmentation that leaves an isolated single consonant. This constraint is called the Possible Word Constraint (hereafter PWC: Norris, McQueen, Cutler, & Butterfield, 1997). In Norris et al.'s experiments, listeners easily find the word *apple* in *vuffapple*, where *vuff* could be a word in English, compare to *fapple*, where they have to leave a single consonant [f] behind. Norris et al. (1997) have shown that when the PWC is implemented in the spoken recognition models such as Shortlist, it significantly improves the performance of the models. Evidence for the PWC has now been found in a range of languages including English (Norris et al., 1997; Norris, McQueen, Cutler, Butterfield, & Kearns, 2001), Dutch (McQueen, 1998), Japanese (McQueen, Otake, & Cutler, 2001) and Sesotho (Cutler, Demuth, & McQueen, 2002), but not Berber (Aissati, McQueen, & Cutler, 2012), which demonstrates that this constraint is language-specific likely based on the syllable structures allowed in the target language.

Parallel research on infants' segmentation also demonstrates infants' sensitivity to these types of bottom-up cues. First, infants develop sensitivity to phonotactic knowledge between 6-9 months, and can use phonotactic knowledge to find words. By 9 months, infants exhibit a preference for phonotactically well-formed speech strings in their native language (Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993). They observed that 9-month-old, but not 6-month-old, English-learning and Dutch-learning infants listened longer to a list of words with phonemic sequences legal in their native language than sequences that are illegal in their native language. At the same age, infants prefer and listen longer to high-probability phonotactic sequences such as *chun* than low-probability phonotactic sequences such as *yush* (Jusczyk, Luce, & Charles-Luce, 1994). Infants at 9-months can also use this phonotactic knowledge and sensitivity in word segmentation. Mattys and Jusczyk (2001) found that infants listened longer to a CVC stimulus when the stimulus previously appeared in a good phonotactic condition, where the phonotactic patterns at the words' edges set the target word apart from adjacent words as in *dice* from "roll dice". However, infants did not listen longer to target words such as *dice* from passages containing the corresponding phonemic pattern across a word boundary as in “cold ice” where the phonotactic patterns at the words’ edges blend the target word into the neighboring words.

Second, infants can also use allophonic information in word segmentation. For instance, Juscyzk, Goodman, and Baumann (1999) familiarized infants with pairs of sequences/words with one item in an allophonic minimal pair (e.g., “nitrates” or “night rates”) and tested if they could differentiate passages with “night rate” and passages with “nitrates”. 10.5 month-olds, but not 9-month-olds, were able to distinguish the two passages. This study shows that infants between 9-10.5 months are sensitive to allophonic differences and use this information in recognizing words.

Infants can also rely on other bottom-up cues such as phonological restrictions at 7-months (Mintz & Walker, 2006) and degree of coarticulation at 8-months (Johnson & Jusczyk, 2001) in finding words from speech. For example, Mintz and Walker (2006) illustrated that even English-learning 7-month-olds prefer listening to sequences that obey vowel-harmony over sequences that violate harmony, indicating their sensitivity to such phonological restrictions.

Infants’ sensitivity to syllable structures has been demonstrated as well. 12-month-old English-learning infants show sensitivity to the PWC in segmenting words from fluent speech (Johnson, Jusczyk, Cutler, & Norris, 2003). For example, infants recognized and listened longer to *win* than other words when it was in a possible word condition as in *winsome*, but this preference went away when *win* was in an impossible condition such as in *wind*. These results suggest that from early on, infant can use this constraint to generate “possible-words” from the speech signal.

1.3.3 Language-specific: Prosodic cues

Another source of information that learners may use in the segmentation process is prosody, the rhythm and intonation of speech. Prosody can help segmentation in two ways: a) the specific rhythm of the language can provide candidates for potential word boundaries, and b) it can help segmenting prosodic units bigger than words.

First, early rhythmic segmentation hypothesis (Nazzi, Iakimova, Bertoncini, Fredonie, & Alcantara, 2006) argues that both infants and adults are able to identify the rhythmic segmentation unit depending on their native language rhythmic structure (i.e., *Stress* in English, German, and Dutch; *Syllable* in French, Spanish and Korean; *Mora* in Japanese). For example, in English, the main rhythmic unit is the trochee, i.e., a Strong syllable followed by a Weak syllable as in *kingdom*. About 85% of the lexical words in the adults' input begin with a strong syllable based on a dictionary with 33,000 entries (Cutler & Carter, 1987). This regularity cues both adults and infants to use a strong syllable as the onset of a word (Curtin, Mintz, & Christiansen, 2005; Echols, Crowhurst, & Childers, 1997; Houston, Santelmann, & Jusczyk, 2004; Jusczyk, Houston, & Newsome, 1999; Norris, McQueen, & Cutler, 1995). For example, native listeners of English detected the target monosyllable real word *mint* from two-syllable sequences faster when the second syllable had a weak stress [ˈmɪnˌtəf] than when both syllables were strong [ˈmɪnˈtef] (Cutler & Norris, 1988). This is because adults insert a word boundary before the second strong syllable in [ˈmɪnˈtef], so it is parsed as [mɪn.tef]), where [t] is treated as the onset of the following syllable.

This rhythmic bias is very strong and even leads listeners to missegment less frequent rhythmic structures, iambs, i.e., a Weak syllable followed by a Strong syllable as in *guitar*. For example, listeners tend to insert word boundaries before strong syllable therefore misperceive “into opposing camps” as “into a posing camp”. They also fail to spot the boundaries before weak syllables and misperceive ‘my gorge is‘ as ‘my gorgeous’ (Cutler & Butterfield, 1992).

Infants as young as 7.5 month-olds show sensitivity to this rhythmic structure and use it to segment words. English-learning infants at 7.5 months can segment SW words from sentences such as *doctor* or *kingdom*. However, they fail to segment WS words such as *guitar*, or *beret*, and even missegment them as *tar*, or *taris* when the be-verb consistently follows the target syllable (Jusczyk et al., 1999). They have to be 11-month-olds to be able to overcome this bias and segment WS words from speech.

Listeners can also use prosodic units and use them to detect the word boundaries. The most prominent prosodic cue is a pause following a prosodic phrase. Even though pauses are not always present in the input, when present, they are highly correlated with the major phrase boundaries, and hence facilitate segmentation. Also, phrase-boundary cues facilitate segmentation (Christophe, Peperkamp, Pallier, Block, & Mehler, 2004). French-learning adults discriminate bisyllable words such as *mati* which were extracted from a long word as in “climatise” from sequences of syllables from two consecutive words “panorama typique” based on the phonological phrase boundary in the latter case.

Infants’ sensitivity to phonological phrase boundary cues facilitating word segmentation has been tested more directly (Christophe, Gout, Peperkamp, & Morgan, 2003). Again, French-learning adults were given sentences that contain ambiguous words as in [d’un **chat grin**cheux]$_{pp}$ “of a grumpy cat” where *chagrin* (homophones with **chat grin**, where the <t> is silent) is an existing word in French. Another set of sentences did not contain such ambiguity as in [d’un **chat dro**gué]$_{pp}$ “of a doped cat”. Adults were asked to detect the word *chat* “cat” in both cases. Here, adults detect the target word faster in the unambiguous cases than in ambiguous cases. However, when the two syllables spanned a phonological phrase as in ...**chat**]$_{pp}$[**grim**pai... with potential ambiguity vs. ...**chat**]$_{pp}$ [**dre**ssait... without potential ambiguity, the reaction time differences disappeared.

Prosodic information is also used in early development. It has been reported that infants are also sensitive to the presence of a pause, and more importantly, the location of pauses in sentence (Hirsh-Pasek et al., 1987; Gerken, Jusczyk, & Mandel, 1994). In these studies infants listen longer to the utterances when pauses coincide with major syntactic phrases, than those that contained mismatched pauses. Also, 13.5-16 months have been shown to be sensitive to phonological phrase boundaries in segmenting words (Gout, Christophe, & Morgan, 2004; Millotte et al., 2010). For example, 13-month-old English-learning infants recognize *paper* within a phonological phrase [...paper]$_{pp}$ but not across phonological phrase boundary ...pay]$_{pp}$[per... (Gout et al., 2004).

1.3.4 When cues collide

In a natural environment, these bottom-up cues often co-occur with each other in the speech stream. A number of previous studies have looked at how these different bottom-up cues are weighted with respect to each other. Special attention has been given to cases where cues mismatch in signalling word boundaries. Such mismatch cases are possible as speech input can be distorted due to background noise, slips of the tongue, or other factors. Norris et al. (1997) analyzed one such case where the phrase "met a fourth time" could be heard as "met a fourf time" either because of dialectal use of the pronunciation *fourf* or because the final fricative ([θ]) was distorted by background noise, leading to perception of [f]. Therefore, an alternative parsing was possible such as "metaphor f time". Even though the bottom-up cues suggested this alternative as a possible parsing, the PWC prevents this segmentation, as it leaves out the single consonant [f] behind. In this case, PWC outweighs the segmental cues and makes it possible to overcome the wrong segmentation due to distorted speech input.

Mattys (2004) was interested in the interaction between stress cues and coarticulation cues. When there was noise in the auditory input, he found that adults used both types of cues yet weighted the stress cues higher than the coarticulation cues. However, when there was no noise in the auditory input, adults only used the coarticulation cues. This study demonstrated that adults weight different types of cues depending on the speech input and the environment that the signal has been produced in.

Other studies have highlighted the importance of the stress cues, showing that even when the segmental information is intact, incorrect stress can disrupt lexical access in Dutch- (Cutler & Donselaar, 2001; Donselaar, van, & Cutler, 2005), Spanish- (Soto-Faraco, Sebastián-Gallés, & Cutler, 2001), and English-speakers (Cooper, Cutler, & Wales, 2002).

For infants, more studies have focused on which cues are learned when, and if they can use both, which cues are weighted higher. The relationship between language-general distributional cues such as TP and language-specific stress cues, and how the weight of each cue may change over the course of language acquisition, has been examined in various studies. For example, at 7-months, infants attend more to TP than to stress cues (Thiessen & Saffran, 2003). However, 8-month-olds rely more on stress and coarticulation cues than TPs when these cues conflict in the speech input (Johnson & Jusczyk, 2001). At 11-months, infants still rely more on stress than TP in a word segmentation task, illustrating that 11-month-olds weight stress cues to word boundaries more heavily than distributional cues (Johnson & Seidl, 2009).

Until now, we have looked at the bottom-up cues that listeners utilize in segmenting words from speech. These bottom-up cues are mostly language-specific with the exception of distributional cues; thus they have to be learned.

Even once learned, these cues leave considerable ambiguity regarding the location of word boundaries (Fisher & Gleitman, 2002). For this reason, theories of adult spoken word recognition typically assume that identification of word boundaries is, to a certain degree, a result of the recognition of a familiar word, rather than a prerequisite to it (Lively, Pisoni, & Goldinger, 1994). For instance, spoken word recognition models such as TRACE (McClelland & Elman, 1986) and Shortlist (Norris, 1994), as well as a bayesian model such as Shortlist B (Norris & McQueen, 2008) argue that word recognition is achieved by competition among possible candidates that are generated from the mental lexicon, and the segmentation problem is resolved as a by-product of this recognition process. Therefore, the role of the top-down cues, i.e., known words, in recognizing and segmenting speech has been highlighted in adults' spoken word recognition. In the next section, I summarize studies that looked at the role of top-down cues in word segmentation.

1.4 Top-down cues

Top-down cues, i.e., known words, signal a possible word boundary thus facilitating the recognition of an adjacent word. For example, English listeners are faster at recognizing *pram* in *prampidge* than *thin* in *thintaup* because more English words start with *pidge* than with *taup* (Norris et al., 1995). Similar results have been shown by Dutch listeners as well (Vroomen & de Gelder, 1995).

Compared to the importance that studies have put on for the role of known-word for adults, the role of top-down cues in infants' segmentation of words has been acquired less attention. One of reasons behind this lack of attention has been the idea that infants do not have enough lexical knowledge for top-down cues to be useful in tackling the word segmentation problem. However, recent studies are suggesting that infants do have some knowledge of lexical items, and can use them to segment adjacent words. For example, English-learning 6-month-olds have been shown to simultaneously segment a word-form and associate it to a visual referent (Shukla, White, & Aslin, 2011), and know the meaning of some frequent words of their native language such as body items like *nose* or food items like *banana* (Bergelson & Swingley, 2012). Thus, infants at 6-months have minimally stored the sound forms of some familiar words, and can associate the sound sequences to meaning. Furthermore, they can use these types of "known words" in segmenting adjacent word. For example, 6-month-olds can rely on very familiar and frequent words such as *mommy/mama* or their own name in segmenting the adjacent word *feet* in the sentence "Mommy's feet were different sizes" (Bortfeld et al., 2005).

A natural question that follows is, what is a "known word" for infants. Parallel research on functional elements suggest that not only content words such as nouns or verbs, but also function words, free standing functional elements such as *a, the* and *but* may also be familiar to infants thus work as "known words" for them. Although function words lack obvious and concrete meanings, they occur frequently enough for infants to recognize them as possible units within the first year of life.

1.4.1 Functional elements as known words for infants

Even newborns - whether prenatally exposed to English or Chinese - have been shown to distinguish English function words from content words (Shi, Werker, & Morgan, 1999). Thus, the ability to distinguish function words from content words seems to be independent of language experience, perhaps supported by phonological, distributional and acoustic cues, at least in languages like Mandarin Chinese, Turkish and English (Shi, Morgan, & Allopena, 1998; Shi et al., 1999). Additionally, various cross-linguistic studies have shown that within the first year of life, infants can recognize function words from a [target function word + noun] phrase (7-9 months for German-learning infants, Hohle & Weissenborn, 2003, and 6-8 months for Canadian French-learning infants, Shi & Gauthier, 2005; Shi, Marquis, & Gauthier, 2006, and 11 months for European-French-learning infants, Hallé, Durand, & de Boysson-Bardies, 2008).

Infants can also use the "known" function words in solving the segmentation problem. Shi and colleagues (Shi, Cutler, Werker, & Cruickshank, 2006; Shi, Werker, & Cutler, 2006) have demonstrated that English-learning 8 month-olds can use function words to segment a familiarized novel noun such as *breek* when familiarised with a two-word phrase such as *the breek*. They also found that only the frequent function word *the*, but not the less frequent *her*, facilitates segmentation. Also both *the* and prosodically-matched *kuh* facilitate segmentation at 8-months. These results demonstrate that a) the frequency of the function words plays an important role in the segmentation ability and b) even the frequent function words are not represented in a phonologically detailed manner, i.e., both *the* and *kuh* can be used early in development. Similar results have been shown with Canadian French-learning 8-month-olds (Shi & Lepage, 2008). They are also able to use the frequent function word *des* (/de/, indefinite plural article), but not the less frequent function word *vos* (/vo/ your, plural form) in segmenting novel nouns presented after the function words.

The frequent function word *the* also facilitates segmentation of vowel-initial words (Kim & Sundara, 2014). Vowel-initial words are reported to be segmented later (13.5-16 months of age: Mattys & Jusczyk, 2001; Nazzi, Dilley, Jusczyk, Shattuck-Hufnagel, & Jusczyk, 2005) than consonant-initial words (6-7.5 months of age: Bortfeld et al., 2005; Jusczyk et al., 1999). This delay in the segmentation of vowel-initial words has been attributed to perceptual factors (Seidl & Johnson, 2008). For example, vowel-initial words lack clear abrupt onsets, and tend to undergo resyllabification (e.g., "last hour" becomes "las tower", Guy, 1991). Seidl and Johnson (2008) illustrated one environment that may facilitate vowel-initial word segmentation: at sentence-edges. Kim and Sundara (2014) demonstrated another environment that the vowel-initial words were segmented at 11-months of age, when the frequent function word *the* precedes the vowel-initial words in the middle of the sentences as in "I like how [**the ash**] runs the circus".

Function words are also used in later language acquisition for word categorization and syntactic analysis. For example, 12-month-old English-learning infants can use function words such as *the, and*, and *in* as frequent frame to categorize nouns (Mintz, 2003). For example, Mintz found that the frame "the __ and" is frequently used to mark the noun category as in "the *horse* and". Models that posit a facilitatory role for function words are called "functional bootstrapping models" (Shi, Cutler, et al., 2006; Shi, 2014). Empirical evidence illustrates that infants from early on can recognize and segment function words and this "knowledge" influences later language acquisition, supporting such models.

This early recognition and use of function words is reported to be due to bottom-up cues in the input such as phonological/acoustic cues (Cutler, 1993; Shi et al., 1998), distributional cues (Shi et al., 1998) as well as frequency cues (Hochmann, Endress, & Mehler, 2010). This dissertation hypothesizes that not only function words, but also functional morphemes, bound functional elements such as *-s, -ing, -ed* can be "known words" for infants. This dissertation also shows that this knowledge of functional morphemes plays a crucial role in word segmentation and representation, and demonstrates this by testing English verb segmentation. The reason behind these hypotheses is that functional elements, whether words or morphemes, have similar acoustic/prosodic cues, distributional cues and frequency cues in the input, which will be further explained in the next subsections.

1.4.1.1 Shared phonological/acoustic cues

First, preverbal infants can recognize function words from the speech stream based on phonological and acoustical cues. It has been reported that with the help of these cues, even newborns can discriminate function words from content words (Shi et al., 1998). Function words tend to be phonologically simpler, usually one syllable such as CVC, CV, or VC as in *her, the*, and *on*. Also, they are acoustically and phonologically weaker in comparison to lexical words. Discrimination of these two categories later develops into a preference; 6-month-olds prefer content forms over function forms (Shi & Werker, 2001).

Functional morphemes and function words share these acoustical and phonological properties. For example, in English, functional morphemes are shorter in duration as they are typically one syllable long (*-s, -ing, -ed, -en, -er, -est*) and acoustically weak due to lack of stress. Their phonological shape is also simpler as they are all one syllable long, in some cases even just one consonant. Therefore, it is possible that infants may also recognize functional morphemes at an early age when they identify and segment function words from speech.

1.4.1.2 Shared distributional cues

Another mechanism that may help infants treat functional morphemes as "known words" is infants' sensitivity to distributional cues. Function words tend to occur at the edges of prosodic units that typically coincide with major syntactic units such as noun phrases or utterance edges (Christophe, Millotte, Bernal, & Lidz, 2008; Gervain, Nespor, Mazuka, Horie, & Mehler, 2008; Kimball, 1973; Shi et al., 1998). Based on the distributional cues, infants between 6-8 months are able to recognize function words (e.g., *the*) from fluent speech and segment them from a [target function word + noun] phrase (Hohle & Weissenborn, 2003; Kimball, 1973; Shi & Gauthier, 2005; Shi, Marquis, & Gauthier, 2006; Hallé et al., 2008), and further use them to pull out adjacent content words (Shi, Cutler, et al., 2006; Shi, Werker, & Cutler, 2006). This sensitivity can be extended to the learning of an artificial language. For example, Italian-learning 7-month-olds prefer that frequent elements occur at the beginning of a bisyllabic word unit, whereas Japanese-learning 7-month-olds prefer that frequent elements occur at the end of a unit, consistent with their native languages' word order (Gervain et al., 2008).

The distributional properties of functional morphemes are not well reported. Nominal functional morphemes such as the plural marker *-s*, will likely occur at the prosodic edge, such as at the end of a noun phrase. However, the distributional properties of other functional morphemes, especially morphemes that are attached to verbs (e.g., *-d, -ing, -en*), will likely depend on the type of verbs that they are attached to. For example, if a verb is intransitive, such as *run*, then the verb with the present progressive form *running* can appear at the end of a verb phrase as in "She is running". However, if a verb is transitive, such as *want*, then the verb with the past tense form *wanted* will require another noun to follow it, as in "He wanted it". This in turn results in *wanted* not being at phrase edges. Parental reports illustrate that even 8-month-olds comprehend several verbs such as *eat, kiss, drink, splash, dance, tickle*, and *sleep*. Among these seven verbs, only three - *kiss, drink* and *tickle* - are definite transitive verbs. These suggest that intransitive verbs that can appear at prosodic edges may be segmented and acquired first.

1.4.1.3 Shared frequency cues

Lastly, based on frequency cues, infants can recognize and segment function words. Function words are limited in number and their frequency of occurrence is much higher than that of content words. For example, out of 20 most frequent words in 27 CHILDES corpora, 14 are function words (Li & Shirai, 2000; see Appendix A for full 20 words with their frequencies). Infants are sensitive to the frequency of function words and are shown to segment high frequency function words at 8-months of age, yet less frequent function words only at 13-months (Shi, Werker, & Cutler, 2006). Based on this high frequency, infants can even recognize function words in an unfamiliar language (Hochmann et al., 2010).

Similar to function words, functional morphemes are likely to be frequent in the input. Languages have far fewer functional morphemes (e.g., only 8 inflectional morphemes in English) than content words (e.g., nouns, verbs), and they are grammatically required in all sentences, therefore occur very frequently in the input. For example, as Willits, Seidenberg, and Saffran (2014) report, the *-ing* morpheme is the sixth most frequent unit in infant directed speech across all relevant speech in the CHILDES database when it is treated as a separate "word". This suggests that the frequency of other functional morphemes might be comparable to that of function words as well. As infants are able to segment function words due to their high frequency, they might be able to pull out functional morphemes and treat them as separate "words" due to their high frequency. In Chapter 3 of this dissertation, we analyze the frequencies of functional morphemes and compares them with those of function words.

1.5 What's there and what's missing?

The studies described in this chapter have begun to trace the picture of the early emergence of word segmentation, showing that infants use a combination of cues, the relative importance of which changes during development. However, many questions remain. In particular, most of the studies on English word segmentation conducted so far have looked at the segmentation of morphologically simple words not giving enough attention to the morphological complexity of the target words. This is highly related to the fact that most of the segmentation studies have been on the noun category, with little research on the other lexical categories.

The morphological complexity of a word becomes highly relevant and especially important once we shift our attention to the verb category. This is because unlike English nouns, English verbs have multiple conjugations, and verb roots such as *walk* regularly appear in various morphologically complex forms as in *walking*, *walked* and *walks*. Adults can not only segment complex forms from the speech, but also recognize roots from these complex forms and relate conjugated forms with each other. How infants segment verbs in various forms and how these multiple forms of the same word influences their segmentation and representation has yet to be studied.

English verb segmentation has been investigated in a few studies, but in these studies this morphological factor has been ignored. As a result, the extraction of the verb category has been reported to lag dramatically behind nouns, such that consonant-initial verbs are not reliably segmented until 13.5 months, with vowel-initial verbs not being segmented until 16.5 months (Nazzi et al., 2005). However, two recent studies using frequent verbal endings demonstrate earlier segmentation of the verb category, *-ing* in English (Willits et al., 2014), and *-e* in French (Marquis & Shi, 2008). These studies raise an interesting possibility that certain morphologically complex forms can be segmented earlier than others, highlighting the importance of considering the morphological status of a word in segmentation research.

This segmentation delay of one category over the other is not a new topic; in fact, previous studies have shown that the segmentation ability varies and depends on number of factors, such as the "known words" (Bortfeld et al., 2005), register (infant-directed speech (IDS) or adult-directed speech (ADS): Thiessen, Hill, & Saffran, 2005), and the position of the word in a utterance (Seidl & Johnson, 2006). The current dissertation suggest one more possible factor - the (morphological) variability in the forms - in explaining the delay of verb segmentation.

In Chapter 2, I summarize how morphologically complex forms are represented in the adult mental lexicon and what theories of language acquisition hypothesize regarding the acquisition of morphologically complex forms.

CHAPTER 2

Background

Once segmented and learned, words are represented in the mental lexicon. How these words are stored and related to each other has been a major topic of research in psycholinguistics. Much of this research has focused on how morphologically complex forms relate to root forms. There are two opposing views on how complex forms should be represented and related to each other in relation to other word pairs such as phonologically related pairs and semantically related pairs. In this chapter, I will summarize and explain the two distinct types of models and evaluate their predictions for the order in which children acquire whole word forms and individual morphemes.

2.1 Representation of morphologically complex forms

How complex forms are related to each other in the mental lexicon is still in debate, and is a topic of interest in many different research areas, including audio/visual speech recognition (a classic, Taft & Forster, 1975), speech processing (Burani & Caramazza, 1987) and neurolinguistics (Blevins, 2006; Marslen-Wilson & Tyler, 2007). Central to this debate is the question of how morphologically complex forms are processed and represented in the mental lexicon. There are three types of complex words in English: a) words with inflectional morphology where a root is combined with a functional morpheme, e.g., *walk**ing***, *walk**s***, and *walk**ed***, b) words with derivational morphology where a root is combined with a derivational morpheme, e.g., ***un**do*, ***re**do*, *free**ly***, and *boy**hood***, and c) compounds, where two roots are combined together, e.g., *hotdog* and *teapot*. In this dissertation, I focus on complex forms with inflectional morphology i.e., functional morphemes, as I am interested in figuring out the role of functional morphemes in word segmentation and representation

Inflectional morphology has several interesting traits. First, its application is very predictable and its appearance depends entirely on grammatical contexts (Anderson, 1992; Bickel & Nichols, 2006). For example, if a subject is 3^{rd} person singular *he, she*, or *it*, the 3^{rd} person singular morpheme *-s* is attached to the verb without exception and regardless of the type of verb as in "He runs fast". Another very important trait of inflectional morphology is that it is typically assumed not to create new words requiring new lexical entries (Marslen-Wilson, 2007). Rather, it produces new forms of the same word marking grammatical functions such as number, tense, aspect, gender, and case. This traditional notion is well displayed in standard dictionaries, in which inflectional variants such as *walk* and *walks* are not listed as separate entries unlike other complex forms which are listed as separate entries (e.g., derivational forms such as *walker* and compounds as in *walkout*). The question is, does this traditional notion accurately describes speakers' mental lexicon: how do adults and infants represent these inflectional variants?

Inflectional morphology is not without exception as shown in irregular forms such as past tense *put*, *bought*, and *broke* and irregular plural nouns as in *children* and *mice*. As these inflected forms do not have a transparent morpheme attached, there is a consensus view that irregulars are learned and represented as undecomposed whole forms (Marslen-Wilson, 2007, but see Albright & Hayes, 2003 for a contrasting view). However, models differ significantly in terms of the representation of regularly inflected complex forms. Out of the eight inflectional morphemes in English, i.e., the 3^{rd} person singular *-s*, the plural *-s*, the possessive *-s*, the present progressive *-ing*, the past tense *-ed*, the past participle *-en*, the comparative *-er*, and the superlative *-est*, the most well studied case is that of the past tense. Researchers disagree on how regular past tense formation, that looks like rule-based bahavior, should be represented and processed in the adults' mental lexicon.

One type of model favors a whole word-based processing approach and argues that both complex forms and simple forms are represented as whole words in the mental lexicon. For instance, Rumelhart and McClelland (1986) and others (Plunkett & Marchman, 1993; Joanisse & Seidenberg, 1999; McClelland & Patterson, 2002) argue that inflected forms are learned and represented as overlapping whole forms that share certain semantic and phonological similarities. In such models, functional morphemes are not represented separately. Therefore, the root *walk* and the inflected forms *walking* and *walks* are all represented in the mental lexicon as non-decomposed whole forms related to each other through sound and meaning similarities.

On the other hand, in morpheme-based processing models (Pinker & Prince, 1988; Pinker, 1999; Pinker & Ullman, 2002) inflected forms such as *walking* and *walks* are not represented as whole words in the mental lexicon. Instead, the complex form *walks*, is generated via rule-based computation combining symbols for the root form *walk* and the individual morphemes *-ing* or *-s*.

These two types of models posit different relationship between pairs of words that are not morphologically related, but instead related phonologically or semantically. For example, the whole word-based processing models predict that phonologically similar (e.g., *win* & *wins*) and / or semantically related words (e.g., *violin* & *cello*) should have a relationship similar to that of morphologically related pairs such as *play* & *played* (Joanisse & Seidenberg, 1999, well summarised in Marslen-Wilson, 2007). The only difference among these diverse pairs, according to these models, would be the strength of the similarity.

For example, morphologically related pairs have the strongest relationship as they share both sounds and meaning, compared to the phonologically related pairs that only share sounds, but not meanings. Likewise, embedded word pairs such as *cap* & *captain* will be related to each other in a similar fashion to morphologically related pairs such as *walk* & *walking* as they are both phonologically similar. However, morphologically related pairs have a stronger relationship because part words do not have any semantic overlap. Within morphologically related words, whole-word processing models predict that regular inflected pairs, that are phonologically more similar, will have a stronger relationship than irregular inflected pairs.

However, in morpheme-based processing models, morphologically related words have a special relationship, in that the complex form is never present in the mental lexicon, only generated via rules. Therefore, the association of morphologically related words is inherently different from word pairs that are semantically and/or phonologically related. Also, embedded word pairs and morphologically related words have different associations as both *cap* and *captain* are represented in the mental lexicon, whereas only the root form is represented fully for the morphological variant pairs. With respect to the difference between irregular and regular inflections, morpheme-based processing models argue that irregulars are stored as memorized whole forms whereas regular inflected words are never stored as wholes. The different assumptions that these two types of models give rise to are summarized in Table 2.1.

Table 2.1: Assumptions of the two processing models

	Whole word-based models	Morpheme-based models
Decomposition	No	Yes
Lexical Relationship	*buy-bought* $<^1$ *play-played*	*buy-bought* $\neq^2$ *play-played*
	wins-win $>$ *winch-win*	*wins-win* $\neq$ *winch-win*

2.1.1 Experimental evidence

Various methods and techniques have been used such as lexical decision, priming, and event-related potentials (ERPs) to give experimental evidence for each type of processing models (see Clahsen, 1999 and Pinker, 1999, for review). Previous studies have reported results on a) **frequency effects** and b) **priming effects** for both whole word forms and root forms, and c) **neurolinguistic differences** between morphologically related words and other phonologically and semantically related pairs. As experimental results can be explained using both types of models, this debate is still very controversial.

2.1.1.1 Frequency effects

Words that frequently occur in the input are processed easier and faster than less frequent words (classic papers; Whaley, 1978; Forster & Chambers, 1973). Thus, frequently occurring complex forms have been shown to be recognized faster and processed more quickly than less frequent complex forms. This complex form (i.e., whole-word) frequency effect has been used to support whole word-based models.

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[1] '$<$' represents stronger relationship

[2] '$\neq$' means not comparable, inherently different relationship

Effects of frequency have also been observed for individual morphemes in complex words (Taft, 1979; Sereno & Jongman, 1997; Baayen, Dijkstra, & Schreuder, 1997). For example, Taft (1979) found that when morphologically complex words were matched in terms of whole-word frequency but differed in root frequencies, e.g., *sized-raked*, where *size* occurs more frequently than *rake*, complex forms with a more frequent root were recognized significantly faster in a lexical decision task. These and similar results have been used to argue for morpheme-based processing models. Roots must exist independently in the mental lexicon, because not just whole-word frequency but also root frequency influences reaction time.

However, whole word-based models can explain these results without assuming the morpheme representation. For example, Bybee's network model (1995) posits activation-spreading links among morphologically related words. That is, every time the word *size* is accessed, all inflected forms of that root such as *sized* and *sizes* are co-activated. By using these activation-spreading links, it is expected that recognition times to whole-word past-tense forms that are linked to high-frequency roots such as *sized* will be shorter than response times to whole-word past-tense forms that are linked to low-frequency roots such as *raked*.

Also, disagreement exists as to the role of frequency in the representation of complex forms. Some question the reported frequency effects, as mixed results have been found. For example, Alegre and Gordon (1999), New, Brysbaert, Segui, Ferrand, and Rastle (2004), and Taft (1979, 2004) report root frequency effects, yet Sereno and Jongman (1997) and Baayen, Wurm, and Aycock (2007) do not. As for the whole-word frequency effects, Alegre and Gordon (1999) find no whole-word frequency effects for low frequency words, in contrast to Baayen et al. (2007)'s study, where they find whole-word frequency effects for low frequency words, with marginal root frequency effects. Even within researchers who agree on the psychological reality of frequency effects, some argue that those frequency effects reflect semantic and conceptual probabilities, not mental representations (Marsden-Wilson & Zhou, 1999; Marslen-Wilson, Moss, & Halen, 1996).

Therefore, we cannot adjudicate between these two types of models based on frequency effects alone.

2.1.1.2 Decomposition

Recall that the morpheme-based models presuppose complex forms to be decomposed and represented in the mental lexicon, whereas the whole word-based models presuppose that whole forms are stored as unanalyzed chunks, non-decomposed units. Results from lexical decision tasks consistently report the automatic decomposition of individual morphemes.

Research by Taft and colleges (Taft & Forster, 1975, 1976; Taft, Hambly, & Kinoshita, 1986) illustrates that non-words like **re-sert*, which appears to be morphologically complex, take longer to reject as words than non-words which lack apparent morphological structure as **refant*. This delay in lexical decision is also seen for non-words with inflectional morphemes (Caramazza, Laudanna, & Romani, 1988). Using Italian, Caramazza et al. (1988) compared reaction time to three different groups of words: a) morphologically non-decomposable nonword, b) non-words with partial morphological structure, and c) morphologically legal non-words (i.e., non-words that are exhaustively decomposable into morphemes). Their results show that adults were faster at rejecting non-decomposable non-words, slowest with morphologically legal non-words. These results were interpreted to suggest that morphological decomposition is automatic, and this automatic decomposition of morpheme delays the processing of morphologically legal non-words.

A recent visual recognition study has also been interpreted in a similar way(Rastle, Davis, & New, 2004). This study investigated the effect on response time of a root's semantic, morphological, and orthographic overlap with the prime whole word form. Three conditions were composed: a) a transparent condition where the two words were both semantically and morphologically related as in *worker-work*, b) an opaque condition where the two words were semantically unrelated yet had a possible affix as in *brother-broth*, and c) an orthographically related condition as in *brothel-broth*. Their results show that facilitatory priming was found in both a) and b), arguing that psuedo-affixed words behaved similarly to real affixed words. Yet, no priming was found in the orthographic condition, showing that pure orthographic (possibly phonological) overlap cannot explain the results. These results were interpreted to support the automatic decomposition of morphemes, such that even *brother* is decomposed into *broth* and *-er*, regardless of its true morphological status.

Whole word-based models also agree on morphological processing at some level, but crucially not at the level of representation. For example, the supralexical model, one type of whole word-based model (Giraudo & Grainger, 2000), argues that all words are retrieved as whole word forms first, and morphological parts are accessed after the recognition of whole forms. Based on this model, the latency effect or priming effect is shown not at the recognition level but in the other, possibly later stages of processing.

2.1.1.3 Neurolinguistic evidence

Recent neurolinguistics studies with brain-imaging techniques have provided strong evidence for the special status of morphologically related words that are different from semantically and phonologically related words. First, a set of studies was designed to separate semantic effects from morphological effects (Marslen-Wilson, 2007; Marslen-Wilson & Tyler, 1998; Marslen-Wilson et al., 2000).

For example, in an ERP study the patterns of brain activity associated with regular and irregular cross-modal repetition priming were almost identical, with both showing left anterior negativities. However, semantic primes showed only a centrally distributed N400-type effect (Marslen-Wilson et al., 2000). These results demonstrate that morphological effects and semantic effects are processed in different regions of the cortex.

Brain-damaged patients further provide valuable evidence of differences between morphological effects and phonological effects (Tyler, Randall, & Marslen-Wilson, 2002; Tyler, Stamatakis, Post, Randall, & Marslen-Wilson, 2005). For example, Tyler, Randall, and Marslen-Wilson (2002) used a speeded same-different judgment task and asked participants to find differences in three diverse sets of pairs: the past tense and stem of regular verbs *played/play*, irregular past tense verbs *taught/teach*, phonologically matched pseudo-regular and irregular pairs *trade/tray; port/peach*, and similarly matched sets of non-word. Data from non-fluent aphasia patients with damage to the dominant left hemisphere revealed that they performed consistently worse on the regular past-tense pairs *played/play* than on the matched pseudo-regular *trade/tray* and non-word pairs.

Until now, research has demonstrated that morphological effects are different from semantic effects and phonological effects. Neurological evidence also suggests that regular and irregular inflected forms are processed differently (Longworth, Marsden-Wilson, Randall, & Tyler, 2005; Marslen-Wilson & Tyler, 1997, 1998; Miozzo, 2003; Patterson, Lambon Ralph, Hodges, & McClelland, 2001; Tyler, de Mornay Davies, et al., 2002; Tyler, Randall, & Marslen-Wilson, 2002; Ullman et al., 1997, 2005). The leading evidence comes from brain-damaged patients' behavioral differences between processes involving regular and irregular forms. Previous research shows that different neural systems are required for the production and perception of regular and irregular inflected forms in English. For example, deficits in the regular inflected forms tend to co-occur with left hemisphere lesions, especially those involving the left inferior frontal cortex and superior temporal cortex. However, deficits in irregular inflected forms tend to co-occur with medial and inferior temporal lesions (Longworth et al., 2005).

These neurolinguistic data can be interpreted in support of both types of processing models. This is because both types of models assume differences between morphologically related words and other non-morphologically related pairs that are phonologically or semantically similar. The whole word-based models assume quantitative difference (similarity **strength**) whereas morpheme-based models assume qualitative differences.

Therefore, in the adult literature, both types of models are well supported. However, in the developmental literature, no study has been designed to tease these two types of models apart. In the following section, I summarise previous studies on the acquisition of morphologically complex forms and the predictions that the two distinct models make on this issue.

2.2 Acquisition of Morphologically complex forms

The two distinct types of models, whole word-based models and morpheme-based models, make differing predictions about the order in which complex forms and individual morphemes are acquired. First, the whole-word processing models presuppose a strict acquisition order between whole words and individual morphemes, arguing that children will acquire the whole forms prior to individual morphemes. That is, only after acquiring a number of different words with a same root, can children demonstrate any knowledge of individual morphemes. Also, these types of models presuppose that children will not be able to distinguish morphologically related pairs such as *wins-win* from phonologically related pairs like *winch-win*, before acquiring the meaning of these forms.

However, morpheme-based processing models do not presuppose such a strict order: therefore, under these models it is possible for infants to decompose morphologically complex forms and relate root forms to inflected forms from the developmental onset of word segmentation. Also, these models hypothesize that prior to meaning acquisition, infants may be able to differentiate morphologically-related pairs (*wins-win*) from phonologically-related pairs (*winch-win*). Crucially, this would rely on their recognition of functional elements. The differing predictions of the two types of models are summarized in Table 2.2.

Table 2.2: Acquisition hypotheses

	Whole word-based models	Morpheme-based models
Before meaning acquisition	*wins-win* $\equiv$ *winch-win*	*wins-win* $\neq$ *winch-win*
Order of acquisition	whole word $>$ morphemes	whole words $\leq$ morphemes

Let us now examine the empirical evidence in support of these developmental predictions. Early studies of the development of morphology focused on the production of complex forms and the developmental sequence in which inflectional morphemes are acquired. The first seminal study was carried out by Berko (1958), who conducted various wug tests (providing novel forms to observe rule applications) with preschool children and first graders (age range: 4-7). She found that forms that have allophones or alternative forms such as *auxiliary be* are acquired later in development than invariant forms such as *-ing*. Based on Berko (1958)'s results, Brown (1973) conducted a corpus analysis with three children (Brown Corpus in CHILDES database, MacWhinney, 2000) and reported the mean order of acquisition of 14 English morphemes. The results illustrate that the 14 grammatical morphemes of English emerge in a more or less invariant order across children, as shown in Table 2.3.

Table 2.3: Mean order of acquisition of 14 morphemes across three children, (Brown, 1973)

Morpheme	Average Rank
1. Present progressive *-ing*	2.33
2-3. *in, on*	2.50
4. Plural *-s*	3.00
5. Past irregular	6.00
6. Possessive	6.33
7. Uncontractible copula	6.50
8. Articles (*a, the*)	7.00
9. Past regular	9.00
10. Third person regular	9.66
11. Third person irregular	10.83
12. Uncontractible auxiliary	11.66
13. Contractible copula	12.66
14. Contractible auxiliary	14.00

In fact, inflected forms tend to appear very early in production. For languages where uninflected roots cannot surface as possible words, inflected forms are already uttered in the one-word stage (Hungarian: MacWhinney, 1976; Finnish: Toivainen, 1980; Italian: Pizzuto & Caselli, 1994). In languages where uninflected roots can surface in the utterance, as in English, the first inflected forms usually appear in the two-word stage (Brown, 1973). Based on this early production of inflected forms, a controversy has emerged between

Full-Competence (Poeppel & Wexler, 1993) and Structure-building approaches (Clahsen, Eisenbeiss, & Penke, 1996) in syntax acquisition, a parallel debate that between morpheme-based models vs. whole word-based models. Full-competence approaches argue that children have functional categories such as INFL (e.g., inflection) early on (e.g., Very Early Knowledge of Inflection, Wexler, 1998). However, structure-buildling accounts argue that early utterances of complex forms are formulaic expressions that the child has learned and stored as unanalyzed chunks.

Based on corpus analysis and experimental results, some studies support structure-building accounts proposing that children learn grammar item by item (Ingram, 1985; Tomasello, 1992, 2000, 2003; Bybee, 1995). For example, Tomasello reported his child's use of 162 verbs and predicative expressions (1992). Among those 162 expressions, almost half were used in only one construction type, and over two-thirds were used in either one, or two construction types. Based on this observation, Tomasello has argued that children's early verb acquisition is organized and structured around individual verbs. Tomasello goes further and argues that young children's earliest linguistic productions are based on concrete items and structures, showing no evidence of abstract syntactic categories or models (Tomasello, 2000). This extends to children's morphological development. He argues that children learn complex verb production item by item: children might use all morphological forms for one verb, but that does not naturally expand to include other verbs. His experimental results also show that children produce verbs that they learn based on the input: they rarely combine newly learned verbs with other words and seldom go beyond what they hear from adults. Similarly, Bybee's network model of morphological organisation and acquisition is based on usage as well: morphology is acquired item by item and by repetition (Bybee, 1988, 1991, 1995, 1998, 2001). Plunkett and Marchman (1993) further suggest that the transition from item-learning to system-building (i.e., learning the morphology or grammar of a language) happens once children have multiple items learned and stored in their mental lexicon. For example, they argue that English past-tense formation starts when a minimum of 50 verbs have been acquired.

However, recent studies on this issue illustrate that production of a morphologically complex forms is influenced by many factors other than the knowledge of the morpheme (Hsieh, Leonard, & Swanson, 1999; Song, Sundara, & Demuth, 2009; Sundara, Demuth, & Kuhl, 2011; Theodore, Demuth, & Shattuck-Hufnagel, 2011; Mealings & Demuth, 2014). For example, Song et al. (2009) and Sundara et al. (2011) demonstrate that the production of the 3^{rd} person singular *-s* is significantly influenced by the coda complexity and the position of the verb within the utterance. Two-year-olds produced more *-s* in simple C context (e.g., Here he *blows*) than CC context (e.g., Here she *drives*). Also, they produced more inflections in sentence-final position (e.g., Here he *blows*) than sentence-medial position (e.g., He *blows* now). Also, children at 22-months distinguish grammatical and ungrammatical sentences with the *-s* morpheme, illustrating that the perception knowledge of morphologically complex forms precedes the production of these forms (Sundara et al., 2011). These results highlight the fact that lack of production does not necessarily mean lack of knowledge.

Also, in contrast to what Tomasello and Bybee suggest, children's acquisition of complex forms does not strictly follow the input frequency of these morphemes, arguing against the proposal that children simply imitate from the input. Table 2.4 summarizes typical relative frequency of morphemes in parental speech. For example, the determiners *the* and *a* are the most frequent morphemes in the childrens' environment even though they are acquired relatively late. This shows that frequency by itself cannot explain developmental order, although it may have some role to play in conjunction with other factors.

Table 2.4: Typical relative frequency of morphemes in parental speech, (O'Grady & Cho, 2001)

Morpheme
1. Articles (*a, the*)
2. Present progressive *-ing*
3.. Plural *-s*
4. Auxiliary *be*
5. Possessive
6. Third person singular
7. Past tense regular

How early are infants sensitive to morphology? Recent studies have looked at infants' **perception** of morphologically complex forms, and have asked whether infants recognize funtional morphemes and relate complex forms to the root forms. For example, 11-month French-learning infants were able to relate a root form to the complex form with a real frequent French morpheme *-e* but not to complex forms with a pseudo morpheme *-u* (Marquis & Shi, 2012). To test this, infants were first familiarized with a root word (either *trid* or *glyt*) and later tested with passages with inflected root words (with a real functor *-e*, *tride* or *glyte*; with a pseudo morpheme *-u*, *tridu* or *glytu*). Only when tested with inflected words with the real functor *-e*, did infants listen longer to the trained root word. Interestingly, when infants were prefamiliarized with the complex forms with the pseudo morpheme *-u* prior to the experiment, infants were able to relate *trid* to *tridu*. These results suggest that infants recognize root forms only from the complex forms with functional elements, and they do this based on distributional cues. Similarly, English-learning 15-month-olds have been shown to segment the suffix *-ing* from various roots, but fail to segment endings that are not morphemes such as *-ot* (Mintz, 2013). English-learning 12-month-olds have also been shown to map complex forms with the *-ing* morpheme to the root forms even in the presence of a phonological alternation; map *pa[d]* to *pa[ɾ]ing* despite the [d] and [ɾ] difference (Sundara, Kim, White, & Chong, Under Revision).

These perceptual studies indicate that preverbal infants recognize functional elements, and this is likely based on distributional cues (Marquis & Shi, 2012). As shown in Chapter 1, based on distributional cues, function words are "known words" for infants as young as 6 months. Infants can use this function word knowledge to a) segment adjacent words, and b) categorized words. Such a role for function words has been noticed and incorporated into acquisition theories. For example, Prosody-functor bootstrapping models (Christophe, Guasti, Nespor, Dupoux, & Van Ooyen, 1997; Christophe et al., 2008; Morgan, R., & Allopenna, 1996; Shi, 2005) argue that infants are born with the mechanism to acquire function words and the recognition of these function words bootstraps word segmentation and grammatical acquisition (Shi, 2014). In frequent frame models (Mintz, 2003), function words are used as frames to segment and categorize words. For example, *the_and* frame can be used by 12-month-olds to segment nouns. Function words are used as frames, because they appear frequently in a fixed grammatical position. Functional morphemes are likely to occur frequently in the input as well, and they are attached to a certain grammatical word, thus have fixed positions. Therefore, it is possible that functional morphemes can also be used as part of frequent frames.

In this dissertation, I hypothesize that functional morphemes can be "known words" for infants from early on, just as function words are for them. I have laid out reasons behind this hypothesis in Chapter 1, and in Chapter 2 provided evidence that functional morphemes are recognized earlier (around 11-12 months) than might be assumed based on previous production studies. Some factors may influence this early representation of functional morphemes, such as frequency and transitional probability of the functional elements. In the next chapter, I conduct a corpus analysis on English functional morphemes to understand their distributional cues.

CHAPTER 3

Corpus Analysis

Distributional cues are thought to be one of the most important cues in morphology acquisition, playing a primary role in the earliest stages of morpheme discovery (Baroni, 2000; Lignos, 2012). Specifically, distributional properties suggest that certain substrings that can occur frequently and combine with other segments are "possible words". Acknowledging the importance of the distributional cues in morpheme recognition and verb acquisition, I conducted corpus analysis of functional elements to understand the input that infants receive.

3.1 Distributional cues: Frequency & Transitional Probability

The two distributional cues that this chapter reports on are frequency and Transitional Probability (TP). The effect of frequency in word segmentation and acquisition has been widely reported in previous research. In fact, the surface frequency effect, which demonstrates differences in word recognition as a function of form frequency, is one of the most reliable phenomena described in psycholinguistics (Taft & Forster, 1975; Taft, 1979, 2004; Burani, Salmaso, & Caramazza, 1984; Meunier & Segui, 1999; Dominguez, Cuetos, & Segui, 2000; Ambridge, Kidd, Rowland, & Theakston, 2015; Estivalet & Meunier, 2015). Also, word frequency is one of the main cues that infants use to identify function words (Shi et al., 1999; Shi, Cutler, et al., 2006; Hochmann et al., 2010). Therefore, it is important to analyze the frequency of functional morphemes to understand its role in morpheme acquisition and representation.

Previously, production studies with children have shown that a number of factors influence when children succeed in decomposing inflected words, i.e., complex forms with functional morphemes (Peters & Menn, 1993; Dressler, 2010). Functional morphemes that appear frequently and with a number of different roots in the input are acquired before morphemes that appear infrequently. Bybee (1995) has suggested that the *type frequency* of a functional morpheme, i.e., the number of roots a functional morpheme combines with, is a decisive factor in acquisition.

In addition to type frequency, *token frequency* is another factor that has been thought to influence the acquisition of functional morphemes (Bybee, 1995). Inflected words that appear frequently in the input of children are among the first forms to be produced by the children themselves (Gagarina & Voeikova, 2009). Besides the token frequency of a specific inflected form, the token frequency of a functional morpheme, i.e., the number of times a functional morpheme occurs in the child's input, is also important in the early acquisition of inflected forms (Perroni Simoes & Stoel-Gammon, 1979; Dabrowska & Szczerbinski, 2006).

In this dissertation, I report all three types of frequency; type frequency and token frequency of a functional morpheme, as well as the token frequency of complex forms, i.e., inflected words.

Another type of distributional cue that is reported in this dissertation is Transitional Probability (TP). The role of TP in word segmentation has been well investigated. Since the seminal work by Saffran, Aslin, and Newport (1996), studies have shown that infants can use TP in segmenting words from fluent speech, and this cue is language-universal (Saffran, 2003; Pelucchi et al., 2009a). Even though limitations on TP have been found in that infants' previous knowledge of word length is crucial for success in word segmentation using TPs (Finn & Hudson Kam, 2008; Johnson & Tyler, 2010; Lew-Williams & Saffran, 2012), the role of TP in infants' language acquisition has been widely acknowledged. In this dissertation, we compare the TP of various functional morphemes and demonstrate that the presence of some functional morphemes predicts clearer and stronger word boundaries than others.

Also, the directionality of TP has been shown to influence word segmentation. Both forward TP (FTP) and backward TP (BTP) have been shown to be equally informative as independent cues to word boundaries (Swingley, 1999) and infants have been shown to use both types of cues (Saffran, Werker, & Werner, 2006; Pelucchi et al., 2009a; Pelucchi, Hay, & Saffran, 2009b). Also, depending on the characteristics and positions of grammatical morphemes, either FTP or BTP is more predictive of word boundaries. For example, Gervain and Guevara Erra (2012) illustrated that backward probabilities are more effective in Hungarian, a heavily suffixing language, whereas forward probabilities are more informative in Italian, which has fewer suffixes and a large number of phrase-initial function words. This dissertation reports both forward and backward TP, as English uses both phrase-initial function words (e.g., *a, the*) as well as suffixes (e.g., *-s, -ing*, and *-d*).

3.2 Corpus

We analyzed the Brent Corpus (Brent & Siskind, 2001) from the CHILDES database (MacWhinney, 2000). This particular corpus was chosen as it includes morphologically transcribed audio-recordings of mothers interaction with their preverbal infants, making it possible to conduct morpheme analysis.

3.3 Methods

3.3.1 Participants

Recordings from sixteen mother-infant pairs are available in the Brent Corpus (Brent & Siskind, 2001), and all were analyzed in the current dissertation. The infant age ranged between 9 to 17 months. Out of sixteen mothers, eight had higher SES, whereas the other eight had lower SES. On average, eleven sessions (range: 8-14) were available for each pair. Sessions were recorded once every two weeks, and each session lasted one and a half to two hours. The middle 75 minutes of each session were extracted and transcribed into the Corpus. The final dataset includes 248 hours of speech and 1,467,855 words.

3.3.2 Procedure

All 8 English functional morphemes were analyzed; the four consonantal morphemes such as plural *-s*, possessive *-s*, 3rd person singular *-s*, and past tense *-d*, and the other four vowel-initial morphemes such as the present progressing *-ing*, the past participle *-en*, the comparative *-er*, and the superlative *-est*. Two separate procedures were used for calculating different types of frequency. First, the CLAN program FREQ function was used in the mother tier to collect the type and token frequencies of functional morphemes. The same program and function was used to calculate the top 10 most frequent complex forms, i.e., inflectional forms with verbal morphemes.

For the morphemes *-s* and *-d*, a vowel-initial variant of each morpheme exists (i.e., [əz] and [əd]), and these were separately counted and reported. The CLAN program FREQ function was also used to pull out all complex forms from which the roots were segmented out. After that, I hand checked all the roots that met the environment for either [əz] or [əd], marked them, and later tallied their numbers. Irregular plurals and past tense forms such as *mice* or *sang* were excluded as these forms do not have transparent functional morphemes, and therefore do not contribute to the acquisition of functional elements.

Additionally, the segmental frequency of the consonantal morphemes were also calculated, for example, the frequency of [s] as a segment, as the segmental frequency will likely interfere with or influence morpheme recognition and segmentation. That is, infants might recognize [s], not because it is a morpheme per se, but because the segment *-s* appears very frequently in the input. The segmental frequency was calculated from the CMU transcribed Brent Corpus (Daland, 2013). This particular corpus was used because we needed a phonetically transcribed corpus as the spelling does not correctly correspond to the sounds. For example, the word *box* ends with the letter *x* that corresponds to the sound [s]. In our analysis, we included words such as *box*, therefore it was necessary to use a phonetically transcribed corpus. The frequencies of the target segments were pulled out in different positions within a word using a python script.

Transitional probability was also calculated in two ways. FTP measures the probability of event Y given event X. Therefore, in morpheme acquisition, this FTP is measured as the probability of individual functional morpheme given a root. As this dissertation focuses on verbal morphology, all the verbs that the mothers used were first pulled out from the sentences with their contexts using the COMBO function in CLAN. Subsequently, I calculated the token frequency of each functional morpheme using the FREQ function in CLAN. As a result, only verbal morphemes are reported.[1] BTP measures the likelihood

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[1] We aim to compare the TP of various morphemes that can potentially appear with same roots. This is because we are calculating the frequency of the morphemes (Y) given the frequency of the roots (X). Therefore nouns, which can only conjugate with the *-s* morpheme, are not included in this calculation.

of X preceding Y. Therefore, in morpheme acquisition, this BTP is measured as the frequency of [root+morpheme] complex forms given the frequency of the functional morpheme.

3.4 Results

3.4.1 Frequency

I first report the token frequency of functional morphemes and compare them with the frequency of function words and frequent content words. By comparing the frequencies of functional morphemes and function words, I aim to show that the two types of functional elements are comparable in terms of their frequency, and both of them are more frequent in the input than the content words. Type frequency will be discussed in the BTP subsection (backward transitional probability).

3.4.1.1 Token frequency of functional morphemes

Table 3.1 summarizes the frequency of all functional morphemes in English. Importantly, both inflectional morpheme frequency and derivational morpheme frequency are reported for *-ing, -en* and *-er*, as it is unlikely that infants at 6-months distinguish the derivational and inflectional usage of the morpheme. On a similar note, the three functional *-s* morphemes are reported individually but later combined as there is no reason to believe that infants at 6-months distinguish the three *-s* morphemes.

First, let us look at the token frequency of functional morphemes shown in Table 3.1. Interestingly, both *-s* (n = 12,583) and *-ing* (n = 12,578) are very frequent and matched in frequency. The past tense morpheme *-d* follows and is the next frequent functional morpheme (n = 2,350), with the other three vowel-initial morphemes being relatively infrequent, occurring less than 1,000 times in the whole Corpus.

Table 3.1: Properties of the functional morphemes in the corpus study. Numbers in parentheses represent the frequencies of the vowel-initial variants.

Functional morpheme	Word class	Meaning (function)	Type frequency	Token frequency
-s/z (əz)	N	Plural	3,867 (50)	8,252 (358)
	N	Possessive	175 (8)	1,784 (14)
	V	3^{rd} person sg.	200 (23)	2,547 (79)
	total		4,242 (81)	12,583 (451)
-t/d (əd)	V	Past tense	298 (51)	1,588 (182)
	Adj	Past participle	183 (51)	762 (115)
	total		481 (102)	2,350 (297)
-ing	V	Present progressive	432	7,264
	N	Gerund	135	5,296
	total		582	12,578
-er	N	Derivational	110	538
	Adj	Inflectional (comparative)	40	187
	total		150	725
-en	Adj	Derivational	3	12
	V	Inflectional	12	350
	total		15	362
-est	Adj	Inflectional (superlative)	26	64

To accurately understand the relative frequencies, let us compare these numbers with the frequency of function words such as *the* and content words such as *mommy/mama*. Table 3.2 reports the token frequency of four function words *the, a/an, his*, and *her(s)*. In previous research, *the* was representatively used as a *high frequency* function word, and *her* was representatively used as a *low frequency* function word (Shi, Cutler, et al., 2006). The frequent function word *the* appears 13,853 times in the Brent Corpus, and the indefinite article, another high frequent function word *a/an*, appears 9,720 times. These numbers are comparable to those of the *functional morphemes -s* and *-ing*.

The low frequency function words *his* and *her(s)* appear 696 times and 582 times respectively. These number of occurrences are comparable to that of the functional morpheme *-er* (n = 725); the past tense morpheme *-d* (n = 2,350) is somewhat more frequent than the low frequency function words.

Table 3.2: Properties of the four function words *the, a(n), his* and *her(s)*

Function words	Token frequency
the	13,853
a/an	9,480/240
his	696
her/hers	577/5

But, are the functional elements really frequent in the input? We now compare these numbers with the frequency of content words. Tables 3.3 and 3.4 report the frequency of top 10 content words and top 10 nouns in the Brent corpus. Interestingly, out of 10 content words reported in Table 3.3, there is only one noun, *mommy/mama*. The other words consist of seven verbs and two adverbs. This table illustrates that the frequent functional elements are two times more frequent in the input compared to the most frequent content word. If we use more rigorous and commonly reported method and summarize only the frequent nouns (Bortfeld et al., 2005; Bergelson & Swingley, 2012), the fre-

Table 3.3: Properties of the top 10 frequent content words.

Content words	Word class	Token frequency
here	Adv	6,372
go	V	6,228
get	V	5,703
there	Adv	5,378
want	V	5,342
come	V	5,342
mommy/mama	N	3,788/736
let	V	3,731
see	V	3,461
put	V	3.064

Table 3.4: Properties of the top 10 frequent nouns.

Noun	Token frequency
mommy/mama	3,788/736
baby	1,684
boy	1,270
Henry	1,098
ball	1,026
book	981
kitty	804
girl	794
Brooklyn	748
water	726

quency difference becomes more drastic.

Based on the token frequency analysis, I hypothesize that preverbal infants may recognize and segment *high frequency* functional morphemes *-s* and *-ing* from fluent speech, as they do with frequent function word *the* (Hohle & Weissenborn, 2003; Shi & Gauthier, 2005; Shi, Cutler, et al., 2006). However, infants at 6-months may not recognize nor segment *low frequency* functional morpheme *-d* as they do not recognize low frequency function words till 11-13 months of age (Shi, Cutler, et al., 2006).

3.4.1.2 Segmental frequency

We also need to consider the segmental frequency for consonantal morphemes, *-s* and *-d*. These two segments can appear in word final position regardless of their morphological status. Therefore, infants might recognize and segment them not because of their morphological status, but because of their frequent appearance in word-final position. To understand the segmental frequency and its role in morpheme acquisition, Table 3.5 reports the number of occurrences of target segments *-s, -z, -t*, and *-d*, in the CMU transcribed Brent Corpus (Daland, 2013). The number of occurrences of the segment -ʃ is also reported here as this segment is used in later experiments in Chapter 4.

The results show the same patterns for both SES groups, so we present a combined table for both groups. We then combined the frequency of [s] & [z] and [t] & [d] to enable a comparison with the frequency of functional morphemes *-s* and *-d*. Both the *-s* morpheme and the *-d* morpheme have voiced ([z] and [d]) and voiceless ([s] and [t]) allomorphs respectively. The number of segment occurrences was later divided by the number of the occurrences of all segments within the Brent corpus, which was 1,483,793 (total 70 segments; 26 consonants).

Table 3.5: Frequency of segments *-s, -z, -t, -d*, and -ʃ in CMU transcribed Brent Corpus (Daland, 2013) in different positions within a word.

Segments	Word-initial	Word-final	Total	% of total segments
[s]	26,532	26,487	62,198	0.04%
[z]	786	26,164	29,095	0.02%
[t]	19,450	67,995	118,104	0.08%
[d]	20,913	23,280	52,410	0.035%
[s] & [z] combined	27,318	52,651	91,293	0.005%
[t] & [d] combined	40,363	91,275	170,514	0.115%
[ʃ]	3,197	1,909	6,287	0.004%

Out of four segments, the segment [t] is the most frequent overall as well as word-finally. The segment [s] follows [t], and [d] is slightly less frequent than [s]. Lastly, [z] is the least frequent segment overall, and in word-initial position. The segment [ʃ], which is not a functional morpheme, occurs significantly less than the other four target segments. If we combine the frequencies of [s] and [z] and [t] and [d] together, we see that [s]/[z] are half as frequent as the [t]/[d] segments in all positions, and crucially in word-final position. Our findings on the segmental frequency are consistent with previous analysis of English adult-directed speech (see Wang & Crawford, 1960 for a summary of 10 studies on this issue).

Table 3.6 reports part of the results from Wang and Crawford (1960) and describes the relative frequencies (in percentile) of target segments out of all 22 consonants in 10 studies. Each study is referred to as its author's name, for example, TRN for Tranka (1935). Among the four target segments, [t] is the most frequent one, with [s] and [d] being somewhat less frequent than [t], and [z] being the least frequent. Although the detailed rankings are slightly different,

Table 3.6: Relative frequency of the four target segments and the segment -ʃ out of 22 consonants (from Wang & Crawford, 1960)

	TRN	FOW	CAR	HAY	WHI	DEW	VOE	FRE	FRY	TOB
[s]	9.23	6.05	5.58	7.65	7.36	7.22	7.52	5.41	7.94	6.22
[z]	1.34	4.12	3.14	3.69	4.58	4.71	3.45	3.05	4.06	3.54
[t]	12.47	10.21	11.35	12.70	10.14	12.13	11.62	13.96	10.72	15.68
[d]	7.13	6.83	4.97	5.80	8.49	7.53	8.24	6.67	9.06	6.76
[ʃ]	3.39	2.37	1.51	2.19	2.18	2.12	1.63	1.36	2.26	1.33

all papers on this issue report that the segments [t]/[d] are more frequent than the segments [s]/[z] (for summary, see Wang & Crawford, 1960).

Particularly relevant to this dissertation is a comparison of the segmental frequency reported in Table 3.5 and the morpheme frequency reported in Table 3.1. Although [s]/[z] are less frequent than [t]/[d] as segments, they are more frequent than [t]/[d] as morphemes. Therefore, if 6-month-olds are sensitive to pure segmental frequency, then they should be able to use [t]/[d], more frequent segments, but not [s]/[z], in the segmentation task. However, if infants are sensitive to morpheme frequency, then we expect an opposite pattern: 6-month-olds should be able to use the frequent morpheme [s]/[z], but not the less frequent morpheme [t]/[d] in the word segmentation task.

How, then, would infants at such a young age differentiate morpheme frequency from segmental frequency? In this dissertation, I consider two possibilities; whole word frequency and Transitional Probability (TP). Whole word frequency helps infants segment morphologically complex words that are frequent. As we will see in the next section, many frequently occurring complex forms share the same root such as *go, going*, and *goes*, making it possible for learners to notice the overlapping root *go*. TP can help infants notice individual morphemes; certain functional morphemes have lower transitional probability such as *-s* as the occurrence of the complex form *cleans* (n = 2) is very low given the root form *clean* (n = 245). However, the complex form with the *-ing* morpheme *cleaning* (n = 45) has higher TP, indicating that the morpheme *-s* delineates a better word boundary between the root and the morpheme compare to the *-ing* morpheme. In the next sections, I discuss the whole word frequency and TP; and how they help infants find word boundaries.

3.4.1.3 Whole word frequency

Another frequency effect that may affect complex form acquisition is token frequency of the whole complex forms (Bybee, 1995). Table 3.7 reports the 10 most frequently occurring whole words in four verbal forms; root forms, complex forms with *-ing*, complex forms with *-s*, and complex forms with *-d*. The numbers in the cells indicate the number of occurrences of those forms in the Corpus. For example, the token frequency of the word *want* is 5,099 and that of the 3^{rd} person singular form *wants* is 175.

Interestingly, about half of the words in Table 3.7 appear more than in one cell, indicating that frequent roots appear in various inflected forms in the input. Therefore, infants not only get many instances of the word *come* (n = 3,997), but they also get many instances of *coming* (n = 243) along with many instances of *comes* (n = 203). This further means that some of the first words that infants may acquire are various forms of the same root; *come*, *coming*, and *comes*. I have emphasized words using boldface and italics that appear in more than one column in Table 3.7 to highlight the fact that multiple inflected forms with the same roots are frequent in the input. The bold-faced words represent words that appear in three columns and italicised words represent words that appear in two columns.

Table 3.7: Whole word frequency for top 10 verbs

whole root	token freq	*-ing* inflected word	token freq	*-s* inflected word	token freq	*-d* inflected word	token freq
go	5,510	**going**	4,465	**goes**	424	dropped	84
do	5,138	*doing*	1,121	says	358	happened	68
want	5,099	*getting*	413	**comes**	203	**wanted**	68
get	4,173	trying	392	**wants**	175	washed	62
come	3,997	**looking**	282	loves	118	dressed	54
see	3,354	**coming**	243	likes	94	tired	51
put	3,056	playing	227	*makes*	85	supposed	49
let	2,978	eating	219	needs	77	used	45
look	2,428	*making*	151	**looks**	70	changed	43
have	1,868	talking	145	hands	55	missed	37

These overlapping roots in frequent complex forms could help infants recognize the roots and further facilitate functional element recognition.

3.4.2 Transitional Probability

Another type of distributional cue that may help infants notice functional elements is Transitional Probability (TP). Previous studies on TP show that sequences that have lower TP such as *prettybaby* indicate a better word boundary than the sequences that have higher TP *prettybaby*. Using this cooccurrence probability, infants successfully treat *pretty* as a word and place a word boundary between *ty* and *ba*.

Therefore, if a given root appears with only one functional morpheme often, then the frequently occurring morpheme does not provide a reliable "word" boundary. For example, if the root *eat* mostly co-occurs with the morpheme *-ing* rather than the morpheme *-s*, then the presence of *-s* gives a relatively stronger boundary than the *-ing*. Table 3.8 reports partial data from all verbs that the mothers uttered in Brent corpus that have full verbal conjugations (see Appendix B for all verbs).

In Table 3.8, we limited our analysis to verbs that have all four conjugations present in the corpus, i.e., *root, -s, -ing, -d* to compare TP of each morpheme given a same root. The *-s* morphemes that are attached to nouns are not reported here, as both the plural *-s* and possessive *-s* are the only morphemes that can be attached to the nouns, therefore making it impossible to compare the TP of those types of *-s* with TPs of other functional morphemes.

There are several things to note in this table. First, the root forms of the verbs appear very frequently in the input. This is due to the characteristics of English, that it does not mark the present tense with overt morphemes except for the 3^{rd} person singular. Also, root forms can appear in imperative sentences and sentences with modal verbs. Second, overall, for the same root, [root + -*ing*] appears more frequently in the input than either the [root + -*s*] form or the [root + -*d*] form. For example, the root *chew* appears 202 times in the input, *chews* appears 1 time, *chewing* appears 40 times, and *chewed* appears 3 times in the Corpus. Therefore, the TP between *chew* and *-ing* is higher than that of *chew* & *-s* and *chew* & *-d*, indicating that the *-ing* provides a less clear "word" boundary than *-s* and *-d*.

Backward transitional probability (BTP) presents similar arguments. It computes the probability that the functional morpheme has been preceded by a root, which is equal to the probability of the complex forms (e.g., root + morpheme) over the probability of the occurrence of the functional morpheme (i.e., token frequency of that functional morpheme). BTP is particularly useful to understand TP differences between *-ing* and *-s*. This is because these two morphemes have similar token frequencies (12,578 and 12,583 respectively; denominators when computing BTP). Therefore, we can directly compare the frequencies of complex forms (e.g., [root + *-s*] vs. [root + *-ing*]; numerators when computing BTP) to understand their BTP differences. Higher frequency in complex forms indicates higher BTP, which signals a less clear "word" boundary. As shown in Table 3.8, the complex form frequency is higher with the *-ing* morpheme (n = 1,175) than with the *-s* morpheme (n = 549). Therefore, the *-s* morpheme, which has lower BTP, signals a better "word" boundary than the *-ing* morpheme.

Based on the complex form frequencies reported in Table 3.8, I have calculated the FTP and BTP for each root. The median FTP and BTP for the three target functional morphemes are reported in Table 3.9. Note that the *-s* morpheme has lower FTP and BTP than the *-ing* morpheme, and the TP for *-d* is in between the two functional morphemes. These results indicate that the morpheme *-s* signals the strongest "word" boundary, and the morpheme *-ing* signals the weakest "word" boundary.

Type token ratio can also be used to compare the different strength of boundaries that these morphemes indicate which is reported in Table 3.10. Unlike the TP values where **low TP** signals a **better** "word" boundary, **high type token ratio** indicates a **better** "word" boundary. The type frequency reports the number of roots that the morpheme is attached to. Given that the token frequency of the morphemes *-s* and *-ing* are very similar, this means that the *-ing* morpheme is attached to fewer roots more often, making it not a good possible independent unit, therefore not a strong "word" boundary indicator. Conversely, the morpheme *-s* appears with varying roots, making it a better possible independent unit, which marks a better "word" boundary.

In summary, based on the findings of the corpus analysis, I hypothesize that preverbal infants may treat high frequency functional morphemes *-s* and possibly *-ing* as possible "words" and represent them separately in their mental lexicon, as they do with high frequent function words such as *the*. However, there might be a difference between *-s* and *-ing*, as *-s* is a better "word" candidate than *-ing*, based on the TP.

Table 3.8: First 24 verbs with functional morphemes and the number of their appearance from Brent Corpus

verb	# root	# *-s*	# *-ing*	# *-d*
bark	3	1	40	13
begin	3	19	2	14
block	2	2	3	2
break	35	1	5	19
buy	55	3	12	21
call	75	2	29	60
change	126	3	13	61
chase	15	2	12	6
chew	202	1	40	3
clean	245	2	45	34
climb	81	6	21	8
close	222	2	10	34
comb	33	1	10	10
come	3,997	203	1	39
cook	22	2	18	1
crawl	50	3	25	4
die	4	1	8	6
dig	8	1	2	1
hop	12	2	1	3
learn	43	1	15	5
leave	236	6	32	120
like	1,512	94	1	11
look	2,428	70	282	31
love	307	118	2	10
sum	9,716	549	1,175	516

Table 3.9: Median FTP and BTP for *-s, -ing* and *-d* for verbs that have full conjugation in Brent Corpus (see Appendix B)

Median	# *-s*	# *-ing*	# *-d*
FTP	0.03	0.16	0.07
BTP	0.0001	0.0007	0.002

Table 3.10: Type token ratio for morphemes *-s, -ing* and *-d* in Brent Corpus

	# *-s*	# *-ing*	# *-d*
type	4,242	582	481
token	12,583	12,578	2,350
ratio	0.34	0.04	0.2

CHAPTER 4

Infant Experiments

Seven experiments were conducted to test preverbal infants' segmentation and representation of morphologically complex forms. Three inflectional morphemes (*-s, -ing, -d*) were used in the Experiments, as they are high frequency morphemes that can attach to verbs. The other three inflectional morphemes (*-er*, *-en* and *-est*) are not frequent enough for preverbal infants to acquire and to track their transitional probabilities (e.g., Table 3.1).

6-month-olds were chosen as the target age for the current dissertation because we aim to test very young infants who have limited words in their mental lexicon to control for any effect based on their prior lexical knowledge. According to previous research, 6-months is the youngest age at which infants first demonstrate word segmentation (Bortfeld et al., 2005), begin to associate sounds and visual referents (Bergelson & Swingley, 2012; Shukla et al., 2011), and track transitional probabilities (Thiessen & Saffran, 2003; Johnson & Tyler, 2010). If 6-month-olds succeed in relating complex forms and root forms, this will suggest that infants begin to represent functional morphemes at the same time as they do whole word forms and, crucially, prior to the acquisition of meaning, thereby supporting morpheme-based models of auditory lexical processing.

4.1 Morphologically complex forms with *-ing*

Cross-linguistically, children commonly have more nouns in their production and comprehension vocabulary compared to verbs. This "noun bias", has been reported for various languages such as English (Bornstein et al., 2004; Caselli et al., 1995; Gentner, 1982), French (Bassano, 2000; Bornstein et al., 2004; Parisse & Le Normand, 2000; Poulin-Dubois, Graham, & Sippola, 1995), Dutch (Bornstein et al., 2004; De Houwer & Gillis, 1998; Verlinden & Gillis, 1988), German (Gentner, 1982), Italian (Bornstein et al., 2004; Caselli et al., 1995; Tardif, Shatz, & Naigles, 1997), Spanish (Bornstein et al., 2004; Jackson-Maldonado, Thal, Marchman, Bates, & Gutierrez-Clellen, 1993), Hebrew (Bornstein et al., 2004; Maital, Dromi, Sagi, & Bornstein, 2000), Kaluli (Gentner, 1982), and Japanese (Gentner, 1982; Sakurai, 1998; Yamashita, 1999). Nazzi et al. (2005) illustrate that this delay of verb acquisition starts early, and is seen first as a delay in the segmentation of verbs. Specifically, they report that English-learning infants segment verbs only at 13.5-16 months of age.

Parental reports from the MacArther-Bates Communicative Development Inventories (CDI; Fenson et al., 1993), however, tells a different story about the acquisition of verbs. 8-month-old infants are reported to comprehend verbs such as *eat, kiss, drink (action), splash, dance, sleep* and etc. The discrepancy between the Nazzi et al. (2005)'s claims and parental reports may be attributed to the lack of understanding on childrens input. First, Nazzi et al. (2005) used bisyllabic verbs in their studies, whereas all the verbs that are reported to be known to young infants are monosyllabic. Monosyllabic verbs differ from bisyllabic verbs prosodically in that they receive strong stress and often exhibit trochaic stress when conjugated with frequent inflectional morphemes such as *-ing* as in *kissing*. In contrast, 70% of the bisyllabic verbs have an iambic stress pattern in English (Kelly & Bock, 1988; Sereno, 1986). As infants have strong preference for trochaic stress over the iambic stress, it might be possible that bisyllabic verbs are segmented later than the monosyllabic verbs, due to their predominant stress pattern. Also, stimuli in Nazzi et al. (2005)'s study did not have any other cues that infants could use to facilitate segmentation of the verb category, such as distribution cues or top-down cues. For example, a more recent paper demonstrates that verbs with the *-ing* morpheme, which occurs frequently in the input, can be segmented earlier than previously reported (Willits et al., 2014). In their study, 7.5-month English-learning infants were able to segment the [verb + *-ing*] form, yet even 9.5 month-olds failed to pull out the uninflected root verbs such as *kiss* in sentences like "I'll *kiss* you on your cheek". Willits et al. (2014) suggest that frequency of the contextual frames, distributional cues, can be utilized by infants in segmenting verbs from fluent speech.

The current dissertation is in line with Willits et al. (2014)'s research yet goes further and hypothesizes that English-learning 6-month-olds, who are at the beginning stage of word segmentation, will be able to segment complex verbs with the *-ing* morpheme with the help of known words such as *mommy* or *mama* (Bortfeld et al., 2005). We use Headturn Preference Procedure (HPP; Kemler-Nelson et al., 1995) to test this in Experiment 1. If infants succeed in segmentation, they should listen longer to the familiar complex forms over novel complex forms during the testing phase.

4.1.1 Experiment 1: *babbing-babbing*

4.1.1.1 Methods

Participants Twenty full-term monolingual English-learning 6-month-olds (mean age = 177 days; range 167:196; 9 girls) participated in this Experiment. According to parental report, none had a history of speech, language or hearing difficulties, nor did they have a cold or ear infection on the day of testing. All were in good health and had at least 90% of their language input in English (average=97; range 90:100). Eight additional infants were tested but their data were excluded because they failed to complete testing due to fussiness (n = 4), parental interference (n = 1), and neither *mommy* nor *mama* was the most familiar form (n = 3).

Stimuli Four CVC nonce words were created for the experiment - *bab, dop, kell*, and *teep*. We varied the onset and the vowel to minimize any effect of individual segments. As for the final consonants, half were voiceless, and half were voiced. We deliberately avoided using [t] and [d] as a final consonant as they are tapped [ɾ] in the *-ing* context.

The words were recorded in four separate lists, with each list containing 15 repetitions of one of the four words separated by an inter-stimulus-interval of about 1 second. Also, four six-sentence passages containing each of the four target words were recorded. These six-sentence passages are listed in Appendix C. Half of the time, the target words were in sentence-initial position and the other half of the time, they were in sentence-final position. Following Bortfeld et al. (2005), infants were tested using passages with either *mommy* or *mama*, depending on the form they were most familiar with. In every instance, the target word followed this familiar word with the appropriate syntax such as "Mommy is babbing...". If neither *mommy* nor *mama* was the most familiar form for a particular infant, that infant's data were discarded.

The stimuli were recorded by a 26-year-old female native English speaker from Southern California. She was instructed to read the words and the passages in an animated voice as if talking to a preverbal infant. The stimuli were recorded in a soundproof booth using a Shure SM10A head-mounted microphone. All stimuli were digitized at a sampling frequency of 22050Hz and 16-bit quantization.

Table 4.1: Acoustic measures of passages

Measures	Passages			
	Exp 1 & 2	Exp 3 & 4	Exp 5	Exp 6
Average Duration (s)	22.7	21.9	22.2	21.9
Duration range (Min:Max)	22.3:23.3	21.1:22.6	21.2:22.6	21.2:22.6
Average Pitch (Hz)	243	242	244	244
Pitch range (Min:Max)	122:421	118:421	125:422	92:424

Table 4.2: Acoustic measures of word lists

Measures	Lists		
	Exp 1	Exp 3	Exp 2 & 4 & 5 & 6
Average Duration (s)	22.4	22.5	22.5
Duration range (Min:Max)	22.3:22.4	22.4:22.6	22.4:22.6
Average Pitch (Hz)	259	262	247
Pitch range (Min:Max)	172:420	136:422	118:422

Acoustic characteristics of the eight passages (four passages for *mommy* condition; four passages for *mama* condition), the average duration, the duration range, average pitch, and the pitch range, for passages and lists are reported in Tables 4.1 and 4.2 respectively. The *mommy* and the *mama* conditions were combined and averaged. Additionally, the average duration of target words was 550ms (SD = 49) in the passages and 644ms (SD = 85) in the lists. The average pitch of target words was 186Hz (SD = 28) in the passages and 195Hz (SD = 29) in the lists. The average intensity of the target words was 77.2dB (SD = 1.8) in the passages and 79.2dB (SD = 1.5) in the lists. All the measurements and analyses were done using PRAAT (Boersma & Weenink, 2013). The average loudness level for all the stimuli during playback was 73dB.

Procedure Infants were tested using the Headturn Preference Procedure (HPP) (Kemler-Nelson et al., 1995; Jusczyk & Aslin, 1995). The infant sat on her caregivers' lap in the center of a three-sided booth. On each side panel, a red light was located at eye level. A green light was mounted on the center panel, also at eye level, and a movie-camera was mounted behind this panel, just above the green light. Each trial began when the green light on the center panel flashed. Once the infant looked at the center panel, one of the red lights on the side panels began to flash. When the infant turned her head towards that light, speech began to play. Stimulus presentation continued until the infant looked away from the flashing light for more than two consecutive seconds or at the end of the trial. The experimenter observed the infant through a monitor connected to the camera facing the infant and recorded the infant's looking time. The experimenter recorded the direction of the infant's headturns, which in turn determined the flashing of the lights and the presentation of the speech. The infant's looking time to the flashing lights was used as a proxy for listening time. Both the caregiver and the experimenter wore noise cancelling headphones that delivered masking music so they could not influence the infant's behavior.

Design Infants were tested using the same paradigm as in Jusczyk and Aslin (1995). Testing was done in two phases. During the familiarization phase, infants heard either the passages with *babbing & dopping* or *kelling & teeping* till they accumulated 45 seconds of listening time to each passage. The trials continued to alternate until the criterion was met for both passages. During the test phase that followed, infants were presented all four word lists with the -*ing* suffix attached (e.g., the repetition of *babbing*), two familiar and two novel. The four word lists were presented in three blocks for a total of 12 test trials. The order of presentation of the word lists was randomized in each block. Listening time to familiar and novel test word lists were averaged separately and compared statistically.

4.1.1.2 Results & Discussion

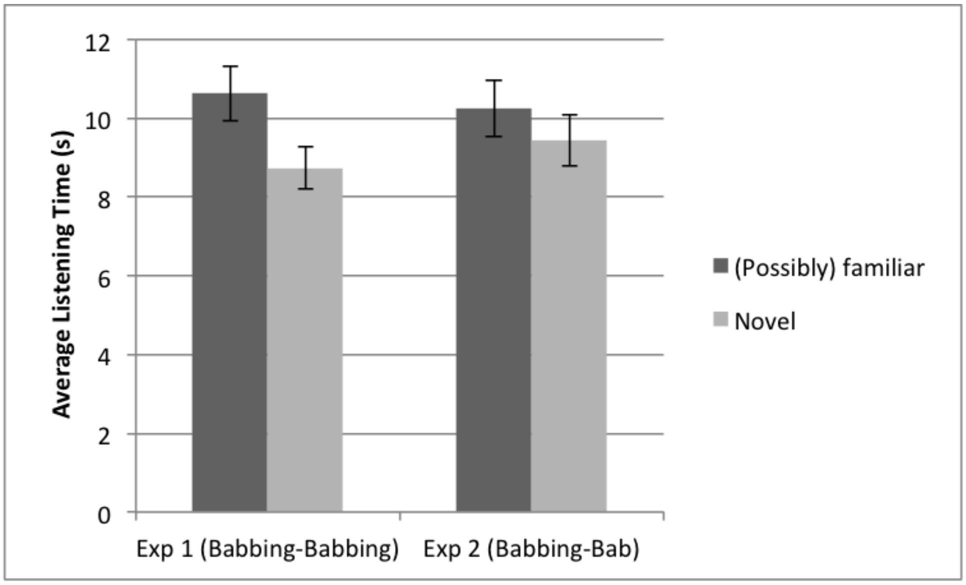

Figure 4.1: Average listening time (+/- SE) to familiar and novel words in Experiments 1 (Babbing-Babbing) and 2 (Babbing-Bab).

Average listening times to the familiar (10.63s; SD = 3.1) and novel word lists (8.72s; SD = 2.3) are presented in Figure 4.1. Out of the 20 6-month-olds tested, 17 listened longer to the familiar words compared to the novel words. A mixed ANOVA was conducted with listening time as the dependent variable, Trial-type (familiar vs. novel) as the within-subjects variable and Condition (*babbing/dopping* vs. *kelling/teeping*) as the between-subjects variable. The main effect of Trial-type ($F(1,18) = 11.846$, $p = .003$, $\eta_p^2 = .397$) and the interaction between Trial-type and Condition ($F(1,18) = 7.753$, $p = .01$, $\eta_p^2 = .301$) were significant. The main effect of Condition was not ($F(1,18) = .201$, $p = .66$, $\eta_p^2 = .011$). A paired sample T-test for each condition revealed that only Condition 2 (*kelling/teeping*) was significant; t(9) = 3.989, $p = .003$. The differences found in Condition 1 (*babbing/dopping*) was not statistically significant; t(9) = .526, p

= .612. This result was driven by one particular infant's datapoint, which was more than two standard deviations away from the mean, a possible outlier. We are currently testing two more infants in each condition, which we believe will remove the interaction that we see here.

Therefore, 6-month-olds successfully segmented morphologically complex words with the *-ing* morpheme from fluent speech, but only in condition 1.

These results demonstrate that verb segmentation itself is not delayed, and the well-documented delay in acquisition of verbs by English-learning infants cannot be attributed to difficulties in segmentation (for a similar idea, see Marquis & Shi, 2008). These results also confirm the facilitatory effect of known words (Bortfeld et al., 2005), highlighting the importance of top-down cues in word segmentation and recognition.

4.1.2 Experiment 2: *babbing-bab*

Previous studies have demonstrated that infants can segment words as well as coherent units bigger than words from fluent speech. For example, using Transitional Probability, infants can pull out words at 8 months (Saffran, Aslin, & Newport, 1996) and also segment high frequency sequences bigger than a word unit at 11-months (Ngon et al., 2013). This ability is also demonstrated by younger infants. Bortfeld et al. (2005) illustrate 6-month-olds' segmentation of nouns from fluent speech such as *bike* and *feet*. At the same age, infants can also segment clauses from continuous speech using acoustic correlates of syntactic boundaries, such as pause duration, pitch, and pre-boundary lengthening (Seidl, 2007). Therefore, it is possible that *babbing* is a unit bigger than a word for 6-month-olds, just like it is for adults. If this is the case, infants at 6-months might be able to segment a smaller word unit from that phrase such as the root *bab*. We test this hypothesis in Experiment 2.

4.1.2.1 Methods

Participants Twenty full-term monolingual English-learning 6-month-olds (mean age = 176 days; range 166:197; 9 girls) participated in this Experiment (average English input = 99; range = 95:100). Selection criteria were the same as Experiment 1. Four additional infants were tested but their data were excluded because they failed to complete testing due to fussiness (n = 2), and neither *mommy* nor *mama* was the most familiar form (n = 2).

Stimuli The acoustic characteristics of the eight passages (four *mommy* passages and four *mama* passages) and four lists of isolated words are reported in 4.1 and 4.2. These tables summarize the average duration, the duration range, average pitch and the pitch range. Recall that the passages used in Experiment 2 were the same as in Experiment 1. Additionally, the average duration of target words was 595ms (SD = 76), the average pitch of target words was 186Hz (SD = 38), and the average intensity of the target words was 79.6dB (SD = 2.3) in the lists.

Procedure & Design The design and procedure were identical to that in Experiment 1. Again, infants were familiarized with passages containing the morphologically complex target words with the *-ing* morpheme. However, during the testing phase, infants in Experiment 2 heard uninflected root forms (e.g., the repetitions of *bab*).

Results & Discussion Average listening times to the familiar (10.24s; SD = 3.1) and novel word lists (9.44s; SD = 2.9) are presented in Figure 4.1. Out of the 20 6-month-olds tested, 12 listened longer to the familiar words compared to the novel words. A mixed ANOVA was conducted with listening time as the dependent variable, Trial-type (familiar vs. novel) as the within-subjects variable and Condition (*babbing/dopping* vs. *kelling/teeping*) as the between-subjects variable. Neither the main effects of Trial-Type ($F(1,18) = 1.358$, $p = .259$, $\eta_p^2 = .07$) nor Condition ($F(1,18) = 2.137$, $p = .161$, $\eta_p^2 = .106$) was significant. No significant interaction ($F(1,18) = .475$, $p = .499$, $\eta_p^2 = .026$) was found between Trial-type and Condition. The small effect size ($\eta_p^2 = .026$) indicates that simply adding a few subjects would not make the statistical comparison significant.

Therefore, 6-month-olds did **not** relate the root form *bab* to the complex form *babbing*. These results confirm previous research on English verb segmentation, where 8.5-months' failure to map [root+-*ing*] to [root] (Mintz, 2013). These results are also in line with previous studies showing that infants do not segment part words from whole words, as demonstrated by their failure to map *doc* to *doctor* (Jusczyk et al., 1999). Thus, *babbing* is a unit that cannot be segmented further for 6-month-olds.

The combined results from Experiments 1 and 2 demonstrate that infants at 6-months may be beginning to segment the [verb + -*ing*] form, but do not relate the [verb] and the [verb + -*ing*] form. This result seems to support whole word-based models of lexical processing, where complex forms are acquired and represented as non-decomposable whole forms by infants.

Before we conclude in favor of whole word-based models of lexical processing, we consider an alternative explanation for infants' failure to relate *babbing* to *bab*. The morpheme *-ing* is a vowel-initial morpheme, and the delay of vowel-initial words segmentation compared to consonant-initial words has been demonstrated by several research (Mattys & Jusczyk, 2001; Nazzi et al., 2005; Seidl & Johnson, 2008). Thus, it is a possible that 6-month-old infants are not able to segment out the *-ing* morpheme, not because they fail to decompose complex forms, but because they disfavor vowel-initial morphemes. If this is the case, then if we use a non vowel-initial morpheme such as *-s*, infants should be able to decompose the complex forms and relate the roots and the inflected forms. To confirm this hypothesis, we conduct Experiments 3, 4, and 5.

Another possible explanation exists. The failure in Experiment 2 might be due to the existence of "is" between the familiar word *mommy* and target verb *babbing*, impeding the role of top-down cue. However, this explanation is unlikely as there was a possessive "s" between *mommy* and the target noun in Bortfeld et al. (2005)'s study as well (e.g., *Mommy's bike had big, black wheels*). In their study, the existence of "s" did not influence the segmentation, therefore it is unlike that the "is" interfered in our results.

4.2 Morphologically complex forms: the suffix *-s*

In Experiments 3, 4, and 5, we test the effect of the non vowel-initial inflectional morpheme *-s*. First, Experiment 3 tests whether English-learning 6 month-olds can segment morphologically complex forms with the *-s* morpheme from sentences. Previous work that used complex verbs with this morpheme revealed that only 13.5-16 months could segment them from speech (e.g., *tickets, orbits*; Nazzi et al., 2005). However, as we have seen in Chapter 3, the morpheme *-s* is as frequent as the morpheme *-ing*, if we combine all three *-s* morphemes together. Therefore, it is possible that 6-month-olds segment inflected forms with the *-s* morpheme and I test this in Experiment 3.

4.2.1 Experiment 3: *babs-babs*

4.2.1.1 Methods

Participants Twenty four full-term monolingual English-learning 6-month-olds (mean age = 183 days; range 169:198; nine girls) participated in this experiment (average English input = 99; 93-100). Selection criteria were the same as in Experiments 1 and 2. Six more infants were tested but their data was excluded as they failed to complete testing due to fussiness (n = 3) and lack of interest (n = 1), has an autism sibling (n = 1), and neither *mommy* nor *mama* was the most familiar form (n = 1).

Stimuli The same CVC nonce words were used - *bab, dop, kell,* and *teep*. As before, half of the final consonants were voiceless, and the other half were voiced, and crucially there were no sibilants. This is because the morpheme *-s* is realized in three different ways ([s], [z], [əz]) depending on the voicing of the last segment. Sibilant ending words (e.g., -s, -z, -sh) that condition the [əz] allomorph were avoided because the addition of a complete syllable is likely to be perceptually more salient than the allomorphs [s] or [z].

The acoustic characteristics of the eight passages (four *mommy* passages and four *mama* passages) and four lists of isolated words are reported in Tables 4.1 and 4.2. These tables summarize the average duration, the duration range, average pitch and the pitch range. Additionally, the average duration of target words was 592ms (SD = 138) in the passages and 740ms (SD = 74) in the lists. The average pitch of target words was 213Hz (SD = 38) in the passages and 239Hz (SD = 74) in the lists. The average intensity of the target words was 76.5dB (SD = 2.4) in the passages and 80.1dB (SD = 2.6) in the lists.

Procedure & Design The design and procedure were identical to the previous two experiments. However, the target words in the passages and in the list were different. First, infants were familiarized with passages containing the morphologically complex target words with the *-s* morpheme with the appropriate syntax such as “Mommy babs and sings...”. During the test phase that followed, infants were presented all four word lists with the *-s* suffix attached (e.g., the repetition of *babs*), two familiar and two novel.

Results & Discussion Average listening times to the familiar (10.29s; SD = 3.4) and novel word lists (9.02s; SD = 2.3) are presented in Figure 4.2. Out of the 24 6-month-olds tested, 19 listened longer to the familiar words compared to the novel words. A mixed ANOVA was conducted with listening time as the dependent variable, Trial-type (familiar vs. novel) as the within-subjects variable and Condition (*babs/dops* vs. *kells/teeps*) as the between-subjects variable. There was a significant main effect of Trial-type ($F(1,22) = 5.653$, $p = .03$, $\eta_p^2 = .204$). Further, neither the main effect of Condition ($F(1,22) = .745$, $p = .4$, $\eta_p^2 = .033$), nor the interaction between Trial-type and Condition ($F(1,22) = .827$, $p = .37$, $\eta_p^2 = .036$) was significant. Therefore, 6-month-olds successfully segmented morphologically complex words from fluent speech.

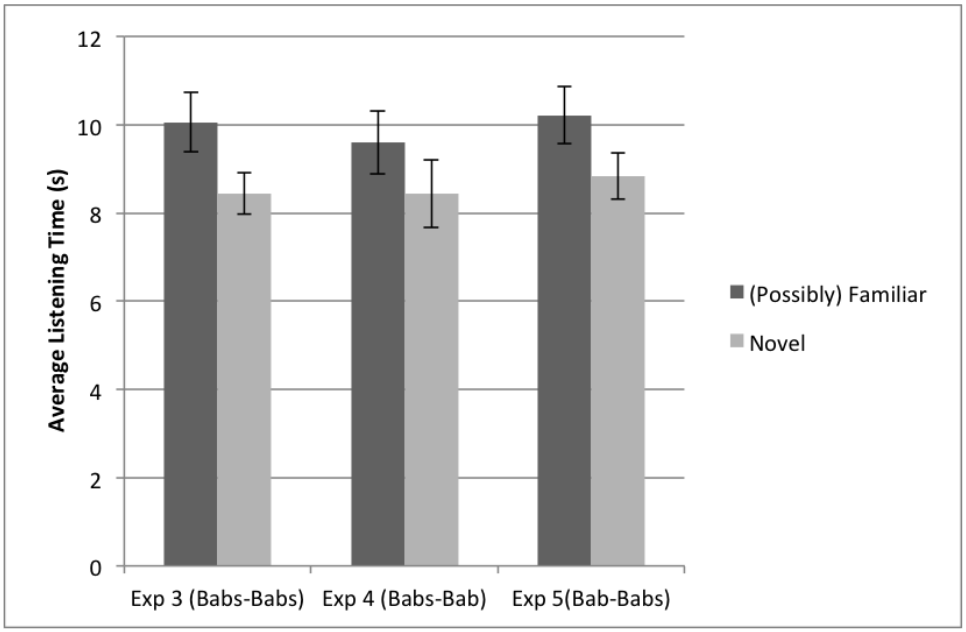

Figure 4.2: Average listening time (+/- SE) to familiar and novel words in Experiments 3 (Babs-Babs), 4 (Babs-Bab) and 5 (Bab-Babs)

The results of Experiment 3 demonstrate that 6-month-old infants are able to segment morphologically complex forms with the *-s* morpheme from fluent speech. These results demonstrate that not only verbs with the *-ing* morpheme, but also with the *-s* morpheme are segmented earlier in language acquisition. Also, these results confirm the role of top-down cues in early language acquisition of verbs, as partially demonstrated by Bortfeld et al. (2005) for nouns.

4.2.2 Experiment 4: *babs-bab*

Experiment 4 was designed to test whether infants can relate the root forms and the morphologically complex forms when the frequent non vowel-initial morpheme *-s* is present. Infants were first familiarized with two passages with morphologically complex words (e.g., *babs* and *dops*) just like in Experiment 3. Unlike in Experiment 3, in the test phase in Experiment 4, infants were presented only with uninflected root forms (e.g., *bab*). Two of these root forms were completely novel for infants (e.g., *kell* and *teep*). However, if infants can decompose morphologically complex forms, then infants should treat the root forms of words that appeared in the passages as familiar and listen longer to them. If 6-month-olds succeed in Experiment 4, this shows that infants can decompose morphologically complex forms at the developmental onset of word segmentation, thereby supporting morpheme-based models of lexical processing.

4.2.2.1 Methods

Participants Twenty four full-term monolingual English-learning 6-month-olds (mean age = 179 days; range 165:204; twelve girls) participated in this experiment (average English input = 99; range = 90:100). Selection criteria were the same as previous experiments. Three more infants were tested but their data were excluded as they failed to complete testing due to parental interference (n = 1), and neither *mommy* nor *mama* was the most familiar form (n = 2).

Stimuli In Tables 4.1 and 4.2, the acoustic characteristics of the four lists of isolated words and the eight passages (four *mommy* and four *mama* passages): average duration, the duration range, average pitch and the pitch range, are reported. Recall that the passages were identical to that used in Experiment 3. Additionally, the average duration, pitch, and intensity of target words in the lists were the same as Experiment 2.

Procedure & Design The design and procedure was identical to that in Experiment 3. Again, infants were familiarized with passages containing the morphologically complex target words. However, during the testing phase, infants in Experiment 4 heard uninflected root forms (e.g., the repetitions of *bab*).

4.2.2.2 Results & Discussion

Average listening times to the potentially familiar (9.29s; SD = 3) and novel word lists (8.2s; SD = 3.3) are presented in Figure 4.2. Out of the 24 6-month-olds tested, 18 listened longer to the possibly familiar words compared to the novel words. A mixed ANOVA was conducted with listening time as the dependent variable, Trial-type (familiar vs. novel) as the within-subjects variable and Condition (*babs/dops* vs. *kells/teeps*) as the between-subjects variable. Again, the main effect of Trial-type was significant ($F(1,22) = 6.46$, $p = .019$, $\eta_p^2 = .227$). Additionally, neither the main effect of Condition ($F(1,22) = .102$, $p = .75$, $\eta_p^2 = .005$), nor the interaction between Trial-type and Condition ($F(1,22) = .048$, p = .6829, $\eta_p^2 = .002$) was significant. This shows that 6-month-olds successfully related root forms and the morphologically complex forms.

The results from Experiment 4 show that infants can segment the functional morpheme -*s* from the root at the onset of word segmentation, prior to meaning acquisition, supporting morpheme-based models of lexical processing.

4.2.3 Experiment 5: *bab-babs*

To confirm and strengthen our results in Experiment 4, we change the order between the passages and lists and familiarized infants with the repetition of isolated words and tested them on passages in Experiment 5. A classic and comprehensive word segmentation study by Juscyzk et al. (1999) demonstrates that for identical match tasks, the results from procedures in which infants are familiarized with isolated words and tested on passages match those when they are familiarized with passages and then tested on isolated words. The current study goes further and asks whether infants can relate words that are not identical match, but morphologically related, when familiarized with the roots and tested on complex forms embedded in sentences.

4.2.3.1 Methods

Participants Twenty four full-term monolingual English-learning 6-month-olds (mean age = 180 days; range 165:198; 12 girls) participated in this experiment (average English input = 97; 90-100). Selection criteria were the same as previous Experiments. Two more infants were tested but their data were excluded as they failed to complete testing due to fussiness (n = 1) and technical difficulties (n = 1).

Stimuli The acoustic characteristics of the four lists of isolated words and the eight passages (four *mommy* and four *mama* passages): average duration, the duration range, average pitch and the pitch range, are reported in Tables 4.1 and 4.2. The passages were the same as Experiments 3 and 4. The lists of words were the same as Experiments 2 and 4.

Procedure & Design The design and procedure of Experiment 5 were slightly different from the previous experiments. Importantly, infants were familiarized with two separate lists of uninflected words (e.g., the repetitions of *bab*) first until they accumulated 30 seconds of listening time to each list. During the test phase, infants heard all four passages containing the morphologically complex target words.

4.2.3.2 Results & Discussion

Average listening times to the potentially familiar (9.29s; SD = 3.1) and novel word passages (8.8s; SD = 2.5) are presented in Figure 4.2. Out of the 24 6-month-olds tested, 20 listened longer to the passages that contain possibly familiar words compared to passages with novel words. A mixed ANOVA was conducted with listening time as the dependent variable, Trial-type (familiar vs. novel) as the within-subjects variable and Condition (*babs/dops* vs. *kells/teeps*) as the between-subjects variable. Again, the main effect of Trial-type was significant ($F(1,22) = 8.207$, $p = .009$, $\eta_p^2 = .272$). Additionally, neither the main effect of Condition ($F(1,22) = .032$, $p = 859$, $\eta_p^2 = .001$), nor the interaction between Trial-type and Condition ($F(1,22) = 1.736$, p = .201, $\eta_p^2 = .073$) was significant. This shows that 6-month-olds successfully related root forms and the morphologically complex forms, confirming the results in Experiment 4.

Two alternative interpretations are also consistent with these findings. First, one might argue that infants at 6 months simply do not differentiate between *babs* and *bab*. However, a recent study has demonstrated that English-learning 6-, 12- and 18-month-olds successfully discriminate morphologically relevant word-final contrasts, specifically *neek* vs. *neeks* & *keet* vs. *keets* (Fais, Kajikawa, Amano, & Werker, 2009). Thus, it is unlikely that our 6-month-olds failed to distinguish *babs* and *bab*. Another possibility is that infants simply relate any part of a word and a whole-word based on phonological similarity, without relying on the recognition of the morpheme. Such an account would explain the success of 6-month-olds in Experiments 4 and 5, but without privileging functional morphemes in any way. I test this possibility in Experiment 6.

4.3 The role of phonological similarity: Psuedo suffix -sh

4.3.1 Experiment 6: *babsh-bab*

In Experiments 4 and 5, infants successfully related root forms and complex forms, likely stripping the functional morpheme *-s* from the complex forms. However, it might be the case that infants were not recognizing the functional morpheme *-s*, rather they were relating a part of a word, *bab*, and the whole word, *babs*. This is unlikely as there is independent evidence that 7.5 months do not relate part words and whole words (do not relate *doc* to *doctor*, Jusczyk et al. (1999)). However, one might argue that infants in Jusczyk et al. (1999)' s study and infants in our Experiments 4 and 5 are performing different tasks, as one study tests the mapping between two syllable words *doctor* to one syllable part word *doc*, whereas our study tests the mapping between two one syllable words *bab* and *babs*. To further strengthen our argument that the success we see in Experiments 4 and 5 are due to the morpheme *-s*, we tested whether infants can relate *bab* and the nonce complex word *babsh*. We chose *-sh* [ʃ] as a pseudo-morpheme because a) it is acoustically most similar to the *-s* morpheme and b) it has been shown that adults do not relate part words and whole words with *-sh* (do not relate *sea* and *seash*; Norris et al. (1997)).

4.3.1.1 Methods

Participants Twenty four full-term monolingual English-learning 6-month-olds (mean age = 177 days; range 167:193; 14 girls) participated in this Experiment (average English input = 98.6; 90-100). Selection criteria were the same as the five previous experiments. Seven additional infants were tested but their data were excluded because they failed to complete testing due to fussiness (n = 4) and parental interference (n = 1), and neither *mommy* nor *mama* was the most familiar form (n = 2).

Stimuli The acoustic characteristics of the eight passages (four *mommy* passages and four *mama* passages) and four lists of isolated words are reported in Tables 4.1 and 4.2. They summarize the average duration, the duration range, average pitch and the pitch range. The lists were the same as in Experiments 2 and 4. Additionally, the average duration of target words was 599ms (SD = 86), the average pitch of target words was 239Hz (SD = 67), and the average intensity of the target words was 77.7dB (SD = 2.8) in the passages.

Procedure & Design The design and procedure was identical to the previous experiments with the exception of Experiment 5. However, during the familiarization phase infants heard sentences with the [target word + pseudo functional element (*-sh*)] (e.g., Mommy *babsh* and sings at the same time) but were again tested on root forms (e.g., the repetitions of *bab*).

4.3.1.2 Results & Discussion

Average listening times to the potentially familiar (10.3s; SD = 3.6) and novel word lists (10.6s; SD = 3.7) are presented in Figure 4.3. Out of the 24 infants, 12 listened longer to the possibly familiar words compared to the novel words. A mixed ANOVA was conducted with listening time as the dependent variable, Trial-type (familiar vs. novel) as the within-subjects variable and Condition (*babsh/dopsh* vs. *kellsh/teepsh*) as the between-subjects variable. Neither the main effect of Trial-type ($F(1,22) = .283$, $p = .6$, $\eta_p^2 = .013$), or Condition ($F(1,22) = .175$,

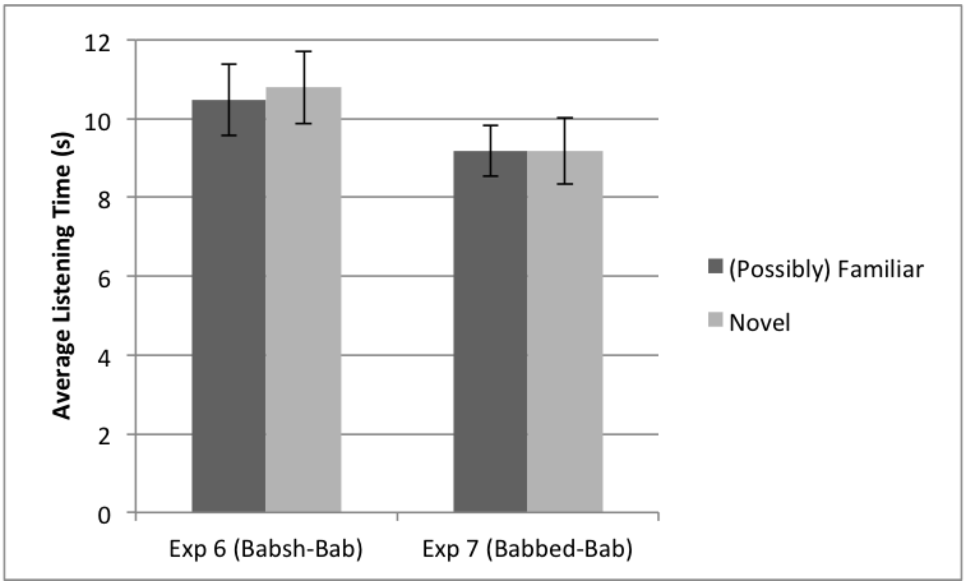

Figure 4.3: Average listening time (+/- SE) to familiar and novel words in Experiments 6 (Babsh-Bab) and 7 (Babbed-Bab)

p = .68, η_p^2 = .008), nor the interaction between Trial-type and Condition (F(1,22) = .151, p = .701, η_p^2 = .007) was significant. This demonstrates that 6-month-olds did not relate the part word *bab* to *babsh*.

These results are consistent with those of Jusczyk et al. (1999), where 7.5-month-olds failed to segment *doc* when they were familiarized with sentences with the word *doctor*. These results are also consistent with adult word recognition studies that once adults recognize a word, other words, including parts of words, are inhibited and harder to spot (McQueen, Norris, & Cutler, 1994).

To confirm that the difference between Experiments 4 (*babs-bab*) and 6 (*babsh-bab*) was statistically significant, we compared the performance using a two-way mixed ANOVA with listening time as the dependent variable, and Trial-type (familiar vs. novel) as the within-subjects variable, and Experiment (4 vs. 6) as the between-subjects variable. As the main effect of Condition was not significant in both experiments, we did not consider Condition as a variable in comparing the two experiments. No significant main effect was found for

Trial-type ($F(1,46) = 1.503$, $p = .227$, $\eta_p^2 = .032$) or Experiment ($F(1,46) = 3.578$, $p = .065$, $\eta_p^2 = .072$). Most importantly, there was a significant interaction between Trial-type and Experiment ($F(1,46) = 4.26$, $p = .045$, $\eta_p^2 = .085$), demonstrating that 6-month-olds behaved differently in the two experiments.

4.4 The role of frequency: The past tense *-d*

Until now, we have shown that a) infants at 6-months can segment complex verbs from sentences and b) they can relate complex forms to root forms yet with limitations: only with the non vowel-initial morphemes such as *-s*. We now ask whether **frequency**, which is known to affect adults' lexical representation, has an effect on infants' representation of complex forms. We test this in Experiment 7.

4.4.1 Experiment 7: *babbed-bab*

As shown in Table 3.1, the past tense morpheme *-d* is less frequent in infant-directed speech. However, it is a non vowel-initial morpheme just like *-s*. Therefore, if infants are not sensitive to the frequency of the functional morphemes, then 6-month-olds should succeed in relating the [root + *-d*] with the [root] form. However, if infants are sensitive to the functional morpheme frequency, then they should fail to relate complex forms with the *-d* morpheme to root forms.

4.4.1.1 Methods

Participants Twenty four full-term monolingual English-learning 6-month-olds (mean age = 182 days; range 166:204; 10 girls) participated in this Experiment (average English input = 98.4; 90-100). Selection criteria were the same as in previous experiments. Six additional infants were tested but their data were excluded because they failed to complete testing due to fussiness (n = 3) and lack of interest (n = 1), and neither *mommy* nor *mama* was the most familiar form (n = 2).

Stimuli In Tables 4.1 and 4.2, the acoustic characteristics of the eight passages (four *mommy* passages and four *mama* passages) and four lists of isolated words are reported. They summarize the average duration, the duration range, average pitch and the pitch range. The lists were the same as Experiments 2, 4, 5, and 6. Additionally, the average duration of target words was 568ms (SD = 102), the average pitch of target words was 227Hz (SD = 60), and the average intensity of the target words was 76.3dB (SD = 3) in the passages.

Procedure & Design The design and procedure was identical to the previous experiments with the exception of Experiment 5. However, during the familiarization phase infants heard sentences with the [target word + past tense functional morpheme (-*d*)] (e.g., Mommy *babbed* and sang at the same time) but were again tested on root forms (e.g., the repetitions of *bab*).

4.4.1.2 Results & Discussion

Average listening times to the potentially familiar (8.7s; SD = 2.7) and novel word lists (8.4s; SD = 2.8) are presented in Figure 4.3. Out of the 24 infants, 15 listened longer to the possibly familiar words compared to the novel words. A mixed ANOVA was conducted with listening time as the dependent variable, Trial-type (familiar vs. novel) as the within-subjects variable and Condition (bab/dop vs. kell/teep) as the between-subjects variable. Neither the main effect of Trial-type ($F(1,22) = .587$, $p = .452$, $\eta_p^2 = .026$) or Condition ($F(1,22) = .175$, $p = .68$, $\eta_p^2 = .008$), nor the interaction between Trial-type and Condition

(F(1,22) = 3.968, p = .06, η_p^2 = .153) was significant. This demonstrates that 6-month-olds did not relate the root form *bab* to *babbed*.

The difference between Experiments 4 (*babs-bab*) and 7 (*babbed-bab*) was compared using a two-way mixed ANOVA with listening time as the dependent variable, and Trial-type (familiar vs. novel) as the within-subjects variable, and Experiment (4 vs. 7) as the between-subjects variable. Condition was not considered as a variable as neither experiment found a significant main effect of Condition. A significant main effect was found for Trial-type (F(1,46) = 6.053, p = .018, η_p^2 = .116). Neither the main effect of Experiment (F(1,46) = 2.07, p = .157, η_p^2 = .043). nor the interaction between Trial-type and Experiment (F(1,46) = 2.07, p = .157, η_p^2 = .043) was significant. These results show that unlike with the pseudo morpheme *-sh*, infants show a trend toward relating verbs with the morpheme *-d* to root forms.

To confirm that the difference between Experiments 6 (*babsh-bab*) and 7 (*babbed-bab*) was statistically significant, we compared the performance using a two-way mixed anova with listening time as the dependant variable, and Trial-type (familiar vs. novel) as the within-subjects variable, and Experiment (6 vs. 7) as the between-subjects variable. No significant main effect was found for Trial-type (F(1,46) = 0.00, p = .99, η_p^2 = 0.00) nor was there a significant interaction between Trial-type and Experiment (F(1,46) = .795, p = .377, η_p^2 = .017). However, the main effect of Experiment was found (F(1,46) = 4.759, p = .034, η_p^2 = .094). These results show that overall, the average listening time for Experiment 6 (10.45s) were longer compared to that of Experiment 7 (8.55s) as shown in Figure 4.3.

CHAPTER 5

Discussion

5.1 General summary of results

In this dissertation, I ask when infants start segmenting morphologically complex verbs. The results of the seven experiments show that from the onset of word segmentation, i.e., at 6-months, infants can segment complex verbs with the help of a known word *mommy* or *mama* (a paradigm used in Bortfeld et al. (2005)).

Next, I ask how these verbs are represented in the mental lexicon. More specifically, I ask whether infants are able to relate complex forms to root forms and what factors mediate the relationship between the two forms. The results illustrate that infants can segment complex verbs with the *-s* and partially with *-ing* from the sentences such as *babs* and *babbing*, relate *babs* to *bab*, but fail to relate the root *bab* to the complex forms with the vowel-initial morpheme *-ing*. Infants' ability to successfully relate *bab* and *babs* was not merely due to phonological similarity, as they did not relate phonologically-similar pairs with each other in the absence of a morphological relationship in Experiment 6 (**babsh* and *bab*). Also, the frequency of the morpheme plays a role in this acquisition, as infants fail to relate complex forms with a less frequent morpheme *-d* in Experiment 7 (**babbed* and *bab*).

These results have implications for our understanding of word segmentation, the acquisition of verbs, the role of functional elements in early language development, and highlight the importance of top-down cues in infants' word segmentation. Also, these results provide evidence for morpheme-based processing models and distribution and functional element based acquisition models. In the following section, I will discuss each of the implications.

5.2 Implications for research on verb acquisition

First, this dissertation has provided new data on English-learning infants' segmentation of the verb category. Previous studies have demonstrated that infants need to be at least 13.5-16 months to be able to segment English verbs such as *tickets* or *orbits* from sentences (Nazzi et al., 2005). Thus, the segmentation of verbs has been thought to be quite delayed compared to segmentation of nouns (e.g., *bike*, *dog* at 6-months: Bortfeld et al., 2005). These results contrast with CDI parental reports (Fenson et al., 1993), where 8-month-olds' are reported to comprehend certain verbs.

However, this dissertation provides the earliest evidence of verb segmentation - at 6-months. In Experiment 3 (*babs* and *babs*), I show that verb segmentation is not delayed, and in fact, even 6 month-olds are able to segment nonce verbs such as *babs* from fluent speech when the frequent "known-word" *mommy* or *mama* precedes it (see also Willits et al. (2014) for evidence that 7.5-month-olds segment verbs with *-ing*).

The developmental delay in the segmentation of verbs (Nazzi et al., 2005) has been thought to be one possible basis for the noun bias in English-learning toddlers' vocabulary (Bates, Bretherton, & Snyder, 1988; Benedict, 1979; Brown, 1973; Nelson, 1973). The findings that English-learning infants as young as 6-months readily segment verbs from fluent speech show that difficulties in segmenting verbs alone cannot account for a noun-bias in the vocabulary of English toddlers.

I do not argue that either *babs* or *babbing* are **verbs** for infants. In fact, there is no reason to believe that 6-month-olds distinguish nouns from verbs. What these results illustrate is that regardless of grammatical categories, infants readily segment words that follow "mommy". Because "mommy" is often followed by verbs, infants can also segment verbs.

5.3 Implications for research on top-down cues

This dissertation also highlights the important role that top-down cues play in early language acquisition. Previous studies on infants' word segmentation have mainly focused on bottom-up cues, giving limited attention to the top down cues. One reason for this has been the belief that infants do not have enough lexical knowledge to use it to find other words.

However, more recently, studies have shown that infants possess more lexical knowledge than has been previously assumed and even infants as early as 6 months do have some representations of frequent content words. For example, Bergelson and Swingley (2012) presented English-learning 6-9 month-olds with sets of pictures while their parents named them. Infants looked at the named picture, illustrating their understanding of the target words. Infants were not trained on these words in the laboratory, demonstrating that even young infants learn words through experience with language. Similarly, Shukla et al. (2011) illustrate that 6-month-olds map segmented target words to visual referents. Both of these studies demonstrate that infants as young as 6-months have some representation of words that they segment from speech stream.

Not only do infants have representations of familiar words, but they can also use this knowledge to segment adjacent words. 6-month-olds have been shown to use their own names and the familiar word *mommy* or *mama* to pull out nouns such as *feet* in sentences "Mommy's feet were different sizes" (Bortfeld et al., 2005). Also, infants can use known-words to overcome the limitation of the Transitional Probability (TP) cues in word segmentation. For example, when 8-month-olds were presented with artificial languages with varying word length, infants failed to use TP to segment words (Johnson & Tyler, 2010). However, when a familiar word *maman* (*mommy* in French) preceded the target word, infants overcame this difficulty and succeeded in segmenting words of varied length from fluent speech (Mersad & Nazzi, 2012).

This dissertation illustrates another environment where known words facilitate language acquisition - verb segmentation. With the help of the known word *mommy* and *mama*, even 6-month-olds were able to segment verbs from fluent speech.

5.4 Implications for research on functional morphemes

Functional morphemes have been a topic of research in language acquisition with respect to syntactic and grammatical development. Earlier studies on this issue have looked at the production of complex forms with functional morphemes and reported the developmental timeline for each functional morpheme (Berko, 1958). Based on production data, these studies argue that infants first learn complex forms as unanalyzed chunks and only later decompose them, to acquire the grammar of English.

However, more recent experimental studies on infants' comprehension of these forms indicate that the recognition of functional morphemes appears earlier than once understood. For example, 18-month-old English-learning infants have been shown to be sensitive to morphosyntactic dependencies (Santelmann & Jusczyk, 1998). In this study, infants' sensitivity to the dependency between the auxiliary verb *is* and a main verb with the ending *-ing* was tested. The results indicate that 18-month-olds are sensitive to the basic relationship between *is* and *-ing*, but 15-month-olds are not. The 18-month-olds, but not the 15-month-olds, listened significantly longer to the passages with the well-formed *is* & *-ing* dependency compared to an ill-formed *can* & *-ing* dependency. These findings indicate that 18-month-olds can track relationships between functional morphemes.

Segmentation and representation of functional elements need to precede the acquisition of this morphosyntactic dependency and recent experimental studies support this early representation. For example, the recognition of the frequent morpheme *-ing* is suggested to appear prior to 12-months of age as English-learning infants at 12-months can relate *pa[d]* to *pa[ɾ]ing* (Sundara et al., Under Revision) and is definitely in place at 15-months as they are able to extract the *-ing* morpheme with varying roots (Mintz, 2013). Similarly, French-learning 11-month-olds are able to relate complex forms to root forms with the frequent functional morpheme *-e* and with pseudo-morpheme *-u* when infants were trained with *-u* prior to the testing (Marquis & Shi, 2012). These studies illustrate preverbal infants' recognition of functional elements. In line with these results, the current dissertation demonstrates early representation of functional elements in language acquisition as the existence of the functional morpheme *-s* facilitates root - complex form mapping at 6-months.

Corpus analysis conducted in this dissertation provides one explanation for how preverbal infants may have representations of functional elements; with the help of distributional cues. The importance of distributional cues such as frequency, in acquiring morphology has been suggested by previously (Baroni, 2000; Lignos, 2012). Using frequency cue, along with acoustic/phonological cues, preverbal infants treat function words as "known words" and use them to solve segmentation problems (Shi, Cutler, et al., 2006; Kim & Sundara, 2014). The corpus analysis in this dissertation illustrates that functional elements and function words are highly frequent, providing evidence that functional elements can also be "known words" for young infants. This in turn may facilitate verb acquisition as well as grammar acquisition.

Infants' early recognition of functional elements and treating them as "possible known **words**" can facilitate other aspects of language acquisition such as the learning of phonotactics and phonological alternation. First, it may help infants deal with illegal phonotactics, i.e., sequences of sounds that are not allowed in one language, that functional morphemes may create. For example, *[bz] is not a legal sequence in English, except when the [z] is a functional morpheme as in *cabs* [kæbz]. If infants treat the functional morpheme as a separate unit, it helps them to learn English phonotactics more coherently. They can learn that the [bz] sequence is not allowed within words, but between words it is possible as in *ca[b] [z]one*. Second, treating functional elements as separate units can help infants quickly notice phonological alternations that are present at the morpheme boundary. For example, in English, [t] or [d] changes to the tap [ɾ] when certain phonological conditions are met. Adding functional morphemes such as *-ing* or *-er* frequently meet the criteria and changes the [t]/[d] sound in a root to [ɾ] as in *pa[d] - pa[ɾ]ing*. If infants treat the *-ing* morpheme as a separate unit, they might be able to notice the change in the root consonant easily and quickly.

5.4.1 Possible Word Constraint and functional elements

Infants do not map part words to whole words as shown in Experiment 6 (fail to relate **babsh* to *bab*). Similar results have been reported in the infant literature (Johnson, Jusczyk, Cutler, & Norris, 2000) as well as in adult literature (Norris et al., 1997). Both 12-month-old English-learning infants and adults listen longer to *win* in *winsome* but not in *winch*. Using these results, Johnson et al. (2000) and Norris et al. (1997) argue that both adults and infants have a Possible Word Constraint (PWC), - an unwillingness to leave out a consonant behind in the segmentation process. With the help of the PWC, language learners are able to limit the possible word candidates from the input which facilitates word segmentation and recognition (Norris et al., 1997).

Consonantal functional morphemes are exceptions to the PWC. That is, to relate the root *walk* to the complex form *walks*, one needs to leave the consonant *-s* behind, which violates the PWC. Adults have both the PWC and knowledge of functional morphemes, and therefore do not relate *win* to *winch* yet relate *win* to *wins*. Even though *-s* is not a possible "word", it is a morpheme, a separate unit. The knowledge of morpheme therefore makes it possible for adults to leave out the *-s* and find root forms from complex forms. The results of this dissertation demonstrate that English-learning infants at 6-months relate *bab* to *babs* (Experiments 4 & 5) but do not relate *bab* to *babsh* (Experiment 6). Infants' failure in Experiment 6 can be used to support the idea that infants at 6-months have knowledge of the PWC. 6-months fail to relate *bab* to *babsh* as such mapping will result in leaving the consonant *[ʃ]* behind. Also, throughout this dissertation, I have argued that infants have knowledge of frequent functional morphemes. That is, they already know that functional morpheme *-s* is a separate unit. This means that infants at 6-months have knowledge of both the PWC and some grammatical morphemes. Having both sets of knowledge early on will facilitate word segmentation and grammar acquisition.

5.5 Implications for research on speech recognition models

Recall that the two different types of recognition models have distinct hypotheses and predictions regarding the acquisition of the complex forms. The whole word-based models hypothesize a strict acquisition order between the whole word and individual morphemes and predict that whole words should be acquired prior to individual morpheme acquisition. They also predict that prior to meaning acquisition, infants will not be able to distinguish phonologically related pairs from morphologically related pairs. On the other hand, morpheme-based processing models do not hypothesize such a strict acquisition order and open the possibility that individual morphemes can be acquired prior to whole words. Also, as prelexical infants may have knowledge of functional elements, it is possible under these models that phonologically related pairs and morphologically related pairs are treated differently.

Table 5.1: Dissertation Results

	Whole word-based models	Morpheme-based models
Before meaning acquisition	*babs-bab* $\equiv$ *babsh-bab*	***babs-bab*** $\neq$ ***babsh-bab***
Order of acquisition	whole word $>$ morphemes	**whole words** $\leq$ **morphemes**

As shown in Table 5.1, our results support morpheme-based models, demonstrating that functional morphemes can be acquired before the acquisition of whole words. To illustrate this, the current dissertation used nonce words. Before acquiring the meaning of *babs*, for example, 6-month-olds were able to relate *babs* and *bab*, with the help of the frequent functional morpheme *-s*.

Also, we have shown that phonologically related pairs (Experiment 6: **babsh-bab*) and morphologically related pairs (Experiment 4: *babs-bab*) are differently associated in infants' mental lexicon. We have also shown that this representation of morpheme is a gradual process; not all morphemes are represented from the beginning. At 6-months, only the *-s* morpheme was recognized and facilitated the root form segmentation. The individual characteristics of morphemes play a role in this morpheme representation. Vowel-initial morphemes such as *-ing* and less frequent functional morphemes such as *-d* are represented later.

5.6 Implications for acquisition models

As the meaning acquisition of individual words may not be required for infants to relate complex forms to root forms, the results of the current dissertation argue against usage-based theories of language acquisition (Tomasello, 1992; Bybee, 1995). Our results show that not the acquisition of the meaning of individual words, but the recognition of individual morphemes facilitates complex form acquisition. Our results highlight the important role that functional elements have in early language acquisition.

These results support distribution based models of acquisition. First, the results of this dissertation support prosody-functor bootstrapping models (Christophe et al., 1997, 2008; Morgan et al., 1996; Shi, 2005) demonstrating that early recognition of functional elements signal word boundaries, thus facilitate word segmentation and acquisition. Also the results of this dissertation provide evidence for distribution-based theories (Maratsos & Chalkley, 1980; Mintz, 2003) by highlighting that distributional cues such as frequency and TP play an importance role in functional element acquisition. Lastly, these results support frequent frame models (Mintz, 2003) and argue that functional elements can be used as frequent frames to find verb roots.

5.7 Predictions

The current dissertation makes several important predictions regarding the acquisition of morphologically complex forms. First, it predicts that oversegmentation of functional elements will appear, especially for consonantal morphemes. For example, the word *box* [bɑks] might be wrongly segmented by prelexical infants as [bɑk] + [s] due to “automatic decomposition” of *-s*. Only after acquiring the meaning of *box*, will infants be able to overcome this strong inclination.

This prediction is in line with previous reports on children's oversegmentation of function words. For example, Peters (1983) reports a dialog between a parent and a child, where an adult told a child that she "must behave", her response was "i am [heɪv]!". This response was interpreted as the child analyzing "behave" as [be + have]. The high frequency of *be* along with lack of stress on it misled the child to oversegment *be* and treat the mono-morphemic "behave" as a bi-morphemic word. I hypothesize that this will be the case for mono-morphemic words that have segments that look like consonantal morphemes such as *box* [bɑks].

Second, regarding vowel-initial morphemes, this dissertation predicts two things. First, vowel-initial morphemes will be segmented later thus acquired later than consonantal morphemes, and second, undersegmentation, treating functional elements as part of the previous words, will appear for vowel-initial morphemes. These predictions are based on the findings of this dissertation in that, only the morpheme *-s* was represented but not the morpheme *-ing*, (even though both are high frequency morphemes), and infants treated the [root + *-ing*] as a non-decomposable unit at 6-months.

These predictions are also in line with previous reports on children's morphological development. Brown (1973) notes that one of his subjects, Adam, makes common errors such as treating *its-a, that-a, get-a*, and *put-a* as single words. These errors demonstrate that vowel-initial morphemes are likely to get undersegmented and treated as part of the previous word.

The delay of vowel-initial morphemes compared to consonantal morphemes has been reported in plural *-s* acquisition. Out of the three variants of the plural morpheme *-s*, [s], [z], and [əz], the vowel-initial variant [əz] is reported to be acquired later than the other two consonantal variants (Mealings, Cox, & Demuth, 2013). I argue that this might be because of the vowel-initial-ness of the [əz] morpheme.

The third important prediction that this dissertation makes is with respect to languages where root forms rarely appear in isolation, i.e., synthetic languages such as Polish or morphologically rich languages such as Korean. Our results predict that infants in these languages will segment out roots and possibly treat them as “possible words”, despite the fact that those roots never or seldomly appear as isolated words. Studies using languages other than English will provide a more comprehensive picture on this topic.

5.8 Future directions for the current research

The current dissertation is the first study that demonstrates 6-month-olds’ segmentation and representation of morphologically complex verbs. More research needs to be done to fully comprehend the acquisition of morphologically complex forms. First, the developmental timeline for the acquisition of functional morphemes needs to be understood. A previous study indirectly reports English-learning 12-month-olds’ use of the *-ing* morpheme (Sundara et al., Under Revision), yet how early in development this morpheme is acquired, and when would other morphemes such as *-d* are acquired, remains to be determined.

Also, it still needs to be determined how detailed the representations of complex forms are. When and how does meaning acquisition influence this representation, and when and how does whole word frequency affect this representation are a couple of important questions that need to be addressed.

Another interesting topic to pursue is how infants represent complex forms with other types of morphological complexity. For example, acquisition of complex forms with derivational morphemes is particularly interesting as there are two different types of derivational morphemes; prefix and suffix. How this different placement of morphemes plays a role in their acquisition needs to be investigated.

Lastly, the role of bottom-up cues in morpheme recognition and acquisition needs to be analyzed. For example, monosyllabic words can be either morphologically simple as in *nose* [noz] or morphologically complex as in *toes* [toz]. How might infants distinguish between such forms? Earlier experimental research found evidence that morphemic and non-morphemic sounds differ acoustically (Walsh & Parker, 1983; Losiewicz, 1992; Plag, Homan, & Kunter, In Print). To be specific, adults produce longer frication noise for morphemic compared to non-morphemic fricatives when these segments occur in utterance-final position and so do 2 year-olds in their production of these word pairs (1;6-2;6 years, three children; Song, Demuth, Evans, & Shattuck-Hufnagel, 2013). Given that 8-14 month-olds show sensitivity to segmental durational cues that signal the relationship between vowel duration and consonantal voicing (Ko, Soderstrom, & Morgan, 2009), there is a possibility that preverbal infants might use bottom-up cues to notice the morphemic status of a word. How and when infants use these bottom-up cues to distinguish morphemic and non-morphemic words will be an interesting topic to study.

5.9 Conclusion

How infants find word-like forms from speech has been an important topic in infants' language acquisition. A vast number of previous studies have looked at how infants use bottom-up cues, i.e., cues in the input such as acoustic/prosodic cues, in segmenting nouns. This dissertation asks whether infants can use **top-down cues** in pulling out **verbs**. The results demonstrate that at the beginning of word segmentation, i.e., at 6-months, infants can segment verbs with the help of a known word *mommy* (a paradigm used in Bortfeld et al. (2005)).

These results are in contrast to the previous results that verb segmentation is delayed compare to noun segmentation (only at 13.5-16 months; Nazzi et al., 2005), where they use these results to explain the delay of verb learning. This dissertation illustrates that verb segmentation is not delayed, therefore the delay of verb learning cannot be due to the segmentation delay, but possibly due to other factors such as variability in the input.

The current dissertation goes further and asks how these verbs are represented. To be specific, this dissertation looks at 6-month-olds' segmentation of morphologically complex verbs, such as *walking, walks,* and *walked*, and asks whether preverbal infants can relate these forms to the root form such as *walk*. The main focus of this research is to understand how prelexical infants, who cannot rely on semantics, relate complex forms to the root forms. The results show that infants can segment complex verbs with the *-s* and partially with the *-ing* from the sentences (*babs* and *babbing*), but only relate *babs* to *bab*. This success was not due to phonological similarity (failure to relate *babsh* and *bab*), with frequency of the morpheme playing a role in this acquisition (failure to relate *babbed* and *bab*).

In this dissertation, we locate the beginning stage of this complex form acquisition and show that at 6-months, infants start segmenting complex verbs, and based on the frequency and phonetic substance of the functional morphemes, infants begin to relate complex forms to root forms. The results of this dissertation carry crucial implications for verb acquisition, the importance of top-down cues in early language development, and the role of functional elements. Also, these results provide evidence for morpheme-based processing models and acquisition models such as prosody-functor models, arguing for early representation of functional elements and their facilitatory influence on word segmentation and representation.

APPENDIX A

Appendix: Top 20 words frequency counts of child directed speech from Li and Shirai (2000)

1.	124,219	you
2.	81,029	the
3.	59,629	it
4.	56,952	a
5.	51,760	to
6.	50,418	I
7.	48,081	what
8.	43,202	that
9.	41,780	and
10.	34,513	is
11.	33,223	do
12.	28,053	in
13.	25,578	oh
14.	24,774	on

15.	22,443	this
16.	22,355	that’s
17.	21,942	your
18.	20,754	have
19.	20,416	no
20.	19,658	don’t

24,156	Total number of different word types used
2,579,966	Total number of words (tokens)
0.009	Type/Token ratio

APPENDIX B

Appendix: All frequent verbs

Table B.1: Forward Transitional Probability for all verbs that have full conjugation in Brent Corpus

# verb	root	*-s*	*-ing*	*-d*
bark	3	1	40	13
begin	3	19	2	14
block	2	2	3	2
break	35	1	5	19
buy	55	3	12	21
call	75	2	29	60
change	126	3	13	61
chase	15	2	12	6
chew	202	1	40	3
clean	245	2	45	34
climb	81	6	21	8
close	222	2	10	34
comb	33	1	10	10
come	3,997	203	1	39
cook	22	2	18	1
crawl	50	3	25	4

# verb	root	*-s*	*-ing*	*-d*
die	4	1	8	6
dig	8	1	2	1
hop	12	2	1	3
learn	43	1	15	5
leave	236	6	32	120
like	1,512	94	1	11
look	2,428	70	282	31
love	307	118	2	10
move	280	3	39	8
need	644	77	2	13
notice	2	1	1	5
open	504	6	9	18
pack	22	1	7	5
pick	173	4	24	15
play	957	7	227	47
pour	31	1	8	4
pull	249	1	50	10
rain	5	3	32	6
roll	188	3	57	18
run	158	2	73	42
save	24	1	8	5
serve	5	1	2	1
shake	77	6	33	4
show	160	1	8	2
smell	103	8	3	1
sound	60	3	1	8

# verb	root	*-s*	*-ing*	*-d*
squeak	5	3	5	1
stand	223	3	64	12
start	62	3	12	17
stay	141	4	9	32
stick	44	2	22	41
stop	425	1	1	12
swim	12	1	19	1
take	1028	25	79	110
taste	77	16	1	1
tear	26	1	1	6
thank	20	9	3	1
tip	16	1	2	1
train	1	1	1	2
turn	499	2	24	24
use	100	7	13	45
wake	27	1	6	14
walk	193	1	103	11
want	5099	175	2	68
wear	134	7	2	5
work	87	13	40	5
sum	21,577	951	1,622	1,137

APPENDIX C

Appendix: Passages used in Experiments

1. Passages used in Experiments 1 and 2

bab

Mommy is babbing and singing at the same time. I feel so happy cause mommy is babbing. I am playing the piano and mommy is babbing. Mommy is babbing while I dance around. Mommy is babbing as grandma is eating. I am jumping up and down as mommy is babbing.

dop

I am so excited cause mommy is dopping. Mommy is dopping and my brother is playing the drum. Mommy is dopping and I am proud of her. Daddy is dancing but mommy is dopping. Mommy is dopping so that I can eat my cereal. My sister is jumping cause mommy is dopping.

kell

My daddy is laughing and mommy is kelling. Mommy is kelling and it makes me happy. Grandpa is smiling as mommy is kelling. I am cooking while mommy is kelling. Mommy is kelling while the stove is on. Mommy is kelling yet my sister is sleeping.

teep

My brother is smiling but mommy is teeping. Mommy is teeping and I feel so happy. My sister is singing and mommy is teeping. Mommy is teeping loudly and so is daddy. I am so excited cause mommy is teeping. Mommy is teeping while I am playing with my sister.

2. Passages used in Experiments 3, 4 and 5

bab

Mommy babs and sings at the same time. I feel so happy whenever mommy babs. I play the piano and mommy babs. Mommy babs if she sees me dancing around. Mommy babs while grandma and grandpa eat. If I jump up and down mommy babs.

dop

I get so excited when mommy dops. Mommy dops when my brother and I play the drum. Mommy dops when she is proud of me. Daddy dances while mommy dops. Mommy dops every time she sees me eating. My sister and I jump when mommy dops.

kell

My daddy always laughs whenever mommy kells. Mommy kells a lot and I love it. Grandpa says he smiles, because mommy kells. I really like when mommy kells. Mommy kells when I play blocks with my brother. Mommy kells whenever she is happy.

teep

My brother smiles every time mommy teeps. Mommy teeps whenever she is happy. My sister and I sing and mommy teeps. Mommy teeps a lot and so does daddy. I get so excided when mommy teeps. Mommy teeps when I play with my sister.

3. Passages used in Experiment 6

bab

Mommy babsh and sings at the same time. I feel so happy whenever mommy babsh. I play the piano and mommy babsh. Mommy babsh if she sees me dancing around. Mommy babsh while grandma and grandpa eat. If I jump up and down mommy babsh.

dop

I get so excited when mommy dopsh. Mommy dopsh when my brother and I play the drum. Mommy dopsh when she is proud of me. Daddy dances while mommy dopsh. Mommy dopsh every time she sees me eating. My sister and I jump when mommy dopsh.

kell

My daddy always laughs whenever mommy kellsh. Mommy kellsh a lot and I love it. Grandpa says he smiles, because mommy kellsh. I really like when mommy kellsh. Mommy kellsh when I play blocks with my brother. Mommy kellsh whenever she is happy.

teep

My brother smiles every time mommy teepsh. Mommy teepsh whenever she is happy. My sister and I sing and mommy teepsh. Mommy teepsh a lot and so does daddy. I get so excided when mommy teepsh. Mommy teepsh when I play with my sister.

4. Passages used in Experiment 7

bab

Mama babbed and sang at the same time. I felt so happy whenever mama babbed. I played the piano and mama babbed. Mama babbed when she saw me dancing around. Mama babbed while grandma and grandpa ate. I jumped up and down and mama babbed.

dop

I got so excited when mama dopped. Mama dopped when my brother and I played the drum. Mama dopped when she was proud of me. Daddy danced while mama dopped. Mama dopped as she saw me eating. My sister and I jumpped when mama dopped.

kell

My daddy always laughed whenever mama kelled. Mama kelled a lot and I loved it. Grandpa said he smiled, because mama kelled. I really liked when mama kelled. Mama kelled when I played blocks with my brother. Mama kelled whenever she was happy.

teep

My brother smiled every time mama teeped. Mama teeped whenever she was happy. My sister and I sang and mama teeped. Mama teeped a lot and so did daddy. I got so excided when mama teeped. Mama teeped when I played with my sister.

REFERENCES

Aissati, A. E., McQueen, J. M., & Cutler, A. (2012). Finding words in a language that allows words without vowels. *Cognition*, *124*(1), 79-84.

Albright, A., & Hayes, B. (2003). Rules vs. analogy in english past tenses: a computational/experimental study. *Cognition*, *90*, 119-161.

Alegre, M., & Gordon, P. (1999). Frequency effects and the representational status of regular inflections. *Journal of Memory and Language*, *40*, 41-61.

Ambridge, B., Kidd, E., Rowland, C. F., & Theakston, A. L. (2015). The ubiquity of frequency effects in first language acquisition. *Journal of Child Language*, *42*, 239-273. doi: 10.1017/S030500091400049X

Anderson, S. R. (1992). *A-morphous morphology*. Cambridge, UK: Cambridge University Press.

Aslin, R. N., Saffran, J. R., & Newport, E. L. (1998). Computation of conditional probability statistics by 8-month-old infants. *Psychological Science*, *9*(4), 321-324.

Baayen, R. H., Dijkstra, T., & Schreuder, R. (1997). Singulars and plurals in dutch: Evidence for a parallel dual-route model. *Journal of Memory and Language*, *37*, 94-117. doi: 10.1006/jmla.1997.2509

Baayen, R. H., Wurm, L., & Aycock, J. (2007). Lexical dynamics for low-frequency complex words: A regression study across tasks and modalities. *Mental Lexicon*, *2*, 419-463.

Baroni, M. (2000). *Distributional cues in morpheme discovery: A computational model and empirical evidence* (Unpublished Ph.D. Dissertation). University of California, Los Angeles.

Bassano, D. (2000). Early development of nouns and verbs in french: exploring the interface between lexicon and grammar. *Journal of Child Language*, *27*, 521-559.

Bates, E., Bretherton, I., & Snyder, L. (1988). *From first words to grammar: Individual differences and dissociable mechanisms*. New York: Cambridge University Press.

Benedict, H. E. (1979). Early lexical development: comprehension and production. *Journal of Child Language*, *10*, 183-200.

Bergelson, E., & Swingley, D. (2012). At 6-9 months, human infants know the meanings of many common nouns. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(9), 3253-3258.

Berko, J. (1958). The childs learning of english morphology. *Word*, *14*, 150-177.

Bickel, B., & Nichols, J. (2006). Inflectional morphology. In T. Shopen (Ed.), *Language typology and syntactic description.* Cambridge, UK: Cambridge University Press.

Blevins, J. P. (2006). English inflection and derivation. In B. Aaarts & A. M. MacMahon (Eds.), *Handbook of english linguistics* (p. 507-536). Oxford: Blackwell.

Boersma, P., & Weenink, D. (2013). *Praat: doing phonetics by computer* [Computer Program]. Retrieved from `http://www.praat.org/`

Bornstein, M. H., Cote, L. R., Maital, S., Painter, K., Park, S.-Y., Pascual, L., . . . Vyt, A. (2004). Crosslinguistic analysis of vocabulary in young children: Spanish, dutch, french, hebrew, italian, korean, and american english. *Child Development*, *75*, 1115-1139.

Bortfeld, H., Morgan, J. L., Golinkoff, R., & Rathbun, K. (2005). Mommy and me: Familiar names help launch babies into speech stream segmentation. *Psychological Science*, *16*, 298-304.

Brent, M. (1999). Speech segmentation and word discovery: a computational perspective. *Trends in Cognitive Sciences*, *3*, 294-301.

Brent, M., & Cartwright, T. A. (1996). Distributional regularities and phonotactic constraints are useful for segmentation. *Cognition*, *61*, 93-125.

Brent, M., & Siskind, J. M. (2001). The role of exposure to isolated words in early vocabulary development. *Cognition*, *28*, 458-467.

Brown, R. (1973). *A first language: The early stages*. Cambridge, MA: Harvard University Press.

Burani, C., & Caramazza, A. (1987). Representation and processing of derived words. *Language and Cognitive Processes*, *2*, 217-227.

Burani, C., Salmaso, D., & Caramazza, A. (1984). Morphological structure and lexical access. *Visible Language*, *18*, 342-352.

Bybee, J. (1988). *Morphology as lexical organization* (M. Hammond & M. Noonan, Eds.). San Diego: Academic Press.

Bybee, J. (1991). Verbs. In W. Bright (Ed.), *Oxford international encyclopedia of linguistics.* Oxford: Oxford University Press.

Bybee, J. (1995). Regular morphology and the lexicon. *Language and Cognitive Processes*, *10*, 425-455.

Bybee, J. (1998). A functionalist approach to grammar and its evolution. *Evolution of Communication*, *2*(2), 249-278.

Bybee, J. (2001). *Phonology and language use*. Cambridge: Cambridge University Press.

Caramazza, A., Laudanna, A., & Romani, C. (1988). Lexical access and inflectional morphology. *Cognition*, *28*, 297-332.

Caselli, M. C., Bates, E., Casadio, P., Fenson, J., Fenson, L., Sanderl, L., & Weir, J. (1995). A crosslinguistic study of early lexical development. *Cognitive Development*, *10*, 159-199.

Christophe, A., Gout, A., Peperkamp, S., & Morgan, J. L. (2003). Discovering words in the continuous speech stream: the role of prosody. *Journal of Phonetics*, *31*, 585-598.

Christophe, A., Guasti, T., Nespor, M., Dupoux, E., & Van Ooyen, B. (1997). Reflections on phonological bootstrapping: its role for lexical and syntactic acquisition. *Language and Cognitive Processes*, *12*, 585-612.

Christophe, A., Millotte, S., Bernal, S., & Lidz, J. (2008). Bootstrapping lexical and syntactic acquisition. *Language and Speech*, *51*, 61-75.

Christophe, A., Peperkamp, S., Pallier, C., Block, E., & Mehler, J. (2004). Phonological phrase boundaries constrain lexical access: I. adult data. *Journal of Memory and Language*, *51*, 523-547.

Clahsen, H. (1999). Lexical entries and rules of language: a multi-disciplinary study of german inflection. *Behavioral and Brain Sciences*, *22*, 991-1060.

Clahsen, H., Eisenbeiss, S., & Penke, M. (1996). Underspecification and lexical learning in early child grammars. In H. Clahsen & R. Hawkins (Eds.), *Generative approaches to first and second language acquisition* (p. 129-159). Amsterdam: Benjamins.

Cooper, N., Cutler, A., & Wales, R. (2002). Constraints of lexical stress on lexical access in english: evidence from native and nonnative listeners. *Language and Speech*, *45*, 207-228.

Curtin, S., Mintz, T. H., & Christiansen, M. H. (2005). Stress changes in representational landscape: Evidence from word segmentation. *Cognition*, *96*(3), 233-262.

Cutler, A. (1993). Phonological cues to open- and closed-class words in the processing of spoken sentences. *Journal of Psycholinguistic Research*, *22*(2), 109-131.

Cutler, A., & Butterfield, S. (1992). Rhythmic cues to speech segmentation: Evidence from juncture misperception. *Journal of Memory and Language*, *31*(218-236).

Cutler, A., & Carter, D. (1987). The predominance of strong initial syllables in the english vocabulary. *Computer Speech and Language*, *2*, 133-142.

Cutler, A., Demuth, K., & McQueen, J. M. (2002). Universality versus language-specificity in listening to running speech. *Psychological Science*, *13*(3), 258-

262.

Cutler, A., & Donselaar, W. v. (2001). *Voornaam* is not a homophone: lexical prosody and lexical access in dutch. *Language and Speech*, *44*, 171-195.

Cutler, A., & Norris, D. (1988). The role of strong syllables in segmentation for lexical access. *Journal of Experimental Psychology: Human Perception and Performance*, *14*, 113-121.

Dabrowska, E., & Szczerbinski, M. (2006). Polish children's productivity with case marking: The role of regularity, type frequency, and phonological diversity. *Journal of Child Language*, *33*, 559-597.

Daland, R. (2013). Variation in the input: a case study of manner class frequencies. *Journal of Child Language*, *40*, 1091-1122. doi: 10.1017/S0305000912000372

De Houwer, A., & Gillis, S. (1998). Dutch child language: an overview. In S. Gillis & A. D. Houwer (Eds.), *The acquisition of dutch* (p. 1-100). Amsterdam: John Benjamins.

Dominguez, A., Cuetos, F., & Segui, J. (2000). Morphological processing in word recognition: a review with particular reference to spanish. *Psicolgica*, *21*, 375-401.

Donselaar, W., van, M., Koster, & Cutler, A. (2005). Exploring the role of lexical stress in lexical recognition. *Quarterly Journal of Experimental PsychoIogy*, *58A*, 251-273.

Dressler, W. (2010). A typological approach to first language acquisition. In M. Kail & M. Hickmann (Eds.), *Language acquisition across linguistic and cognitive systems* (p. 109-124). Amsterdam: Benjamins.

Dumay, N., Frauenfelder, U. H., & Content, A. (2002). The role of the syllable in lexical segmentation in french: Word-spotting data. *Brain and Language*, *81*, 144-161.

Echols, C. H., Crowhurst, M. J., & Childers, J. B. (1997). The perception of rhythmic units in speech by infants and adults. *Journal of Memory and Language*, *36*, 202-225.

Estivalet, G., & Meunier, F. (2015). Decomposability and mental representation of french verbs. *Frontiers in human neuroscience*, *9*, 1-10.

Fais, L., Kajikawa, S., Amano, S., & Werker, J. (2009). Infant discrimination of a morphologically relevant word-final contrast [Journal Article]. *Infancy*, *14*(4), 488-499. Retrieved from `http://dx.doi.org/10.1080/15250000902994255` doi: 10.1080/15250000902994255

Fenson, L., Dale, P. S., Reznick, J. S., Bates, E., Hartung, J., Pethick, S. J., ... Reilly, J. (1993). *Macaurhur communicative development inventories: User's guide and technical manual* [Book]. San Diego, CA: Singular Publishing.

Finn, A., & Hudson Kam, C. (2008). The curse of knowledge: First language knowledge impairs adult learners' use of novel statistics for word segmentation. *Cognition*, *108*, 477-499. doi: http://dx.doi.org/10.1016/j.cognition.2008.04.002

Fisher, C., & Gleitman, L. R. (2002). Language acquisition. In H. F. Pashler & C. Gallistel (Eds.), (Vol. 1: Learning and motivation, p. 445-496). New York: Wiley.

Forster, K. I., & Chambers, S. M. (1973). Lexical access and naming time. *Journal of Verbal Learning and Verbal Behavior*, *12*, 627-635.

Gagarina, N., & Voeikova, M. (2009). Acquisition of case and number in russian. In U. Stephany & M. Voeikova (Eds.), *Development of nominal inflection in first language acquisition: A cross-linguistic perspective* (p. 179-215). Berlin: Mouton de Gruyter.

Gentner, D. (1982). Why nouns are learned before before verbs: Linguistic relativity versus natural partitioning. In S. A. K. II (Ed.), *Language, thought and culture, language development vol. 2* (p. 301-334). Hillsdale, NJ: Erlbaum.

Gerken, L. A., Jusczyk, P. W., & Mandel, D. R. (1994). When prosody fails to cue syntactic structure: 9-month-olds’ sensitivity to phonological versus syntactic phrases. *Cognition*, *51*, 237-265.

Gervain, J., & Guevara Erra, R. (2012). The statistical signature of morphosyntax: A study of hungarian and italian infant-directed speech. *Cognition*, *125*, 263-287.

Gervain, J., Nespor, M., Mazuka, R., Horie, J., & Mehler, J. (2008). Bootstrapping word order in prelexical infants: A japanese-italian cross-linguistic study. *Cognitive Psychology*, *57*, 56-74.

Giraudo, H., & Grainger, J. (2000). Effects of prime word frequency and cumulative root frequency in masked morphological priming. *Language and Cognitive Processes*, *15*, 421-444. doi: 10.1080/01690960050119652

Gout, A., Christophe, A., & Morgan, J. L. (2004). Phonological phrase boundaries constrain lexical access ii. infant data [Journal Article]. *Journal of Memory and Language*, *51*, 248-267.

Graf Estes, K., Evans, J. L., Alibali, M. W., & Saffran, J. R. (2007). Can infants map meaning to newly segmented words? statistical segmentation and word learning. *Psychological Science*, *18*, 254-260.

Grainger, J. (1990). Word frequency and neighborhood frequency effects in lexical decision and naming. *Journal of Memory and Language*, *29*, 228-244.

Guy, G. (1991). Explanation in variable phonology : an exponential model of morphological constraints. *Language Variation and Change*, *3*, 1-22.

Hallé, P., Durand, C., & de Boysson-Bardies, B. D. (2008). Do 11-month-old french infants process articles? [Journal Article]. *Language and Speech*, *51*(1-2), 23-44.

Hirsh-Pasek, K., Kemler Nelson, D. G., Jusczyk, P. W., Cassidy, K., Druss, B., & Kennedy, L. (1987). Clauses are perceptual units for young infants [Journal Article]. *Cognition*, *26*, 269-286.

Hochmann, J.-R., Endress, A. D., & Mehler, J. (2010). Word frequency as a cue for identifying function words in infancy. *Cognition*, *115*, 444-457.

Hohle, B., & Weissenborn, J. (2003). German-learning infants' ability to detect unstressed closed-class elements in continuous speech. *Developmental Science*, *6*(2), 122-127.

Houston, D., Santelmann, L. M., & Jusczyk, P. W. (2004). English-learning infants' segmentation of trisyllabic words from fluent speech [Journal Article]. *Language and Cognitive Processes*, *19*(1), 97-136.

Hsieh, L., Leonard, L. B., & Swanson, L. A. (1999). Some differences between english plural noun inflections and third singular verb inflections in the input: The contributions of frequency, sentence position, and duration [Journal Article]. *Journal of Child Language*, *26*, 531-543.

Ingram, D. (1985). The psychological reality of children's grammars and its relation to grammatical theory. *Lingua*, *66*, 79-103.

Jackson-Maldonado, D., Thal, D., Marchman, V., Bates, E., & Gutierrez-Clellen, V. (1993). Early lexical development in spanish-speaking infants and toddlers. *Journal of Child Language*, *20*, 523-549.

Joanisse, M. F., & Seidenberg, M. S. (1999). Impairments in verb morphology after brain injury. *Proceedings of the National Academy of Sciences*, *96*, 7592-7597.

Johnson, E., & Jusczyk, P. W. (2001). Word segmentation by 8-month-olds: When speech cues count more than statistics. *Journal of Memory and Language*, *44*(4), 548-567.

Johnson, E., Jusczyk, P. W., Cutler, A., & Norris, D. (2000). 12-month-olds show evidence of a possible-word constraint. *Journal of the Acoustical Society of America*, *108*, 2481. Retrieved from `http://dx.doi.org/10.1121/1.4743154` doi: 10.1121/1.4743154

Johnson, E., Jusczyk, P. W., Cutler, A., & Norris, D. (2003). Lexical viability constraints on speech segmentation by infants. *Cognitive Psychology*, *46*, 65-98.

Johnson, E., & Seidl, A. (2009). At 11 months, prosody still outranks statistics. *Developmental Science*, *12*, 131-141.

Johnson, E., & Tyler, M. D. (2010). Testing the limits of statistical learning for word segmentation. *Developmental Science*, *13*, 339-345. doi: http://dx.doi.org/10.1111/j.1467-7687.2009.00886.x

Juscyzk, P. W., Goodman, M. B., & Baumann, A. (1999). Nine-month-olds' attention to sound similarities in syllables. *Journal of Memory and Language*, *40*, 62-82.

Jusczyk, P. W., & Aslin, R. N. (1995). Infants' detection of the sound pattern of words in fluent speech. *Cognitive Psychology*, *23*, 1-23.

Jusczyk, P. W., Friederici, A. D., Wessels, J. M. I., Svenkerud, V. Y., & Jusczyk, A. M. (1993). Infants' sensitivity to the sound patterns of native language words. *Journal of Memory and Language*, *32*, 402-420.

Jusczyk, P. W., Houston, D. W., & Newsome, M. (1999). The beginnings of word segmentation in english-learning infants. *Cognitive Psychology*, *39*(3-4), 159-207.

Jusczyk, P. W., Luce, P., & Charles-Luce, J. (1994). Infants' sensitivity to phonotactic patterns in the native language [Journal Article]. *Journal of Memory and Language*, *33*, 630-645.

Kelly, M. H., & Bock, J. K. (1988). Stress in time [Journal Article]. *Journal of Experimental Psychology: human Perception and Performance*, *14*, 389-403.

Kemler-Nelson, D. G., Jusczyk, P. W., Mandel, D. R., Myers, J., Turk, A., & Gerken, L. (1995). The head-turn preference procedure for testing auditory perception. *Infant Behavior and Development*, *18*, 111-116.

Kim, Y. J., & Sundara, M. (2014). Segmentation of vowel-initial words is facilitated by function words. *Journal of Child Language*, *27*, 1-25. doi:

http://dx.doi.org/10.1017/S0305000914000269

Kimball, J. (1973). Seven principles of surface structure parsing in natural language. *Cognition*, *2*, 15-47.

Ko, E.-S., Soderstrom, M., & Morgan, J. (2009). Development of perceptual sensitivity to extrinsic vowel duration in infants learning american english. *The Journal of the Acoustic Society of America*, *126*, EL134-EL139.

Lew-Williams, C., & Saffran, J. (2012). All words are not created equal: Expectations about word length guide infant statistical learning. *Cognition*, *122*, 241-246. doi: dx.doi.org/10.1016/j.cognition.2011.10.007

Li, P., & Shirai, Y. (2000). *The acquisition of lexical and grammatical aspect*. Berlin & New York: Mouton de Gruyter.

Lignos, C. (2012). Infant word segmentation: An incremental, integrated model. In N. Arnett & R. Bennett (Eds.), *Proceedings of the 30th west coast conference on formal linguistics* (p. 237-247). Cascadilla Proceedings Project.

Lively, S. E., Pisoni, D. B., & Goldinger, S. D. (1994). Spoken word recognition. In M. A. Gernsbacher (Ed.), *Handbook of psycholinguistics* (p. 265-301). New York: Academic Press.

Longworth, C. E., Marsden-Wilson, W. D., Randall, B., & Tyler, L. K. (2005). Getting to the meaning of the regular past tense: evidence from neuropsychology. *Journal of Cognitive Neuroscience*, *17*, 1087-1097.

Losiewicz, B. L. (1992). *The effect of frequency on linguistic morphology* (Unpublished Ph.D. Dissertation). University of Texas, Austin, TX.

MacWhinney, B. (1976). Hungarian research on the acquisition of morphology and syntax. *Journal of Child Language*, *3*, 397-410.

MacWhinney, B. (2000). *The childes project: Tools for analyzing talk* (Vol. 2) [Audiovisual Material]. Lawrence Erlbaum Associates.

Maital, S. L., Dromi, E., Sagi, A., & Bornstein, M. H. (2000). The hebrew communicative development inventory: language specific properties and crosslinguistic generalizations. *Journal of Child Language*, *27*, 43-67.

Maratsos, M., & Chalkley, M. A. (1980). In K. Nelson (Ed.), *Children's language* (Vol. 2, p. 127-214). New York: Gardner.

Marquis, A., & Shi, R. (2008). Segmentation of verb forms in preverbal infants. *Journal of the Acoustical Society of America*, *123*.

Marquis, A., & Shi, R. (2012). Initial morphological learning in preverbal infants. *Cognition*, *122*(1), 61-66.

Marsden-Wilson, W., & Zhou, X. (1999). Abstractness, allomorph, and lexical architecture. *Language and Cognitive Processes*, *14*, 321-352.

Marslen-Wilson, W. (2007). Morphological processes in language comprehension. In G. Gaskell (Ed.), *Oxford handbook of psycholinguistics* (p. 175-193). Oxford: Oxford University Press.

Marslen-Wilson, W., Csibra, G., Ford, M., Hatzakis, J., Gaskell, G., & Johnson, M. H. (2000). Associations and dissociations in the processing of regular and irregular verbs: electrophysiological evidence. *Journal of Cognitive Neuroscience*, 117-118.

Marslen-Wilson, W., Moss, H. E., & Halen, v., S. (1996). Perceptual distance and competition in lexical access. *Journal of Experimental Psychology: Human Perception and Performance*, *22*, 1376-1392.

Marslen-Wilson, W., & Tyler, L. K. (1997). Dissociating types of mental computation. *Nature*, *387*, 592-594.

Marslen-Wilson, W., & Tyler, L. K. (1998). Rules, representations, and the english past tense. *Trends in Cognitive Science*, *2*, 428-435.

Marslen-Wilson, W., & Tyler, L. K. (2007). Morphology, language and the brain: the decompositional substrate for language comprehension. *Philosophical Transactions of The Royal Society Biological Sciences*, *362*, 823-836. doi: 10.1098/rstb.2007.2091

Mattys, S. L. (2004). Stress versus coarticulation: Toward an integrated approach to explicit speech segmentation. *Journal of Experimental Psychology: Human Perception & Performance*, *30*, 397-408.

Mattys, S. L., & Jusczyk, P. W. (2001). Phonotactic cues for segmentation of fluent speech by infants. *Cognition*, *78*, 91-121.

Mattys, S. L., White, L., & Melhorn, J. F. (2005). Integration of multiple speech segmentation cues: A hierarchical framework. *Journal of Experimental Psychology: General*, *134*, 477-500.

McClelland, J. L., & Elman, J. L. (1986). The trace model of speech perception. *Cognitive Psychology*, *18*, 1-86.

McClelland, J. L., & Patterson, K. (2002). Rules or connections in past-tense inflections: What does the evidence rule out? *Trends in Cognitive Sciences*, *6*, 465-472.

McQueen, J. M. (1998). Segmentation of continuous speech using phonotactics. *Journal of Memory and Language*, *39*, 21-26.

McQueen, J. M. (2007). Eight questions about spoken word recognition. In M. G. Gaskell, G. Altmann, P. Bloom, A. Caramazza, & P. Levelt (Eds.), *Oxford handbook of psycholinguistics.* Oxford: Oxford University Press.

McQueen, J. M., Norris, D., & Cutler, A. (1994). Competition in spoken word recognition: Spotting words in other words. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *20*, 621-638.

McQueen, J. M., Otake, T., & Cutler, A. (2001). Rhythmic cues and possible-word constraints in japanese speech segmentation. *Journal of Memory and Language*, *45*, 103-132.

Mealings, K., Cox, F., & Demuth, K. (2013). Acoustic investigations into the later acquisition of syllabic -es plurals. *Journal of Speech, Language, and Hearing Research*, *56*, 1260-1271.

Mealings, K., & Demuth, K. (2014). The role of utterance length and position in 3-year-olds' production of third person singular -s. *Journal of Speech, Language, and Hearing Research*, *57*, 484-494.

Mersad, K., & Nazzi, T. (2012). When mommy comes to the rescue of statistics: Infants combine top-down and bottom-up cues to segment speech. *Language Learning and Development*, *8*, 303-315. doi: 10.1080/15475441.2011.609106

Meunier, F., & Segui, J. (1999). Morphological priming effect: the role of surface frequency. *Brain and Language*, *68*, 54-60. doi: P10.1006/brln.1999.2098

Millotte, S., Morgan, J., Margules, S., Bernal, S., Dutat, M., & Christophe, A. (2010). Phrasal prosody constrains word segmentation in french 16-month-olds. *Journal of Portuguese Linguistics*, *9*, 67-86.

Mintz, T. (2003). Frequent frames as a cue for grammatical categories in child directed speech. *Cognition*, *90*, 91-117.

Mintz, T. (2013). The segmentation of sub-lexical morphemes in english-learning 15-month-olds. *Frontiers in Psychology*, *4*, 1-12. doi: 10.3389/fpsyg.2013.00024

Mintz, T., & Walker, R. (2006). Infants' sensitivity to vowel harmony and its role in word segmentation. Albuquerque, New Mexico: Paper presented at the annual meeting of the Linguistic Society of America.

Miozzo, M. (2003). On the processing of regular and irregular forms of verbs and nouns: evidence from neuropsychology. *Cognition*, *87*, 101-127.

Mirman, D., Magnuson, J. S., Graf Estes, K. G., & Dixon, J. A. (2008). The link between statistical segmentation and word learning in adults. *Cognition*, *108*, 271-280.

Morgan, J. L., R., S., & Allopenna, P. (1996). Perceptual bases of rudimentary grammatical categories: Toward a broader conceptualization of bootstrapping. In J. L. Morgan & K. Demuth (Eds.), *Signal to syntax* (p. 263-286). Mahwah NJ, USA: Lawrence Erlbaum.

Nakatani, L. H., & Dukes, K. D. (1977). Locus of segmental cues for word juncture. *Journal of the Acoustical Society of America*, *62*, 714-719.

Nazzi, T., Dilley, L., Jusczyk, A. M., Shattuck-Hufnagel, S., & Jusczyk, P. W. (2005). English-learning infants' segmentation of verbs from fluent speech. *Language and Speech*, *48*(3), 279-298.

Nazzi, T., Iakimova, I., Bertoncini, J., Fredonie, S., & Alcantara, C. (2006). Early segmentation of fluent speech by infants acquiring french: Emerging evidence for cross linguistic differences. *Journal of Memory and Language*, *54*, 283-299.

Nelson, K. (1973). Structure and strategy in learning to talk. In *Monographs of the society for research in child development* (Vol. 38 (1-2 Serial No. 149), p. 1-137).

New, B., Brysbaert, M., Segui, J., Ferrand, L., & Rastle, K. (2004). The processing of singular and plural nouns in french and english. *Journal of Memory and Language*, *51*, 568-585.

Ngon, C., Martin, A., Dupoux, E., Cabrol, D., Dutat, M., & Peperkamp, S. (2013). (non)words, (non)words: evidence for a proto-lexicon during the first year of life. *Developmental Science*, *16*, 24-34. doi: 10.1111/j.1467-7687.2012.01189.x

Norris, D. (1994). Shortlist: a connectionist model of continuous speech recognition. *Cognition*, *52*, 189-234.

Norris, D., McQueen, J., & Cutler, A. (1995). Competition and segmentation in spoken-word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*, 1209-1228. doi: 10.1037//0278-7393.21.5.1209

Norris, D., & McQueen, J. M. (2008). Shortlist b: A bayesian model of continuous speech recognition. *Psychological Review*, *115*, 357-395. doi: 10.1037/0033-295X.115.2.357

Norris, D., McQueen, J. M., Cutler, A., & Butterfield, S. (1997). The possible word constraint in the segmentation of continuous speech. *Journal of Memory and Language*, *44*, 103-132.

Norris, D., McQueen, J. M., Cutler, A., Butterfield, S., & Kearns, R. (2001). Language-universal constraints on speech segmentation. *Language and Cognitive Processes*, *16*, 637-660.

O'Grady, W., & Cho, S. W. (2001). Chapter 10. first language acquisition. In W. O'Grady & J. Archibald (Eds.), *Contemporary linguistic analysis: An introduction* (p. 326-362). Toronto: Pearson-Longman.

Parisse, C., & Le Normand, M.-T. (2000). How children build their morphosyntax: the case of french. *Journal of Child Language*, *27*, 267-292.

Patterson, K., Lambon Ralph, M. A., Hodges, J. R., & McClelland, J. L. (2001). Deficits in irregular past-tense verb morphology associated with degraded semantic knowledge. *Neuropsychologia*, *39*, 709-724.

Pelucchi, B., Hay, J., & Saffran, J. R. (2009b). Statistical learning in a natural language by 8-month-old infants. *Child Development*, *80*, 674-685.

Pelucchi, B., Hay, J. F., & Saffran, J. R. (2009a). Learning in reverse: eight-month-old infants track backward transitional probabilities. *Cognition*, *113*, 244-247.

Perroni Simoes, M., & Stoel-Gammon, C. (1979). The acquisition of inflections in portuguese: A study of the development of person markers on verbs. *Journal of Child Language*, *6*, 53-67.

Peters, A. (1983). *The units of language acquisition*. Cambridge: Cambridge University Press.

Peters, A., & Menn, L. (1993). False starts and filler syllables: Ways to learn grammatical morphemes. *Language*, *69*, 742-777.

Pinker, S. (1999). *Words and rules: The ingredients of language*. New York: Harper-Collins.

Pinker, S., & Prince, A. (1988). On language and connectionism: analysis of a parallel distributed processing model of language acquisition. *Cognition*, *28*, 73-193.

Pinker, S., & Ullman, M. T. (2002). The past and future of the past tense. *Trends in Cognitive Sciences*, *6*, 456-463.

Pizzuto, E., & Caselli, M. (1994). The acquisition of italian verb morphology in a cross-linguistic perspective. In Y. Levy (Ed.), *Other children, other languages: Issues in the theory of language acquisition* (p. 137-187). Hillsdate, NJ: Erlbaum.

Plag, I., Homan, J., & Kunter, G. (In Print). *Homophony and morphology: The acoustics of word-final s in english.*

Plunkett, K., & Marchman, V. A. (1993). From rote learning to system building: acquiring verb morphology in children and connectionist nets. *Cognition*, *48*, 21-69.

Poeppel, D., & Wexler, K. (1993). The full competence hypothesis of clause structure in early german. *Language*, *69*, 1-33.

Poulin-Dubois, D., Graham, S., & Sippola, L. (1995). Early lexical development: the contribution of parental labelling and infants' categorization abilities. *Journal of Child Language*, *22*, 325-343.

Rastle, K., Davis, M. H., & New, B. (2004).
Psychonomic Bulletin and Review, *11*, 1090-1098.

Rumelhart, D. E., & McClelland, J. L. (1986). On learning the past tenses of english verbs. In J. L. McClelland, D. E. Rumelhart, & the PDP research group (Eds.), *Parallel distributed processing: Explorations in the microstructure of cognition. volume ii.* (p. 216-271). Cambridge, MA: MIT Press.

Saffran, J. R. (2001). Words in a sea of sounds: the output of statistical learning. *Cognition*, *81*, 149-169.

Saffran, J. R. (2003). Statistical language learning: Mechanisms and constraints. *Current Directions in Psychological Science*, *12*, 110-114. doi:

dx.doi.org/10.1111/1467-8721.01243

Saffran, J. R., Aslin, R. N., & Newport, E. (1996). Statistical learning by 8-month-old infants. *Science*, *274*, 1926-1928.

Saffran, J. R., Newport, E. L., & Aslin, R. N. (1996). Word segmentation: The role of distributional cues. *Journal of Memory and Language*, *35*, 606-621.

Saffran, J. R., Werker, J. F., & Werner, L. A. (2006).
In R. Siegler & D. Kuhn (Eds.), *Handbook of child development* (Vol. 6th edition, p. 58-108). New York: Wiley.

Sakurai, C. (1998). Why nouns before verbs? a case study of japanese early lexical acquisition. In *Cls 34: The panels* (p. 511-519).

Santelmann, L. M., & Jusczyk, P. W. (1998). Sensitivity to discontinuous dependencies in language learners: evidence for limitations in processing space. *Cognition*, *69*, 105-134.

Seidl, A. (2007). Infants' use and weighting of prosodic cues in clause segmentation. *Journal of Memory and Language*, *57*, 24-48.

Seidl, A., & Johnson, E. (2006). Infant word segmentation revisited: edge alignment facilitates target extraction. *Developmental Science*, *9*, 565-573. doi: 10.1111/j.14677687.2006.00534.x

Seidl, A., & Johnson, E. (2008). Boundary alignment enables 11-month-olds to segment vowel initial words from speech. *Journal of Child Language*, *35*, 1-24. doi: 10.1017/S0305000907008215

Sereno, J. A. (1986). Stress pattern differentiation of form class in english. *Journal of the Acoustical Society of America*, *79*, S36.

Sereno, J. A., & Jongman, A. (1997). Processing of english inflectional morphology. *Memory and Cognition*, *25*, 425-437.

Shi, R. (2005). Early syntactic categories in infants. In H. Cohen & C. Lefebvre (Eds.), *Handbook of categorization in cognitive science* (p. 481-495). Amsterdam: Elsevier.

Shi, R. (2014). Functional morphemes and early language acquisition. *Child Development Perspectives*, *8*(1), 6-11. doi: 10.1111/cdep.12052

Shi, R., Cutler, A., Werker, J., & Cruickshank, M. (2006). Frequency and form as determinants of functor sensitivity in english-acquiring infants. *Journal of the Acoustical Society of America*, *119*, EL61-EL66. doi: 10.1121/1.2198947

Shi, R., & Gauthier, B. (2005). Recognition of function words in 8-month-old french-learning infants. *The Journal of the Acoustical Society of America*, *117*, 2426-2427. doi: 10.1121/1.4786583

Shi, R., & Lepage, M. (2008). The effect of functional morphemes on word segmentation in preverbal infants. *Developmental Science*, *11*(3), 407-413.

Shi, R., Marquis, A., & Gauthier, B. (2006). Segmentation and representation of function words in preverbal french-learning infants. In D. Bamman, T. Magnitskaia, & C. Zaller (Eds.), *Proceedings of the 30th annual boston university conference on language development* (p. 549-560). Somerville, MA: Cascadilla Press.

Shi, R., Morgan, J. L., & Allopena, P. (1998). Phonological and acoustic bases for early grammatical assignment: A cross-linguistic perspective. *Journal of Child Language*, *25*, 169-201.

Shi, R., & Werker, J. F. (2001). Six-month-old infants' preference for lexical words. *Psychological Science*, *12*, 70-75.

Shi, R., Werker, J. F., & Cutler, A. (2006). Recognition and representation of function words in english-learning infants. *Infancy*, *10*(2), 187-198.

Shi, R., Werker, J. F., & Morgan, J. L. (1999). Newborn infants' sensitivity to perceptual cues to lexical and grammatical words. *Cognition*, B11-B22.

Shukla, M., White, K. S., & Aslin, R. N. (2011, 04). Prosody guides the rapid mapping of auditory word forms onto visual objects in 6-mo-old infants. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(15), 6038–6043. Retrieved from `http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3076873/` doi: 10.1073/pnas.1017617108

Song, J., Demuth, K., Evans, K., & Shattuck-Hufnagel, S. (2013). Durational cues to fricative codas in 2-year-olds' american english: Voicing and morphemic factors. *The Journal of the Acoustical Society of America*, *133*, 2931-2946. doi: 10.1121/1.4795772

Song, J., Sundara, M., & Demuth, K. (2009). Phonological constraints on childrens production of english third person singular s. *Journal of Speech, Language, and Hearing Research*, *52*, 623-642.

Soto-Faraco, S., Sebastián-Gallés, N., & Cutler, A. (2001). Segmental and suprasegmental mismatch in lexical access. *Journal of Memory and Language*, *45*, 412-432.

Sundara, M., Demuth, K., & Kuhl, P. (2011). Sentence-position effects on childrens comprehension & production of english 3rd person singular -s. *Journal of Speech, Language and Hearing Research*, *54*, 55-71.

Sundara, M., Kim, Y. J., White, J., & Chong, A. J. (Under Revision). There is no pat in patting: Phonetic similarity biases infants' learning of phonological alternations.

Suomi, K., McQueen, J. M., & Cutler, A. (1997). Vowel harmony and speech segmentation in finnish. *Journal of Memory and Language*, *36*, 422-444.

Swingley, D. (1999). Conditional probability and word discovery: A corpus analysis of speech to infant. In M. Hahn & S. Stoness (Eds.), *Proceedings of the 21st annual conference of the cognitive science society* (p. 724-729). Mahwah, NJ: Erlbaum.

Taft, M. (1979). Recognition of affixed words and the word frequency effect. *Memory & Cognition*, *7*, 263-272.

Taft, M. (2004). Morphological decomposition and the reverse base frequency effect. *The Quarterly Journal of Experimental Psychology*, *57A*, 745-765.

Taft, M., & Forster, K. I. (1975). Lexical storage and retrieval of prefixed words. *Journal of Verbal Learning and Verbal Behavior*, *14*, 638-647.

Taft, M., & Forster, K. I. (1976). Lexical storage and retrieval of polymorphemic and polysyllabic words. *Journal of Verbal Learning and Verbal Behavior*, *15*, 607-620.

Taft, M., Hambly, G., & Kinoshita, S. (1986). Visual and auditory recognition of prefixed words. *Quarterly Journal of Experimental Psychology*, *38A*, 351-366.

Tardif, T., Shatz, M., & Naigles, L. (1997). Caregiver speech and childrens use of nouns versus verbs: a comparison of english, italian, and mandarin. *Journal of Child Language*, *24*, 535-565.

Theodore, R. M., Demuth, K., & Shattuck-Hufnagel, S. (2011). Acoustic evidence for positional and complexity effects on childrens production of plural -*s*. *Journal of Speech, Language, and Hearing Research*, *54*, 539-548. doi: 10.1044/1092-4388(2010/10-0035)

Thiessen, E. D., Hill, E., & Saffran, J. R. (2005). Infant-directed speech facilitates word segmentation. *Infancy*, *7*, 53-71.

Thiessen, E. D., & Saffran, J. R. (2003). When cues collide: Use of stress and statistical cues to word boundaries by 7- to 9-month-old infants. *Developmental Psychology*, *39*, 706-716.

Toivainen, J. (1980). *Inflectional affixes used by finnish-speaking children aged 1-3 years*. Helsinki: Suomalaisen Kirjallisuuden Seura.

Tomasello, M. (1992). *First verbs: A case study in early grammatical development*. Cambridge University Press.

Tomasello, M. (2000). Do young children have adult syntactic competence? *Cognition*, *74*, 209-253.

Tomasello, M. (2003). *Constructing a language: A usage-based theory of language acquisition*. Cambridge, MA: Harvard University Press.

Tranka, B. (1935). *A phonological analysis of present-day standard english* (Vol. 5).

Prague.

Tyler, L. K., de Mornay Davies, P., Anokhina, R., Longworth, C., Randall, B., & Marslen-Wilson, W. D. (2002). Dissociations in processing past tense morphology: neuropathology and behavioural studies. *Journal of Cognitive Neuroscience*, *14*, 79-97.

Tyler, L. K., Randall, B., & Marslen-Wilson, W. D. (2002). Phonology and neuropsychology of english past tense. *Neuropsychologia*, *40*, 1154-1166.

Tyler, L. K., Stamatakis, E. A., Post, B., Randall, B., & Marslen-Wilson, W. D. (2005). Temporal and frontal systems in speech comprehension: an fmri study of past tense processing. *Neuropsychologia*, 1963-1974.

Ullman, M. T., Corkin, S., Coppola, M., Hickok, G., Growdon, J. H., Koroshetz, W. J., & Pinker, S. (1997). A neural dissociation within language: evidence that the mental dictionary is part of declarative memory and that grammatical rules are processed by he procedural system. *Journal of Cognitive Neuroscience*, *9*, 266-276.

Ullman, M. T., Pancheva, R., Love, T., Yee, E., Swinney, D., & Hickok, G. (2005). Neural correlates of lexicon and grammar: evidence from the production, reading, and judgement of inflection in aphasia. *Brain and Language*, *93*, 185-238.

van der Lugt, A. (2001). The use of sequential probabilities in the segmentation of speech. *Perception and Psychophysics*, *63*, 811-823.

van de Weijer, J. (1998). *Language input for word discovery* (Unpublished Ph.D. Dissertation). Max Planck Institute, Nijmegen.

Verlinden, A., & Gillis, S. (1988). Nouns and verbs in the input: Gentner (1982) reconsidered. In F. V. Besien (Ed.), *First language acquisition* (p. 163-187). Antwerp, Belgium: ABLA.

Vroomen, J., & de Gelder, B. (1995). Metrical segmentation and lexical inhibition in spoken word recognition. *Journal of Experimental Psychology:*

Human Perception and Performance, *23*, 710-720.

Vroomen, J., Tuomainen, J., & de Gelder, B. (1998). The roles of word stress and vowel harmony in speech segmentation. *Journal of Memory and Language*, *38*, 133-149.

Walsh, T., & Parker, F. (1983). The duration of morphemic and non-morphemic /s/ in english. *Journal of Phonetics*, *11*, 201-206.

Wang, W., & Crawford, J. (1960). Frequency studies of english consonants. *Language and Speech*, *3*, 131-139.

Warner, N., Kim, J., Davis, C., & Cutler, A. (2005). Use of complex phonological patterns in processing: Evidence from korean. *Journal of Linguistics*, *41*, 353-387.

Weber, A., & Cutler, A. (2006). First-language phonotactics in second-language listening. *Journal of the Acoustical Society of America*, *119*, 597-607.

Wexler, K. (1998). Very early parameter setting and the unique checking constraint: A new explanation of the optional infinitive stage. *Lingua*, *106*, 23-79.

Whaley, C. (1978). Wordnonword classification time. *Journal of Verbal Learning and Verbal Behavior*, *17*, 143-154.

Willits, J., Seidenberg, M., & Saffran, J. R. (2014). Distributional structure in language: Contributions to noun-verb difficulty differences in infant word recognition. *Cognition*, *132*, 429-436.

Yamashita, Y. (1999). The acquisition of nouns and verbs in young japanese children: why do verbal nouns emerge early? In *Bucld 23 proceedings* (p. 741-752).