

# **Mechanisms of Segmentation and Morphological Learning in Infants**

**Rushen Shi and Alexandra Marquis  
Université du Québec à Montréal**

## **1. Introduction**

A prerequisite for learning a vocabulary during early language development is the ability to segment words from continuous speech. This is because speech directed to infants consists predominantly of multi-word utterances (e.g., Shi, Morgan, & Allopenna, 1998; van de Weijer, 1998). Finding words from running speech is not straightforward for a number of reasons. First, there are no reliable pauses between words. Speech units such as phonetic sounds and words are not produced in a strictly linear fashion like strung beads. Rather, speech production reflects a great deal of parallel encoding of linguistic units (e.g., Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967), resulting in one-to-many and many-to-one mapping between acoustic cues and linguistic units. There is considerable co-articulation between phonetic categories and words. There is not only a lack of clear boundaries between words, but also a high degree of variability for any given word. Other factors also contribute to the variable acoustic realization of words and phonetic categories, such as speaker differences, affect, speech rate, focus, etc. Therefore, segmenting words and categorizing them is not a trivial task for infants.

A great deal of attention has been devoted to the problem of word segmentation in infants for the past 15 years. Since the first experimental demonstration by Jusczyk and Aslin (1995) that infants can segment word forms from continuous speech before the onset of word learning, many studies attempted to determine the means by which word segmentation is achieved, particularly how infants find word boundaries. English-learning infants have been shown to use strong stress to locate word onset at 7.5 months of age (Jusczyk, Houston, & Newsome, 1999), consistent with the observation that English content words predominantly begin with a strong syllable (Cutler & Carter, 1987). French-learning infants, on the other hand, rely on syllabic cues to segment words (Nazzi, Iakimova, Bertoncini, Fredonie, & Alcantara, 2006). These responses reflect native-language prosodic characteristics, i.e., English being a stress-timed language and French being a syllable-timed language. Infants can also use other speech cues to segment words, such as coarticulation phonotactic cues, phonotactic cues, allophonic cues, etc. (e.g., Curtin, Mintz, & Byrd, 2001; Mattys & Jusczyk, 2001). Most experiments using natural languages tested noun segmentation. A few studies tested infants' verb

segmentation (Marquis & Shi, 2008; Nazzi, Dilley, Jusczyk, Shattuck-Hufnagel, & Jusczyk, 2005). Infants have also been shown to segment function words before one year of age (e.g., Hallé, Durand, & de Boysson-Bardies, 2008; Höhle & Weissenborn, 2003; Shady, 1996; Shafer, Shucard, Shucard, & Gerken, 1998; Shi, Marquis, & Gauthier, 2006; Shi, Werker, & Cutler, 2006), even though these words are prosodically and phonologically reduced in comparison to nouns and verbs (Cutler, 1993; Shi, et al., 1998). Note that function words appear much later than content words in children's production (e.g., Brown, 1973). The high frequency of occurrence of function words in the input was shown to play a role in the early segmentation of function words (Shi, Cutler, Werker, & Cruickshank, 2006; Shi & Lepage, 2008). In well-controlled experiments with artificial languages, infants were able to use transitional probabilities alone to find word boundaries (e.g., Saffran, Aslin, & Newport, 1996).

Most studies have focused on testing one single cue, for the purpose of obtaining precise information regarding what cues infants are capable of using for word segmentation. However, natural languages normally contain rich sources of information. How do infants segment words when multiple cues are available? Intuitively, when different cues support the same word boundary, segmentation should not be impeded if not further enhanced. But what would happen when two cues indicate different word boundaries? It is possible that infants may become confused and fail to segment any possible word forms, or they may lean on one of the cues to determine word boundaries. Little is known about the conditions and possible constraints that underlie infants' segmentation bias for one cue over another when these cues are in conflict.

A limited number of published studies have directly tested conflicting cues in word segmentation (e.g., Johnson & Jusczyk, 2001; Mattys, Jusczyk, Luce, & Morgan, 1999; Thiessen & Saffran, 2003). For example, Johnson and colleagues (Johnson & Jusczyk 2001; Johnson & Seidl, 2008) showed that when transitional probability cues were pitted against speech cues (i.e., stress cue and co-articulation cue respectively), eight-month-old and 11-month-old English-learning infants weighed speech cues more than transitional probabilities in word segmentation. In another study (Thiessen & Saffran, 2003), American infants at seven months of age relied on statistical cues to segment words, but the reliance was shifted to stress cues at nine months, an age when infants become increasingly attuned to native-language prosodic and phonotactic properties (e.g., Jusczyk, Cutler, & Redanz, 1993; Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993; Jusczyk, Luce, & Charles-Luce, 1994).

The above studies on conflicting cues in word segmentation were done with artificial languages. The question needs to be tested with natural languages, although perfect stimuli control is harder with natural languages. One goal of the present study is to fill this gap by testing infants' segmentation biases in the presence of conflicting cues that occur naturally in language.

The second goal of this study is to understand how infants learn to segment units that are smaller than a word (e.g., bound morpheme). The knowledge of within-word morphological structures represents an important part of the

grammar. How may the segmentation mechanisms shown in the literature, typically on words or word-like units, apply to morphological parsing such as stems and inflections (e.g., *see-ing*)?

There is evidence that infants begin to recognize bound morphemes (e.g., *-ing*) some time after their first birthday. In a study on the perception of non-adjacent dependencies (Santelmann & Jusczyk, 1998), English-learning infants showed sensitivity to the relationship of the bound morpheme *-ing* with a preceding non-adjacent word (e.g., *is*). Soderstrom and colleagues (2007) recently found that 16-month-old American infants perceived grammatical relations involving the English bound morpheme *-s*. Although these studies were not direct segmentation tasks, they nevertheless showed that infants do attend to bound morphemes. Mintz (2004) specifically tested infants' segmentation of bound morphemes. In that study 15-month-old English-learning infants preferred to listen to bare stems that had occurred with the *-ing* morpheme during familiarization over those that had occurred with the pseudo-suffix *-dut*.

The present study inquired how infants acquiring French may segment stems and sub-syllabic bound morpheme. In particular, we manipulated the experimental stimuli such that two word-internal parses would be possible due to two conflicting cues, statistical versus syllabic boundary cues. Hence, we not only aim at understanding segmentation mechanisms in general, but also hope to gain information concerning how the mechanisms may lead to initial morphological learning.

## 2. Experiment 1

In this experiment we asked how infants may segment suffixed words into smaller morphological units. To illustrate with an equivalent English example, the correct parsing for the suffixed word *moving* should be *mov-ing*. This is supported by transitional probability cues since *-ing* occurs with a large number of stem types in English. However, resyllabification is required whenever there is a stem coda consonant, so the syllabic boundary cues support different parsing, *mo-ving*. The same is the case in French. For example, the verb *couper* ("to cut") contains the stem *coupe* (/kup/) and the bound morpheme *-er* (/e/). Resyllabification is also required in French, *cou-per*, with the /p/ of the stem more co-articulated with the following vowel suffix. The conflicting statistical and phonological patterns offer an ideal chance for testing infants' segmentation mechanisms and their initial morphological parsing. Our stimuli included the suffixed form, the statistical parse and the syllabic boundary parse. This design enabled us to examine how infants may begin to build morphological paradigms (such as *moving-move-moved* in English, and *couper-coupe-coupera* in French).

### 2.1.1. Participants and Stimuli

Participants were 14-month-old monolingual Quebec-French-learning infants. Sixteen infants completed the experiment. Stimuli were three non-

words: *glater* (/glate/), *glate* (/glat/) and *glat* (/gla/). We made the spelling of these words follow the orthographic regularities in French so that the speaker could naturally pronounce the stimuli during recording. (To make the presentation of the study clearer, we will express the three words only in phonemic transcription hereafter, /glate/, /glat/, and /gla/.) The word /glate/ contains a stem and the suffix (/e/). Verbs belonging to the /e/ group are highly regular (e.g., *marcher*, *manger*, *couper*) and account for over 90% of commonly used verbs in French (Bescherelle, 1980). Besides being the verb infinitive suffix, /e/ is also homophonous with the verb past participle *-é* (/e/), so *couper* and *coupé* have the same pronunciation. The word /glat/ is the verb stem. Verb stems as bare forms can occur as the second person singular imperatives (e.g., *Coupe!* /kup/, “Cut!”). They also occur as the present tense forms (the first and second person singular, and the third person singular and plural), which are equivalent to both the present tense and the present continuous aspect in English (e.g., the French equivalent of “I walk everyday” and “I am walking now” would have the same verb form, the bare stem *marche*). Finally, the word /gla/ is morphologically unrelated to the suffixed form /glate/.

A female native speaker of Quebec French recorded the stimuli using the infant-directed speech style. The recording was made in an IAC acoustic chamber, at 44.1 Khz sampling frequency with a bit rate of 16 bits. Multiple repetitions of each non-word with varying intonation contours were recorded. The final stimuli set consisted of eight tokens for each of the non-words. The average token duration was 860.9 msec for /glate/, 695.7 msec for /glat/, and 491.9 msec for /gla/ (see the appendix for more acoustic measures).

In addition to the speech stimuli, sounds of water bubbles were used as pre- and post-experiment trials. The pre-experiment trial served to introduce the infant to the procedure, while the post-experiment trial allowed us to determine if the infants were on task throughout the experiment. The bubble sounds were distinct from the speech stimuli, so we expected infants’ looking time to recover during the post-experimental trial relative to the last test trial. We also included a flashing light accompanied by cricket sounds as the stimuli for the attention getter, to attract the infant’s attention between trials during the experiment.

The visual image for all trials was a boundless, abstract picture. It was presented in synchrony with the auditory stimuli during each trial of the experiment. This synchrony was designed to better induce infants’ looking responses to the auditory stimuli.

### **2.1.2. Design and Predictions**

The experiment consisted of two phases, the Familiarization phase and the Test phase. During the Familiarization phase, trials containing the tokens of the suffixed non-word /glate/ were presented. Repetitions of the tokens appeared in a random order across trials. When infants accumulated a total of 33 sec of looking time, the Familiarization phase terminated and the experiment advanced automatically to the Test phase. Two types of trials were presented during the

Test phase, the /glat/ versus the /gla/ type. The Test phase began with either the /glat/ or /gla/ type, counter-balanced across infants. The tokens of each type were presented in a random order. The maximal length was 21 sec for the familiarization trials and 16 for the test trials. The inter-stimulus interval between tokens was 750 msec during the Familiarization phase. For the Test phase, the duration from the onset of a word token to the onset of the following token within a trial was set at 1250 msec, so the inter-stimulus interval was approximately 750 msec.

The stimuli of the experiment were structured such that the familiarization word /glate/ and the test word /glat/ constitute a basic verb paradigm (i.e., the two forms are related morphologically). In contrast, the test word /gla/ bears no morphological relationship to /glate/. Since most verbs in French belong to the /e/ group, the number of verb stem types that co-occur with the /e/ suffix is high. That is, the transitional probability between a stem and the suffix /e/ is low. We predicted that if infants parsed /glate/ into smaller units based on this statistical knowledge, they should show a looking preference for the related /glat/ type over the unrelated /gla/ type during the Test phase. However, if infants had no ability of storing the general transitional probabilities of /e/ with various stems in the natural speech environment, but rather could only track the statistical information of the stimuli during the experimental session (i.e., the high transitional probability between any elements within /glate/), they should treat /glate/ as an inseparable whole word unrelated to /glat/ and /gla/. In this case, their looking times to the two test words should not differ.

On the other hand, the vowel suffix /e/ must be resyllabified with the coda consonant /t/ of the stem /glat/, leading to /gla-te/, as it is the case of real verbs in French that contain a stem coda (e.g., *manger*, *couper*). The stem boundary is therefore mis-aligned with the syllable boundary. If infants in our experiment parsed the word on the basis of the syllabic cue, they should prefer /gla/ over /glat/ during the Test phase.

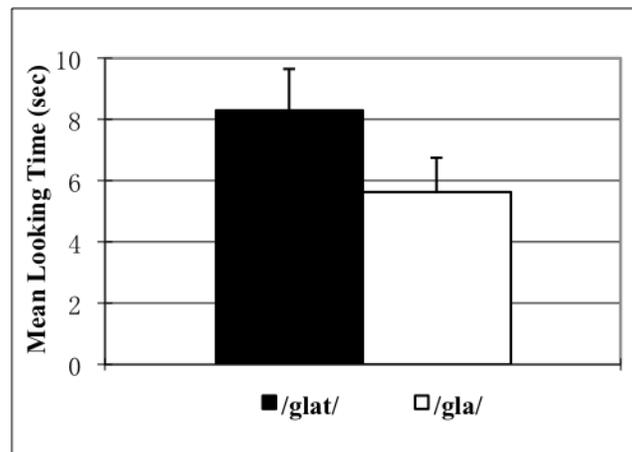
### **2.1.3. Procedure**

Infants were individually tested in a visual fixation procedure. In a sound-attenuated room the infant sat on the parent's lap in front of a display monitor, which presented the visual stimuli. Loudspeakers, which presented the auditory stimuli, were placed at the same location as the monitor. The parent was asked not to interact with his/her infant during the experiment. The experimental program (Cohen, Atkinson, & Chaput, 2000) presented the trials, recorded all looks of the infant, and automatically calculated the total looking time across familiarization trials. As soon as the total looking time reached the familiarization criterion, the software moved the experiment to the Test phase. The researcher was blind to the stimuli of the experiment. She observed the infant's eye movement from the adjacent room through a closed circuit TV, pressing down a computer key whenever the infant looked at the display monitor. Each trial was initiated contingent upon the infant's look towards the

monitor, and terminated when the infant stopped looking for one sec or till the maximal length of the trial was reached.

## 2.2. Results

Infants' looking times for the /glat/ test trial type (the statistical parse) and the /gla/ test trial type (the syllabic boundary parse) were analyzed in a paired t-test. The results confirmed the prediction of the statistical based parsing. As shown in Figure 1, infants showed a significant looking preference for /glat/ (Mean= 8.28 sec; SE= 1.37 sec) over /gla/ (Mean=5.61 sec; SE= 1.14 sec),  $t(15)=2.724$ ,  $p=.016$ , 2-tailed. This suggests that they relied on the transitional probability between the frequent suffix and various stems in the natural speech environment to segment the form /glate/ into the stem /glat/ and the vowel morpheme /e/, despite the conflicting syllabic cue (i.e. /gla-te/). Note that in the natural input this kind of syllabic cue is consistently present for all /e/-suffixed verbs containing a coda consonant on the stem.



**Fig. 1.** Infants' looking (listening) time to the two test words, /glat/ (the statistical parse) versus /gla/ (the syllabic boundary parse) after they were familiarized with /glate/, a word that contained the stem /glat/ affixed with the morpheme /e/.

## 3. Experiment 2

The results of Experiment 1 suggest that when statistical and syllabic cues are both present but in conflict, 14-month-old French-learning infants can rely on statistical information to parse words into smaller units that correspond to the stems and bound morphemes. However, an alternative explanation may account for the results. Is it possible that the results of Experiment 1 simply reflect a general preference for word forms ending with a coda consonant, rather than

statistical based parsing? If this was the case, the kind of words during familiarization should have had no influence on infants' response pattern during test. We tested this possibility in Experiment 2. In particular, we asked how infants would respond to the two test words if the familiarization word was a disyllabic form phonetically similar to /glate/ but contained no suffix, that is, no statistical cue for word-internal parsing.

### 3.1.1. Participants, Stimuli, Design, Procedure and Predictions

A new group of 14-month-old monolingual Quebec-French-learning infants participated in this experiment. Sixteen infants completed the task. Another non-word was used for the Familiarization phase, *glatou* (/glatu/). This non-word resembled the familiarization word in Experiment 1, /glate/, in the number of syllables. The phonetic segments were also similar. However, unlike /glate/, this word was a mono-morphemic disyllabic form containing no suffix. The word was recorded by the same speaker who produced the stimuli of the previous experiment. The selection of the tokens of this word followed the same method as in Experiment 1. The final set consisted of eight tokens of /glatu/, and the average token duration was 899.5 msec (see the appendix). All the other stimuli remained the same as in Experiment 1.

The procedure and design were identical to that of Experiment 1, the only difference being that infants were familiarized with the mono-morphemic disyllabic form /glatu/. After familiarization, infants were presented with the same test trials as in Experiment 1.

For the familiarization word /glatu/, no statistical information was available to support the parsing of the word into smaller units, since the final vowel was not a French suffix. On the contrary, the repeated presentations of the word during the Familiarization phase yielded high transitional probability between the two syllables and between every two phonemes, supporting a whole-word parse. Therefore, infants were expected to show no response difference in the Test phase if they interpreted neither of the test words (/glat/, /gla/) as related to /glatu/.

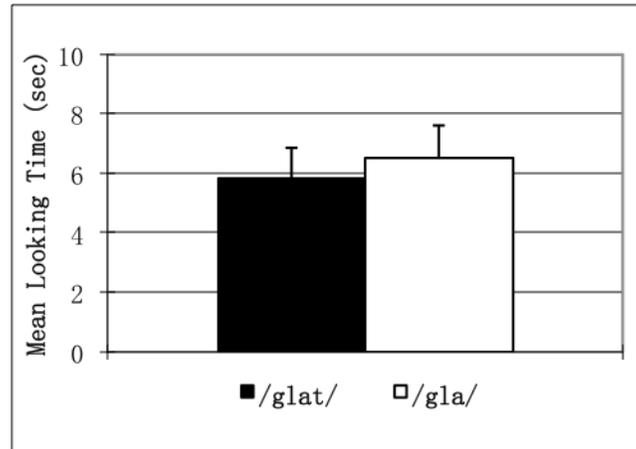
On the other hand, the familiarization word /glatu/ still contained the syllabic boundary cues. We predicted that if infants had a syllabic bias for parsing, they should prefer the syllabic /gla/ over the extra-syllabic /glat/.

Either of the above predicted outcomes would allow us to confirm that the results of Experiment 1 (i.e., a preference for the form /glat/ following the familiarization of /glate/ was indeed based on statistical cues related to the frequent vowel suffix /e/).

## 3.2. Results

As in Experiment 1, infants' looking times for /glat/ (the extra-syllabic parse) and /gla/ (the syllabic parse) during the Test phase were analyzed in a paired t-test. As shown in Figure 2, looking time for the /glat/ (Mean=6.44 sec;

SE= .97 sec) was not different from /gla/ (Mean=5.46 sec; SE= .93 sec),  $t(15)=.913, p=.376$ .



**Fig. 2.** Infants' looking (listening) time to the two test words, /glat/ (the extra-syllabic parse) versus /gla/ (the syllabic boundary parse) after they were familiarized with /glatu/, a mono-morphemic disyllabic word that contained so suffix.

To further ascertain that infants in the two experiments indeed responded differently, we analyzed the data of both experiments in a 2x2 mixed ANOVA, with Parse Type (/glat/ versus /gla/) as the within-subject factor, and Familiarization (/glate/ versus /glatu/) as the between-subject factor. There was no main effect of Parse Type ( $F(1, 30) = 1.346, p = .26$ ), no main effect of Familiarization ( $F(1, 30) = .498, p = .49$ ), but a significant Parse Type x Familiarization interaction ( $F(1, 30) = 6.297, p = .018$ ).

These results show that infants interpreted neither test word as related to the familiarization word /glatu/ in Experiment 2. Furthermore, infants did not show syllabic based parsing in this experiment. The combined analysis of both experiments further confirmed that infants in Experiment 1 indeed relied on the transitional probability between the frequent suffix /e/ and various stems in the natural speech environment to segment /glate/ into two sub-units (the stem /glat/ and the suffix /e/), despite the consistent conflicting syllabic cue.

#### 4. General Discussion

In two experiments we showed that infants aged 14 months, i.e., at the beginning of word learning, are able to segment suffixed words into smaller units that correspond to stems and sub-syllabic bound suffixes. Furthermore, using a natural language, we demonstrated that when statistical cues and syllabic cues occur in conflict and indicate different boundaries, infants rely more on

statistical cues. These findings also reveal that infants' processing of word-internal units already resembles adults' parsing of stems and bound morphemes.

One issue concerns the testing procedure. Some studies using preferential looking procedures reported novelty preference whereas others found familiarity preference. The direction of preference is related to a number of factors (see Hunter, & Ames, 1988; Roder, Bushnell, & Sasseville, 2000). We predicted familiarity preference in our study based on the fact that other studies using natural languages typically showed familiarity preference (e.g., Bortfeld, Morgan, Golinkoff, & Rathbun, 2005; Jusczyk & Aslin, 1995; Jusczyk, et al., 1999), whereas experiments using artificial languages often reported novelty preference (e.g., Marcus, Vijayan, Bandi Rao, & Vishton, 1999; Saffran, et al., 1996). In addition, since long exposure during familiarization in general tends to lead to novelty preference and short exposure to familiarity preference, we expected a familiarity preference because our familiarization phase was short. But is it possible at all that our results in Experiment 1 reflected a novelty preference indicating a segmentation process based on the syllabic boundary? This interpretation can be excluded given the results of Experiment 2, as infants heard the same test words but showed a null result, that is, no evidence of a general bias for parsing units at the syllabic boundary. Therefore, infants in Experiment 1 indeed computed the within-word transitional probabilities and used this information to segment the units despite the mis-alignment of their boundary with the syllable.

Infants' responses in our experiments further indicate that coda consonants were perceived and encoded in their representation. The two test words /glat/ and /gla/ were identical except that /glat/ has a coda stop consonant. In previous word segmentation studies infants have been shown to well perceive and represent word onset consonant (e.g., Bortfeld, et al., 2005; Jusczyk & Aslin, 1995). Less is known about infants' perception of coda consonants (but see Swingley, 2005). The present study shows that infants not only perceived the coda consonant of the test word /glat/, but also related it to the statistical computation that they performed on the familiarization word /glate/.

The results of our study contribute to the understanding of segmentation mechanisms in infants. Furthermore, we showed that the outcomes of infants' segmentation can yield rudimentary morphological knowledge that is part of the structures of the adult grammar. The evidence that infants perceive bound grammatical morphemes and process them in an adult-like fashion is consistent with the view (e.g., Christophe, Guasti, Nespor, Dupoux, & van Ooyen, 1997; Shi, et al., 1998; Shi, 2005) that function words/morphemes are accessible to infants from the onset of language learning and can bootstrap the acquisition of the grammar.

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## Appendix

Mean acoustic values and standard deviations (SD) of the stimuli words

	Duration (ms)	Mean F0 (Hz)	Mean amplitude (dB)
/gla/ (8 tokens)	491.9 (108.9)	218.5 (59.2)	73.1 (3.4)
/glat/ (8 tokens)	695.7 (70.6)	228.4 (69.9)	66.9 (2.6)
/glate/ (8 tokens)	860.9 (275.3)	312.5 (17.8)	73.9 (2.5)
/glatu/ (8 tokens)	899.5 (310.2)	313.8 (16.5)	73.5 (2.9)

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