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Word Segmentation in Monolingual Infants Acquiring Canadian English and Canadian French: Native Language, Cross-Dialect, and Cross-Language Comparisons

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In five experiments, we tested segmentation of word forms from natural speech materials by 8-month-old monolingual infants who are acquiring Canadian French or Canadian English. These two languages belong to different rhythm classes; Canadian French is syllable-timed and Canada English is stress-timed. Findings of Experiments 1, 2, and 3 show that 8-month-olds acquiring either Canadian French or Canadian English can segment bi-syllable words in their native language. Thus, word segmentation is not inherently more difficult in a syllable-timed compared to a stress-timed language. Experiment 4 shows that Canadian French-learning infants can segment words in European French. Experiment 5 shows that neither Canadian French- nor Canadian English-learning infants can segment two syllable words in the other language. Thus, segmentation abilities of 8-month-olds acquiring either a stress-timed or syllable-timed language are language specific.

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An essential skill in processing spoken language is the segmentation of continuous fluent speech into words. This is not a trivial accomplishment. In natural speech, words are rarely demarcated by pauses or other obvious acoustic landmarks and many boundary cues and distributional patterns that support word segmentation vary across languages. Like adults, infants encounter few isolated words in the input directed to them (Brent & Siskind, 2001; van de Weijer, 1998). Hence, word segmentation is one of the first challenges that infants face in acquiring their native language. This ability is important for the development of the lexicon in which word forms become linked to meaning. As well, the perception of fluent speech as a sequence of word forms is critical for the acquisition of grammar, that is, the rules specifying the kind of word sequences that form acceptable utterances in the native language.

The ability to extract word forms from natural speech utterances emerges between 6 and 12 months of age in infants learning English (e.g., Jusczyk & Aslin, 1995), French (Marquis & Shi, 2008; Nazzi, Iakimova, Bertoncini, Frédonie, & Alcantara, 2006; Shi, Marquis, & Gauthier, 2006), Dutch (Houston, Jusczyk, Kuijpers, Coolen, & Cutler, 2000), and German (Höhle & Weissenborn, 2003). Although segmentation has been investigated in multiple languages, the literature to date is dominated by research in English. The present research is primarily concerned with how infants learning French begin segmenting words when they encounter natural speech utterances and the extent to which infants' segmentation abilities are tied to their familiarity with their native language.

Jusczyk and colleagues conducted the first studies of infant word segmentation (Jusczyk & Aslin, 1995; Jusczyk, Houston, & Newsome, 1999). Using natural speech materials, they tested English-learning infants using a variation of the Headturn Preference Procedure (HPP) in which infants were first familiarized with words produced in isolation and then presented different test passages of connected speech. In some test passages, the familiarized word occurred frequently and in other passages a novel word occurred frequently. If infants listened longer to the test passages with the familiarized word this was taken as evidence that they can extract the word from fluent connected speech. Using this paradigm, Jusczyk and colleagues showed that English-learning infants can segment monosyllabic words between 6 and 7.5 months and bi-syllabic words by 7.5 months. Early in development English-learning infants segment only stressed monosyllables and bi-syllabic words with a trochaic (strong-weak) stress pattern; they do not yet segment words with an iambic (weak-strong) stress pattern. Analyses of conversational English shows that more than 90% of content words begin with stressed syllables (see Cutler & Carter, 1987). Jusczyk and colleagues concluded that when infants are beginning to segment word forms from fluent speech they exploit the prosodic properties of native language.

The role of prosody is evident in other aspects of infant speech processing as well. Newborns are sensitive to prosodic differences between languages, specifically those based on rhythm, and further differentiation of languages within the native language rhythm class improves rapidly in early infancy (Bosch & Sebastián-Gallés, 1997, 2001; Mehler et al., 1988; Nazzi, Bertoncini, & Mehler, 1998; Nazzi, Jusczyk, & Johnson, 2000; Ramus, Hauser, Miller, Morris, & Mehler, 2000). The categorization of languages into one of three basic rhythm classes (stress-timed, syllable-timed, mora-timed) has been recognized for some time (Abercrombie, 1967; Pike, 1945). Recent studies describe the acoustic-phonetic bases of this classification scheme (Low, Grabe, & Nolan, 2000; Ramus, Nespor, & Mehler, 1999).

At the word level, cross-linguistic studies reveal an initial language-general sensitivity to word stress patterns that shifts to favor native language properties over the first year of life (Echols, Crowhurst, & Childers, 1997; Höhle, Bijeljac-Babic, Herold, Weissenborn, & Nazzi, 2009; Jusczyk, Cutler, & Redanz, 1993; Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993; Jusczyk & Thompson, 1978; Pons & Bosch, 2010; Sansavini, Bertoncini, & Giovanelli, 1997; Skoruppa et al., 2009; Turk, Jusczyk, & Gerken, 1995). Electrophysiological data also reveal a developmental attunement to native language word stress patterns (Friederici, Friedrich, & Christophe, 2007; Goyet, de Schonen, & Nazzi, 2010).

Although Jusczyk, Houston, et al. (1999) focused on infants' exploitation of native language prosody in early word segmentation, English infants in their studies were also using information about syllable co-occurrence patterns. Specifically, only re-occurring bi-syllabic sequences within a trochaic template were segmented from connected speech. Thus, the ability to track distributional patterns in connected speech also supports infants' emerging word segmentation skills (e.g., Goodsitt, Morgan, & Kuhl, 1993; Saffran, Aslin, & Newport, 1996; Saffran, Newport, & Aslin, 1996).

Since the early research on word segmentation, there has been an ongoing debate concerning the type(s) of cues infants use to begin segmenting words and how cue integration or weighting changes as infants develop more efficient and language-specific word segmentation skills. Much of this work involves simplified artificial language (AL) materials that are played continuously for several minutes to infants in the laboratory; infants are then presented test probe items from the AL to assess what they learned from this focused exposure. Studies using the AL approach show that English-learning 7-month-olds are able to use either transitional probabilities between syllables (Thiessen & Saffran, 2003) or the predominant stress pattern of their native language (Curtin, Mintz, & Christiansen, 2005) to find word forms in connected speech. However, when English-learning infants are provided with conflicting transitional probabilities and prosodic cues, 6-month-olds rely more on transitional probabilities (Thiessen & Saffran, 2003), whereas 8- (Johnson & Jusczyk, 2001), 9- (Thiessen & Saffran, 2003), and 11-month-olds rely more on prosody, specifically stress (Johnson & Seidl, 2008). These findings show an increasing reliance on prosodic information as infants refine their word segmentation skills.

Given that word segmentation depends to some extent on cues and patterns that are specific to a particular language, cross-linguistic studies are also highly informative with respect to the development of this skill. Although cross-linguistic comparisons of infant word segmentation include just a few studies using natural speech materials, there are clear parallels with adult segmentation findings which show a connection between word segmentation and language rhythm.

The unit of word segmentation in adults has been shown to differ according to language rhythm class. Specifically, adults speakers of English and Dutch (stress-timed languages) rely on trochaic stress patterns, whereas speakers of French and Spanish (syllable-timed languages) track syllables, and speakers of Japanese (a mora-timed language) access mora units (Cutler, Mehler, Norris, & Segui, 1986; Cutler & Norris, 1988; Mehler, Dommergues, Frauenfelder, & Segui, 1981; Murthy, Otake, & Cutler, 2007; Otake, Hatano, Cutler, & Mehler, 1993; Peretz, Lussier, & Beland, 1998; Sebastián-Gallés, Dupoux, Segui, & Mehler, 1992; Vroomen, Van Zon, & de Gelder, 1996). Moreover, monolingual adults do not easily adapt their segmentation behavior; rather, they typically apply the prosodic biases of their native language when they encounter a rhythmically novel speech stream (e.g., Cutler & Otake, 1994; Tyler & Cutler, 2009).

Based on cross-linguistic findings with adults and segmentation patterns of English-learning infants, Jusczyk, Houston, et al. (1999) proposed the rhythm hypothesis to predict infants' cross-linguistic performance on word segmentation. According to this view, familiarity with the rhythmic structure of the native language directs attention to specific prosodic units that support word segmentation. Houston et al. (2000) tested the rhythm hypothesis by comparing segmentation of bi-syllabic words by English-learning and Dutch-learning infants. Dutch and English are both stressed-timed languages with a predominantly trochaic word stress pattern (Ramus et al., 1999; Rietveld & Koopmans-van Beinum, 1987). Following the rhythm hypothesis, Houston et al. reasoned that if the rhythmic properties of the native language have a strong influence on early word segmentation this may enable young infants to segment bi-syllabic trochaic words, not just in their native language, but also in languages within the same rhythm class as their native language. Consistent with this prediction, both English-learning and Dutch-learning 9-month-olds were able to segment bi-syllabic trochaic words in Dutch when tested in the standard HPP task. Familiarity with specific phonetic units or phonotactic sequences of Dutch was not necessary for English infants to successfully segment in a nonnative language. Rather, both Dutch and English infants appear to focus their attention on similar metrical patterns as a result of their familiarity with rhythmically similar languages.

The support for the rhythm hypothesis is, however, equivocal. Pelucchi, Hay, and Saffran (2009) examined English-learning infant's segmentation of trochaic (strong-weak) words in Italian using a task that combined some of the demands of the AL approach with stimulus characteristics of a natural language approach. Eight-month-olds were exposed (for over 2 min) to a set of naturally produced real sentences in Italian in which two target words occurred frequently; this exposure was longer than the standard HPP task (typically 45 sec to each of the two passages, when familiarized with passages). Following this exposure, infants were presented isolated productions of the familiar target words and novel words in a preference test. English-learning infants succeeded in this task (preferring the familiar words) despite the differences in rhythmic structure of English, which is a stress-timed language, and Italian, a syllable-timed language. The target Italian words contained some non-English phonetic detail, but were phonotactically legal sequences in English and had an English-like, trochaic stress pattern. Thus, English-learning infants' success in segmenting word forms with the predominant stress pattern observed in English, that is, trochees, in an unfamiliar language with a novel speech rhythm may have been due, at least in part, to their familiarity with English word prosody. As well, the lengthy exposure times may have allowed infants to engage processing mechanisms or strategies that they cannot easily apply in a standard HPP task with natural language stimuli where word repetition rates are more limited. Clearly, further cross-linguistic research is needed to clarify the factors influencing infants' segmentation of nonnative speech materials.

Another issue that can be addressed via cross-language research is whether there are inherent differences across languages with respect to when and how word segmentation skills emerge in early development. Presently, there appear to be differences between rhythmically different languages when we compare findings from studies of native language segmentation conducted with infants acquiring American English and infants acquiring European French (hereafter EFrench). Using natural speech and the HPP paradigm, Nazzi et al. (2006) found that infants learning EFrench differ from their English-learning peers in two ways—when they begin to segment words and what units they favor in their early word segmentation. Recall that in Jusczyk, Houston, et al. (1999), English-learning 7.5-month-olds were able to segment bi-syllabic words in their native language. In contrast, EFrench-learning infants tested by Nazzi et al. were not able to segment a bi-syllabic word unit until 16 months of age (see also Gout, 2001). At 12 months, EFrench-learning infants segmented just the second syllable (and under certain conditions, the first syllable) but failed to segment bi-syllabic words as a unit. At 16 months, EFrench-learning infants were successful at segmenting bi-syllabic words as one unit, but failed to segment the individual syllables. These findings suggest that EFrench-learning infants begin segmenting words by first tracking syllables and then detecting syllable co-occurrence patterns. Thus, there appear to be cross-linguistic differences in the unit that infants favor as they begin to segment words, with English-learning infants favoring trochaic stress patterns, and French-learning infants favoring syllables. Although the Jusczyk, Houston, et al. and Nazzi et al. studies used similar methods, there were differences with respect to stimulus development and testing procedure. Thus, a more controlled comparison of English-learning and French-learning infants is needed to confirm that differences are related to differences in language structure.

The present study was designed to broaden the scope of cross-language research to gain further insights into the role of language experience in emerging word segmentation skills. To date, cross-language segmentation studies with infants are sparse and limited almost exclusively to research on infants acquiring stress-timed languages. Using a natural language approach, we focused on the early word segmentation skills of infants acquiring either Canadian French (CFrench) or Canadian English (CEnglish) and addressed two issues that were raised by previous cross-language findings.

First, are there differences across languages from different rhythm classes with respect to the developmental onset of word segmentation skills? Previous studies point to substantial age differences between infants acquiring French and English, with segmentation of bi-syllabic words emerging as early as 8 months in English-learning infants (Jusczyk, Houston, et al., 1999), and not until 16 months in French-learning infants (Nazzi et al., 2006). In Experiment 1, we address the issue of cross-linguistic differences in the onset of word segmentation by directly comparing segmentation of CEnglish-learning and CFrench-learning infants in the same lab using the same test methods and comparable speech materials. In Experiments 2 and 3, we assess CFrench-learning infants' segmentation of the syllables that constitute the bi-syllabic words to confirm that the results obtained in Experiment 1 are indeed due to infants' successful segmentation of bi-syllabic words.

The second issue targeted in this study concerns the extent to which early word segmentation skills can be transferred to nonnative speech. Is the transfer of early word segmentation skills restricted to languages or dialects that conform to the native language rhythm? Or is this a more general skill that can be applied with some success to any unfamiliar language or dialect? Previous cross-language findings support the idea that infants can exploit the prosodic biases they have gained from experience with their native language rhythm to segment an unfamiliar language with a similar prosodic structure. However, to date, with the exception of Pelucchi et al. (2009) where infants segmented words with an English stress pattern following a lengthy familiarization phase, no studies have directly assessed segmentation across rhythmically different languages. Thus, it is unclear whether infant's successful segmentation of nonnative speech material requires some shared prosodic characteristics with the native language or is it supported by more general processing mechanisms that infants can apply broadly to languages in different rhythm classes. In Experiments 4 and 5, we addressed these issues by testing infants' success at cross-dialect and cross-language segmentation. In Experiment 4, we assessed CFrench-learning infants' ability to segment bi-syllabic words in a different dialect, that is, EFrench. In Experiment 5, we examined infants' segmentation of bi-syllabic words in a rhythmically different nonnative language—CFrench-learning infants were tested on CEnglish stimuli; CEnglish-learning infants were tested on CFrench stimuli.

EXPERIMENT 1

Findings reported by Jusczyk, Houston, et al. (1999) and Nazzi et al. (2006) suggest that word segmentation skills emerge substantially later in infants acquiring EFrench (tested in Paris) compared to infants acquiring English (tested in the United States). The reason(s) behind these age differences are unclear. Nazzi et al. is the only published data on bi-syllabic word segmentation in infants acquiring French or any syllable-timed language. It is possible that segmenting bi-syllabic words is more difficult in syllable-timed languages in general or EFrench in particular.

Alternatively, although the HPP paradigm was used in both studies, age differences across these studies may be due to differences in methodologies implemented in each lab. The studies differed in the register of the speech stimuli—child directed in the Jusczyk, Houston, et al. study compared to adult-directed in the Nazzi et al. (2006) study. They also differed in the overall familiarization duration—in the Jusczyk, Houston, et al. study infants were familiarized to word lists for 30 sec each, whereas Nazzi et al. familiarized infants to each word list for 20 sec.

In Experiment 1, we tested both CFrench-learning and CEnglish-learning infants on segmentation of bi-syllabic words in their respective native language, using identical testing procedures. CFrench-learning infants were tested on their segmentation of two-syllable words with iambic stress, the predominant word stress pattern in French. CEnglish-learning infants were tested on their segmentation of two-syllable words with trochaic stress, the predominant word stress pattern in English. Natural child-directed speech materials were prepared in the same way for each language group and identical testing procedures and instrumentation were implemented.

Eight-month-olds were tested in both groups. We expected CEnglish learning 8-month-olds to successfully segment two-syllable words in their native language, thus extending earlier findings on American English to CEnglish-learning infants. If segmenting two-syllable words is more challenging for infants learning a syllable-timed language, as might be inferred based on Nazzi et al.'s (2006) results, we expected CFrench-learning 8-month-olds to fail in this experiment. However, if the late emergence of word segmentation in Nazzi et al. is due to methodological factors or due to specific properties of EFrench, we expected CFrench learning 8-months to successfully segment two-syllable words in their native language.

Methods

Participants

Thirty-two infants between the ages of 7 months 8 days and 8 months 23 days, 16 CFrench-learning and 16 CEnglish-learning were tested on segmentation of two-syllable words in their native language. All infants were recruited in Montreal where many children acquire more than one language. Infants' language background was assessed via a detailed questionnaire and interview with parents. This tool provides information to estimate infant's language exposure via interactions with family and caregivers in a typical week. We included infants whose language exposure was minimally 90% CFrench or 90% CEnglish. However, the majority of the subjects received 100% exposure to one language. The CFrench infants (five boys and 11 girls) had a mean age of 7 months 25 days ($SD = 12$ days); the CEnglish infants (12 boys and four girls) had a mean age of 7 months 30 days ($SD = 10$ days).[1] Sixteen additional babies were tested but their data were not analyzed due to fussiness ($n = 2$), very short looks during test trials, that is, looking time to at least one passage under 3 sec ($n = 11$), segmentation index (test minus control) more than 2 *SD*s above or below the group average ($n = 1$), and technical problems ($n = 2$).

[1]Due to the imbalance in gender, we re-ran all analyses with gender as a between-subjects variable. There was no significant main effect or interaction with gender. Hence, it is not included in any reported analysis.

Stimuli

The stimuli were recorded by a female simultaneous bilingual speaker of CFrench and CEnglish. She acquired both languages from birth and has used both languages regularly throughout her life. The talker recorded four passages in each language; each passage featured a different bi-syllabic word. The French words were "beret," "surprise," "devis," and "guitare"; the English words were "hamlet," "kingdom," "doctor," and "candle." Each passage consisted of six sentences with the target word occurring once per sentence; twice at the beginning; twice in the middle, and twice at the end of the sentence. The French passages are presented in Table 1. The English words and passage materials were the same ones used by Jusczyk, Houston, et al. (1999). The talker was recorded first producing a set of passages in each language and then was asked to produce 20–30 repetitions of each bi-syllabic word. She was instructed to produce the passages and words as if she was speaking to a child. She practiced reading the passages aloud before making the recording. Filler passages were included in the recording materials.

The four target passages and word lists in each language were excised from the recording. The overall duration and number of repetitions for passages and lists are presented in Table 2 (CEnglish on the left and CFrench in middle column). We measured the duration, amplitude and pitch (f0) of each syllable, of each bi-syllabic target word token, in the passages, and in the word lists. Table 3 shows mean acoustic values for the words produced in the passages and for the words produced in lists. Mean

TABLE 1
French Sentences Used in the Four Passages

Guitare passage

Elle a sorti ses belles guitares. Trois guitares ne seraient pas assez. Il faut d'autres guitares pour la fête. Ne faites pas trop attention aux guitares. On voit plusieurs guitares avant de choisir. Les guitares ne sont pas accordées.

Beret passage

La mode est aux bérets et autres chapeaux. Plusieurs bérets sont encore en vente. Ces jolis bérets sont à ma soeur. Elle a besoin de trois bérets. Il faut mettre les bérets sur la table. On va apporter d'autres bérets.

Surprise passage

Voici de belles surprises pour vous. Il a voulu faire plusieurs surprises. D'autres surprises risquent encore de se produire. Les surprises sont faciles à éviter. Mieux vaut deux que trois surprises. Il s'attend aux surprises à venir.

Devis passage

Les devis reçus sont raisonnables. Elle a d'autres devis à envoyer. On doit faire confiance aux devis. Il y a trois devis posés sur la table. Voilà de bien beaux devis. Plusieurs devis sont falsifiés.

TABLE 2
Descriptive Measures of Passages and Word Lists

	Canadian English		*Canadian French*		*European French*	
Measures	*Passages*	*Lists*	*Passages*	*Lists*	*Passages*	*Lists*
Average total duration (sec)	21.9	22.4	21.3	21.7	18.4	20.6
Duration range (Min–Max)	20.0–23.9	21.3–24.5	20.3–23.0	19.5–23.2	17.9–19.6	20.2–21.5
Number of target words	6	12–15	6	13–16	6	13–17
Average duration of target words (msec)	459	604	578	742	432	530
SD duration of target words (msec)	74	92	122	178	124	143

TABLE 3
Acoustic Measures of Target Words in Passages and Lists

	Canadian English		*Canadian French*		*European French*	
Measures	*Syllable 1*	*Syllable 2*	*Syllable 1*	*Syllable 2*	*Syllable 1*	*Syllable 2*
Passage words						
Duration (msec)	275	188	223	355	152	280
Amplitude (dB)	71	67.3	72.8	72.1	69.3	65.2
Pitch (Hz)	204	196	231	243	230	247
List words						
Duration (msec)	319	290	259	515	143	387
Amplitude (dB)	75.5	75.1	72.8	75	76.5	71.4
Pitch (Hz)	246	270	234	256	243	251

values were computed separately for each language. Each acoustic measure was analyzed in a Language (CEnglish versus CFrench) by Syllable (1 versus 2) analysis of variance (ANOVA). Separate ANOVAs were conducted for the tokens produced within passages and in the list format. Simple effects of Syllable in each language were analyzed for each set of measures to evaluate potential cues to word stress. The statistical comparisons for CEnglish are reported before those for CFrench.

As expected, we observed duration differences indicating syllable-initial stress for the CEnglish words and syllable-final stress for the CFrench words. For tokens produced within passages, significant effects were evident for Language, $F(1, 46) = 17.2$, $p < .0001$, partial $\eta^2 = 0.272$, and for Language by Syllable interaction, $F(1, 46) = 58.08$, $p < .0001$, partial $\eta^2 = 0.558$. Simple effects analyses of Syllable duration were significant for each language but in opposite directions. The first syllable was longer in CEnglish, $t(23) = 5.442$, $p < .0001$, $d = 1.66$; the second syllable was longer in CFrench, $t(23) = 5.611$, $p < .0001$, $d = 1.57$. A t test conducted using the magnitude of the syllable duration difference (Syllable 1 minus Syllable 2) as the dependent measure showed the duration cue to be significantly larger in CFrench compared to CEnglish, $t(46) = 2.88$, $p < .0001$, $d = 2.43$. Analyses of the duration for the list words showed the same pattern that was observed for passage words, except that the main effect of Syllable duration was also significant, $F(1, 109) = 132.90$, $p < .0001$, partial $\eta^2 = 0.594$.

Amplitude and pitch differences suggesting syllable-initial stress for CEnglish and syllable-final stress for CFrench were also present, but inconsistent. As seen in Table 3, in CEnglish, amplitude was higher for Syllable 1 only in passage words, $t(23) = 2.97$, $p = .005$, $d = 0.58$, whereas in CFrench, amplitude was higher on Syllable 2 only in list words, $t(55) = 2.13$, $p = .038$, $d = 0.41$. Further, in CEnglish, no differences in pitch were observed for passage or list words; in CFrench, pitch was higher on Syllable 2, but only in the list words, $t(55) = -2.04$, $p = .05$, $d = -0.35$.

Overall, for the words in the CEnglish passages, the first syllable was longer and louder than the second syllable. As might be expected, the CEnglish list words were longer than the passage words; however, the duration difference between syllables was reduced. The only statistically reliable cue to distinguish between the two syllables in the lists as well as passage words was duration. For the words in the CFrench passages, the second syllable was longer. The CFrench list words were also longer than passage words; in these list words, the second syllable was longer, louder, and higher in pitch than the first syllable. Again, the only reliable cue to distinguish between the two syllables in the CFrench list as well as passage words was duration.

Procedure

We implemented HPP (Kemler-Nelson et al., 1995) to assess word segmentation as described in Jusczyk and Aslin (1995). Infants were seated on their parent's lap facing the center panel of a three-sided pegboard booth. At the beginning of each trial, the light on the center panel flashed directing the infant's gaze toward the center. Then, a light on either the right, or the left side panel flashed, attracting the infant's look toward that panel. When the infant turned and looked to the light, a speech sample was played through a loudspeaker located just below the light, behind the pegboard. By choosing how long to look toward the light on each trial, the infant controlled how long he/she listened to the speech stimuli. If the infants looked away from the panel ($> 30°$) for more than 2 sec, the speech stimuli stopped playing. The infant's looking/listening time was recorded by a live observer, the experimenter, seated outside the pegboard booth. On half the trials, the flashing light and speech was played on the right; on the other half, the flashing light and speech was played on the left. The parent and experimenter wore headphones and listened to music to prevent influencing the infant's behavior. Testing lasted for about 10 min.

Testing was done in two phases: A familiarization phase followed by a test phase. In the familiarization phase, infants heard a word repeated when they looked at a flashing light; two different words lists were presented during this stage. The word lists were alternated across trials; presentation order was counterbalanced across infants. Familiarization continued until the infant had accumulated at least 30 sec of listening time to each list. In the test phase, the infant heard four passages. In two of the passages, one of the familiarized words occurred repeatedly throughout the passage (familiar passages) and in the other two passages a novel word, not previously heard during familiarization, occurred repeatedly throughout the passage (novel passages). In the test phase, each infant was presented three blocks of test trials in which each of the four passages (two familiar and two novel) occurred once; each block had a different random ordering of the four passages. The listening time to familiar and novel passages was averaged separately and compared statistically. To demonstrate segmentation, infants were expected to listen significantly longer to familiar compared to novel passages. Note that if an infant did not listen to the passage presented during a test trial for at least 3 sec, they were unlikely to hear the target word even once. For this reason we excluded from analysis data from infants who showed short looking times (less than 3 sec) on one or more test trials.

Design

Half of the CFrench-learning infants heard "guitare" and "devis" during familiarization, and the other half heard "beret" and "surprise." All infants were presented the same four CFrench passages during the test phase. Likewise, half of the CEnglish-learning infants heard the words "hamlet" and "kingdom" during familiarization, and the other half heard "doctor" and "candle." All infants were presented the same four CEnglish passages during the test phase.

Results and discussion

We computed the mean looking time for each infant for familiar and novel passages presented during the test phase. The average listening times (*SE*) for the 8-month-olds tested on their native language are shown in Figure 1.

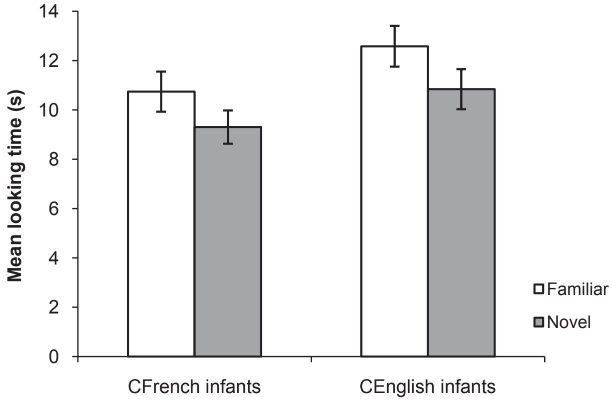

Figure 1 Native language segmentation.

These values are reported separately for CFrench and CEnglish infants tested on speech material from their native language.

Recall that all infants were familiarized till they had heard each of the two word lists for at least 30 sec. To further confirm that CFrench infants tested in the two conditions were familiarized to the same extent, familiarization times were compared using independent sample *t* tests with Familiarization Condition (devis/guitare versus beret/surprise) as a between-subjects factor. For the CFrench infants, there was no significant difference when familiarization times were compared, $t(14) = -0.32, p = .75$. Similarly, for CEnglish infants as well, there was no significant difference in familiarization times for infants tested in the two familiarization conditions (doctor/candle versus hamlet/kingdom), $t(14) = -1.0, p = .31$.

Fifteen out of 16 CFrench infants and 11 out of 16 CEnglish infants listened longer to familiar compared to novel passages, the pattern expected if segmentation is successful. To determine whether 8-month-olds were successful at segmenting two-syllable words in their native language, listening time was analyzed in a mixed model ANOVA with Group (CFrench versus CEnglish) as a between-subjects factor, and Passage Type (familiar versus novel) as a within-subjects factor. Only the main effect of Passage Type was significant, $F(1, 30) = 16.1, p < .001$, partial $\eta^2 = 0.35$. Next, paired *t* tests were conducted separately for each group to confirm that both CFrench and CEnglish infants successfully segmented two-syllable words. CFrench infants listened significantly longer to the familiar passages ($M = 10.7$ sec; $SD = 3.3$ sec) compared to the novel passages ($M = 9.3$ sec; $SD = 2.7$ sec), $t(15) = 4.12, p = .001, d = 0.46$. Likewise, CEnglish infants listened significantly longer to the familiar passages ($M = 12.6$ sec;

SD = 3.3 sec) compared to the novel passages (*M* = 10.8 sec; *SD* = 3.3 sec), $t(15) = 2.45$, $p = .03$, $d = 0.55$. Thus, the CFrench- as well as CEnglish-learning infants successfully segmented two-syllable words in their native language.

Overall, findings of Experiment 1 show that both CFrench- and CEnglish-learning infants were successful in segmenting two-syllable words in their native language. This outcome shows that word segmentation is not more challenging for infants acquiring a syllable-timed language than it is for infants acquiring a stress-timed language. Thus, the later emergence of word segmentation for EFrench in Nazzi et al. (2006) is either due to methodological differences across studies of English and French or due to specific properties of EFrench. However, before drawing firm conclusions, we ran a second experiment to address an alternative interpretation of the results from Experiment 1.

EXPERIMENT 2

It was possible that the CFrench infants in Experiment 1 were simply extracting the more prominent, stressed syllable and not segmenting the whole bi-syllabic unit. If this is the case, we cannot conclude that CFrench-learning infants are segmenting bi-syllabic words at the same age as their CEnglish-learning peers. Jusczyk, Houston, et al. (1999) also questioned whether their English-learning 8-month-olds were simply tracking the stressed (initial) syllable when tested on segmentation of trochaic bi-syllabic words. To address this issue they familiarized English infants with just the stressed (initial) syllable of the bi-syllabic words and then tested them using the same passages (containing the bi-syllabic words). They reasoned that if infants' success in the whole word condition was due to tracking only the stressed syllable, then infants will show the same performance when familiarized with just the stressed syllable and tested with passages containing the bi-syllabic words. However, English infants failed to segment when familiarized with stressed syllable only, confirming that infants were extracting a bi-syllabic unit in the whole word condition. However, a different outcome emerged when Jusczyk, Houston, et al. applied this same strategy to explore English infants' segmentation of bi-syllabic words with iambic stress (stress on second syllable). English 8-month-olds failed to show segmentation when tested with the whole bi-syllabic iambic word but they succeeded when tested on segmentation of just the stressed (final) syllable from an iambic word. This outcome, along with other findings, showed that English infants use stress patterns to find word onsets in the speech stream. Recent electrophysiological study by Kooijman, Hagoort, and Cutler (2009) shows a similar segmentation strategy in infants acquiring Dutch, also a stress-timed language. Moreover, as outlined above, Nazzi et al. (2006) uncovered a different segmentation pattern in French-learning infants using a similar testing scheme.

In Experiment 2, we implemented the Jusczyk, Houston, et al. test protocol to assess whether CFrench-learning infants are simply tracking the stressed syllable in the bi-syllabic word condition (Experiment 1). Accordingly, we tested CFrench babies on their ability to segment the stressed syllable alone. CFrench infants were first familiarized with just the second, stressed syllable (e.g., [vi] and [tar] or [re] and [pris]) and then presented the same four test passages (containing the two-syllable words) as in Experiment 1. If CFrench infants are simply segmenting the stressed syllable instead of the whole bi-syllablic word, they should show the same pattern observed in Experiment 1 and listen longer to the familiar compared to novel passages. However, if CFrench-learning infants are indeed segmenting the two-syllable words and not just the more prominent, second syllable, they were expected to fail in the stressed-syllable only condition.[2]

Methods

Participants

Twenty four infants (12 boys and 12 girls) from CFrench-speaking families between the ages of 7 months 26 days and 8 months 17 days (*M* age = 8 months 3 days; *SD* = 6 days) were tested. Recruitment and subject inclusion criteria were the same as in Experiment 1. Nine additional infants were tested but their data were not analyzed due to fussiness ($n = 5$), very short looks during test trials, that is, looking time to at least one passage under 3 sec ($n = 3$), or segmentation index (test minus control) more than 2 *SD*s above or below the group average ($n = 1$).

Stimuli

Productions of the isolated second syllables in list form were recorded by the same CFrench talker as in Experiment 1; these materials were included in the initial recording session described in Experiment 1. Each list of

[2]In Experiments 2 and 3, we explored single syllable segmentation by CFrench-learning infants to assess potential cross-language differences in the emergence of word segmentation in French and English. We assume that the previous findings with respect to stressed syllable segmentation in American-English learning infants tested by Jusczyk, Houston, et al. (1999) will generalize to CEnglish-learning infants.

syllables produced in isolation ([pris] from “surprise,” [vi] from “devis,” [ta] from “guitare,” and [re] from “beret”) contained 18–21 tokens; the average list duration was 20.9 sec (range = 19.3–23 sec). The acoustic properties of the isolated second syllables productions were similar to values measured for the bi-syllabic list words (shown in Table 3) with a mean duration of 490 msec (SD = 126), mean intensity of 73.7 dB (SD = 5.1), and mean f0 of 250 Hz (SD = 74).

Procedure

Same as in Experiment 1.

Design

Same as in Experiment 1, except that CFrench infants were familiarized with just the second syllable, [vi] and [ta] or [re] and [pris] and then tested on the CFrench passages.

Results and discussion

The total familiarization times were not significantly different for infants tested in the two familiarization conditions ([vi]/[ta] versus [re]/[pris]), $t(22) = 0.8$, $p = .4$. Average looking times (SE) for CFrench infants tested on the stressed, second syllable only are presented on the left in Figure 2. Surprisingly, most infants (15 out of 24) listened longer to the novel compared the familiar passages, a pattern opposite of the one

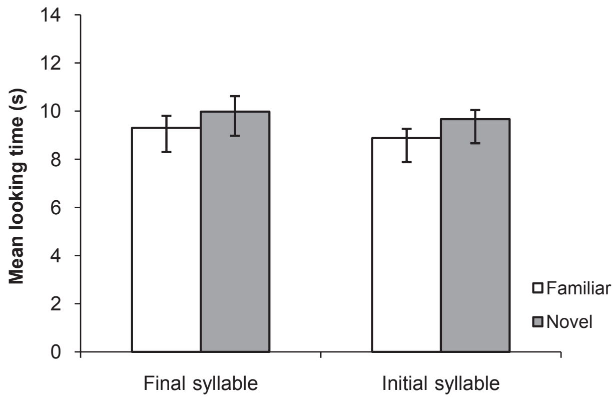

Figure 2 CFrench segmentation of syllables.

observed in Experiment 1. This trend was also evident in the group data; average listening time was 9.98 sec (SD = 3.2) for the novel passage and 9.3 sec (SD = 2.5 sec) for the familiar passage. This difference approached statistical significance, $t(23) = -1.77$, $p = .089$, $d = -0.23$. Thus, when tested on segmentation of the stressed syllable alone, CFrench-learning 8-month-olds did not show the pattern that was observed when tested on the full word. These divergent patterns indicate that CFrench infants tested in the whole word condition (Experiment 1) were not simply tracking the more prominent, stressed, second syllable. Nevertheless, the novelty preference trend observed here suggests that CFrench may have some ability to track just the stressed syllable when the task focuses their attention on this unit.

EXPERIMENT 3

Findings of Experiments 1 and 2 confirm that CFrench 8-month-olds can segment bi-syllabic iambic words and may also retain some ability to track the stressed syllable. The later finding is consistent with Nazzi et al.'s (2006) hypothesis that French-learning infants use a syllable-based segmentation strategy. To further test this claim, we tested whether CFrench infants were also able to segment the initial syllable of the bi-syllabic words used in Experiment 1. If CFrench infants can both track syllabic units and extract bi-syllabic word forms, we would expect to find the same pattern observed in Experiment 2 in which CFrench-learning 8-month-olds were tested on segmentation of the final stressed syllable alone. Specifically, following familiarization with just the initial syllable (of the bi-syllabic word), we expected the infants to listen longer to the passages containing a novel bi-syllabic word.

In word segmentation, tasks conducted using the HPP with natural speech infants typically demonstrate successful segmentation by listening significantly longer to the familiar passages compared to the novel passages. However, a novelty preference pattern is often observed when infants are familiarized with AL materials (involving simpler, more controlled stimuli and longer exposure periods) and then tested with short sequences that occurred (familiar) or did not occur (novel) in AL (e.g., Saffran, Aslin, et al., 1996). Because a novelty preference was unexpected in the present test paradigm it is informative to re-examine CFrench infant's ability to track the component syllables of the bi-syllabic word. A replication of the novelty preference observed in Experiment 2 would indicate that this pattern can also reveal segmentation in the HPP paradigm and is not simply a spurious outcome.

Methods

Participants

Twenty four infants (12 boys and 12 girls) from CFrench-speaking families between the ages of 7 months 23 days and 8 months 13 days (*M* age = 8 months 3 days; *SD* = 6.5 days) were tested. Recruitment and subject inclusion criteria were the same as in Experiment 1. Eight additional infants were tested but their data were not analyzed due to fussiness ($n = 5$), very short looks during test trials, that is, looking time to at least one passage under 3 sec ($n = 1$), technical problems ($n = 1$), or segmentation index (test minus control) more than 2 *SD*s above or below the group average ($n = 1$).

Stimuli

Using the CFrench word lists from Experiment 1, we deleted the second stressed syllable from each word, leaving only the initial syllable of each CFrench word.[3] Thus, in the edited lists [sur] was retained from ‘‘surprise,’’ [de] from ‘‘devis,’’ [gi] from ‘‘guitare,’’ and [be] from ‘‘beret’’. These edited lists were used for familiarization in Experiment 3; each list was 13 sec in duration. As the syllables were excised from list words used in Experiment 1, the number of productions per list is identical to the CFrench word lists (in Table 2) and the acoustic properties of the syllables are identical to the values reported for the first syllable of the CF list words in Table 3.

Procedure

Same as in Experiment 1.

Design

Same as in Experiment 1, except that CFrench infants were familiarized with just the initial syllable, [de] and [gi] or [be] and [sur] and then tested on the CFrench passages.

Results and discussion

The total familiarization times were not significantly different for infants tested in the two familiarization conditions ([de]/[gi] versus [be]/[sur]), $t(22) = 0.26$, $p = .8$. Average looking times (*SE*) for CFrench infants tested

[3]We edited the word list because the initial syllable alone had not been recorded and it was not possible to make another recording with the same speaker.

on the initial syllable alone are presented on the right in Figure 2. As in Experiment 2, most of the infants (20 out of 24) listened longer to the novel compared the familiar passages, replicating the pattern observed in Experiment 2 (final syllable) but showing the opposite of the pattern observed in Experiment 1 (full word). This pattern was also reflected in the average listening times. In this condition, CFrench-learning infants listened significantly longer to the novel passages ($M = 9.7$ sec; $SD = 1.9$ sec) compared to the familiar passages ($M = 8.9$ sec; $SD = 1.9$ sec), $t(23) = -2.6, p = .02, d = -0.42$.

Next, we analyzed the results from CFrench infants tested with whole words (Experiment 1), final syllables (Experiment 2), and initial syllables (Experiment 3) together in an ANOVA with Condition (whole word versus initial syllable versus final syllable) as a between-subjects factor and Passage Type (familiar versus novel) as a within-subjects factor. Only the interaction of Condition and Passage Type was significant, $F(2, 61) = 10.7, p < .001$, partial $\eta^2 = 0.26$. The main effect of Condition was not significant, $F(1, 61) = 0.46, p = .6$, partial $\eta^2 = 0.02$, neither was the main effect of Passage Type, $F(1, 61) = 0.001, p = .9$, partial $\eta^2 = 0$.

The interaction between Condition and Passage Type was due to a greater listening time to the novel compared to the familiar passages in final syllable and initial syllable conditions, a pattern opposite of the one observed in whole word condition. This was confirmed when separate Condition × Passage Type ANOVAs were conducted comparing final and whole word conditions and comparing initial and whole word conditions. Both ANOVAs showed a significant Condition × Passage Type interaction—for the final versus whole word experiment, $F(1, 38) = 14.9$, $p < .001$, partial $\eta^2 = 0.28$; and for the initial versus whole word experiment, $F(1, 38) = 22.2, p < .001$, partial $\eta^2 = 0.37$. Main effects of Condition and Passage Type were not significant in either ANOVA.

Overall, the diverging response patterns observed across the whole word and syllable conditions confirm that CFrench-learning 8-month-olds are indeed able to segment bi-syllabic words from fluent speech and do not succeed in this task by simply tracking just one of the constituent syllables. Thus, both CEnglish- and CFrench-learning infants can segment two-syllable words at 8 months of age. This outcome for CEnglish-learning infants' replicates and extends findings reported by Jusczyk, Houston, et al. (1999) with American English-learning infants. The parallel findings for CFrench and CEnglish infants indicate that word segmentation skills are acquired on roughly the same schedule across these rhythmically different languages. Our findings also show that the later emergence of bi-syllabic word segmentation in Nazzi et al. (2006) is related to methodological factors or to language-specific properties of EFrench. The findings across Experiments 1, 2, and 3 also suggest that in addition to segmenting bi-syllabic words, CFrench-learning 8-month-olds retain some ability to track the component syllables of an iambic bi-syllabic word,[4] at least when infant attention is focused on just one of the syllables in the familiarization stage of the task.

EXPERIMENT 4

The findings across Experiments 1, 2, and 3 failed to reveal any cross-linguistic differences with respect to the age at which infants acquiring CFrench and CEnglish segment bi-syllabic words. In Experiment 4, we investigated effects of language experience on early word segmentation. Previous cross-linguistic studies suggest that prosody has a strong influence in early word segmentation. Consistent with this view, several studies show that infants can segment in an unfamiliar language so long as the rhythm of the language or the prosody of the target words is consistent across languages. The presence of phonetic mismatches with the native language does not block segmentation in this context (Houston et al., 2000; Pelucchi et al., 2009). If this view is correct, segmentation should be successful across different dialects of the same language, given that dialects typically share the same basic rhythmic structure and prosodic patterning of words. However, the unresolved age differences in word segmentation between CFrench findings (Experiments 1, 2, and 3) and Nazzi et al.'s (2006) EFrench findings show that dialect-specific segmentation cannot be readily dismissed.

We addressed these issues in Experiment 4 by assessing whether infant word segmentation is dialect specific. To do so, we tested CFrench-learning 8-month-olds on their ability to segment EFrench. On the phonetic level, French dialects of France and Canada differ with respect to vowels, with CFrench containing more vowel variation. Unlike dialects of France, in CFrench lax vowels occur allophonically and vowels are produced with diphthongization (Picard, 1987). On the prosodic level, comparative analyses show that CFrench has more variable intonation compared to dialects of France; perceptual tests show that these intonation differences can support identification of regional dialect (Quebec versus France) in francophone adults who are not trained in phonetics (Menard, Ouellon, & Dolbec, 1999).

If early word segmentation is guided by global native language prosody—either at the rhythmic level or word-level—we expected CFrench infants to succeed when tested with EFrench speech material. However, if age differences in segmenting EFrench (Nazzi et al., 2006) and CFrench

[4]Note that the sample size in Experiments 2 and 3 ($n = 24$) is larger than in Experiment 1 ($n = 16$). Thus, the novelty preferences observed in Experiments 2 and 3 are smaller than the familiarity preferences observed in Experiment 1.

(Experiments 1, 2, and 3) are due to European French being more challenging to segment, then global prosodic similarities may not be enough to support segmentation in this dialect. In this case, CFrench infants should fail to segment two-syllable words in EFrench.

Methods

Participants

Sixteen infants (eight boys; eight girls) between the ages of 7 months 14 days and 8 months 14 days from CFrench-speaking families were tested. The mean age was 7 months 27 days ($SD = 11$ days). Recruitment and subject inclusion criteria were the same as that in Experiment 1. Ten additional babies were tested but their data were not analyzed due to fussiness ($n = 1$) and very short looks during test trials ($n = 9$).

Stimuli

The four French passages and target word lists used in Experiment 1 were recorded as they were produced by a female native speaker of EFrench (from Lyon). The speaker was a mother with one young daughter and was accustomed to speaking in a child-directed fashion. Following the recording protocol used in Experiment 1, we recorded her first producing a set of passages, and then repetitions of each target word. She was instructed to read the passages and repeat the words as if she was speaking to a child. She practiced reading the passages several times before making the recording. Filler passages were included in the recording materials.

The four target passages and word lists were extracted from the recording. Mean durations and number of words in EFrench passages and lists are reported in Table 2 (right column). Acoustic measures, duration, amplitude, and pitch were obtained for each syllable of each target word token produced in the EFrench dialect. Mean values for these words in passages and lists are shown in Table 3. For each measure, the acoustic values for the EFrench tokens are presented on the far right. To compare the two dialects of French we conducted a Dialect (CFrench versus EFrench) by Syllable (1 versus 2) ANOVA for each acoustic measure. Separate ANOVAs were conducted for the tokens produced in the passages and in the lists. Simple effects of Syllable (in each Dialect) were analyzed for each set of measures to evaluate potential cues to word stress.

Analysis of duration measures for the passage words revealed a significant main effect of Dialect, $F(1, 46) = 17.31$, $p < .0001$, partial $\eta^2 = 0.273$, indicating that CFrench words were longer than EFrench words. In other words, the EFrench stimuli were produced at a faster rate of speech. There was also a significant main effect of Syllable, $F(1, 46) = 49.7$, $p < .0001$, partial $\eta^2 = 0.519$, but no Dialect by Syllable interaction, $F(1, 46) = 0.20$, $p = .888$, partial $\eta^2 = 0.00$. Simple effects analyses of Syllable confirmed that Syllable 2 was longer than Syllable 1 in both dialects—CFrench, $t(23) = 5.61$, $p < .0001$, $d = 1.57$, and EFrench, $t(23) = 4.6$, $p < .0001$, $d = 1.38$. The same pattern of results was found in the analysis of duration for words produced in the list format. A t test comparing the magnitude of the syllable duration difference (Syllable 1 minus Syllable 2) showed no reliable differences in size of the duration cue across dialects for either passage or list words.

Amplitude and pitch differences across syllables were present in both dialects but were inconsistent. As seen in Table 3, in CFrench amplitude was higher on Syllable 2 only in list words, $t(55) = 2.13$, $p = .038$, $d = 0.41$. In EFrench, amplitude was higher on Syllable 1 for both passage, $t(23) = 5.20$, $p < .0001$, $d = 0.66$, and list words, $t(59) = 10.15$, $p < .0001$, $d = -0.94$; note, this pattern is inconsistent with syllable-final word stress expected for French words in isolation. Further, in CFrench, pitch was higher on Syllable 2 but only for lists words, $t(55) = -2.04$, $p = .046$, $d = -0.35$, whereas in EFrench there were no pitch differences across syllables.

Overall, EFrench words were shorter than CFrench words and had more consistent stress cues across the passage words and list words. For the CFrench stimuli, only the duration cue was reliable for the passage words while all three cues were reliable for the list words. For the EFrench words, duration cues were reliable in the passage and the list words whereas the amplitude and pitch cue were not reliable in either context.

Procedure

Same as in Experiment 1.

Design

Same as in Experiment 1.

Results and discussion

The total familiarization times were not significantly different for infants in the two familiarization conditions (devis/guitare versus beret/surprise), $t(14) = 2.0$, $p = .06$. Average looking times (*SE*) for CFrench infants tested on the EFrench speech material are plotted in Figure 3. Eleven out of 16 infants tested showed the pattern (familiar > novel) expected if segmentation

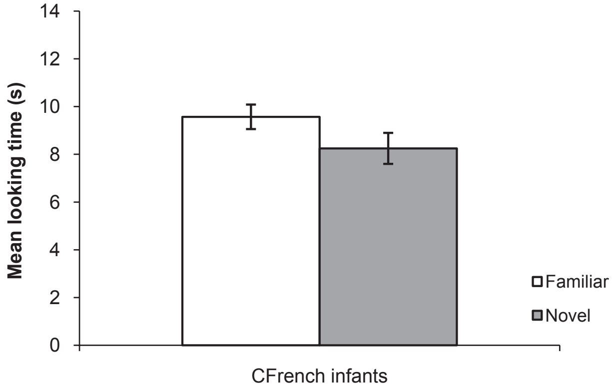

Figure 3 Cross-dialect–European French segmentation.

is successful. Listening time on test trials was analyzed in a paired *t* test with Passage Type (familiar versus novel) as a within-subjects factor. CFrench infants looked significantly longer at the familiar passages ($M = 9.6$ sec; $SD = 2.1$ sec) compared to the novel passages ($M = 8.3$ sec; $SD = 2.6$ sec), $t(15) = 2.6, p = .02, d = 0.55$.

To directly compare CFrench infants tested on each dialect of French, we also conducted a two-way ANOVA with Dialect (CFrench–Experiment 1 versus EFrench–Experiment 4) as a between-subjects factor and Passage Type (familiar versus novel) as a within-subjects factor. Only the main effect of Passage Type was significant, $F(1, 30) = 20.2$, $p < .001$, partial $\eta^2 = 0.40$. Overall, the results of Experiment 4 showed that infants acquiring CFrench can also segment words in EFrench.

The successful segmentation of EFrench was even more remarkable given that the rate of speech for the EFrench stimuli (mean duration of target word 432 msec in passages; 530 msec in lists) was faster when compared to the rate of speech of the CFrench stimuli (mean duration of target word 578 msec in passages, and 742 msec in lists) used in Experiment 1. Thus, for CFrench learning infants, EFrench is not more challenging to segment that CFrench. There are common prosodic cues that CFrench infants can exploit effectively within their native language rhythm-class. This outcome provides further support for the role of native language prosody in early word segmentation.

EXPERIMENT 5

As a next step in exploring the role of language experience on early word segmentation, we examined infant word segmentation in a rhythmically different nonnative language. Specifically, we were interested in whether CFrench infants could segment two-syllable words in CEnglish, and vice versa. If familiarity with neither the native language rhythm nor word stress pattern plays a strong role in early word segmentation, we would expect both language groups to succeed in these cross-language segmentation tests. This outcome suggests that infant word segmentation relies on general speech/auditory processing mechanisms or skills that can be adapted to segment novel speech streams. In this case, the ability to segment word forms from naturalistic samples of connected speech is not narrowly restricted to the native language or the native rhythm class.

However, if early word segmentation skills are not broad based but depend on some biases or patterns acquired from experience processing the native language (for a review, see Cutler, 1994), then we expected both language groups to fail the cross-language segmentation task. This outcome would show that infants cannot rapidly adapt their early word segmentation abilities to any novel language. Consistent with earlier studies, infants may require some match between the novel speech stream and their native language properties, minimally a match in word-level prosody.

Methods

Participants

Thirty-two infants between the ages of 7 months 5 days and 8 months 15 days, 16 CFrench-learning and 16 CEnglish-learning, were tested on segmentation of two-syllable words in the nonnative language. Recruitment and language background screening for the infants were exactly the same as has been described in Experiment 1. The CFrench infants (15 boys and one girl) had a mean age of 7 months 26 days (SD = 11 days); the CEnglish infants (nine boys and seven girls) had a mean age of 8 months 0 days (SD = 11 days). Four additional babies were tested but their data were not analyzed due to very short looks during test trials, that is, looking time to at least one passage under 3 sec.

Stimuli

Same as in Experiment 1.

Procedure

Same as in Experiment 1.

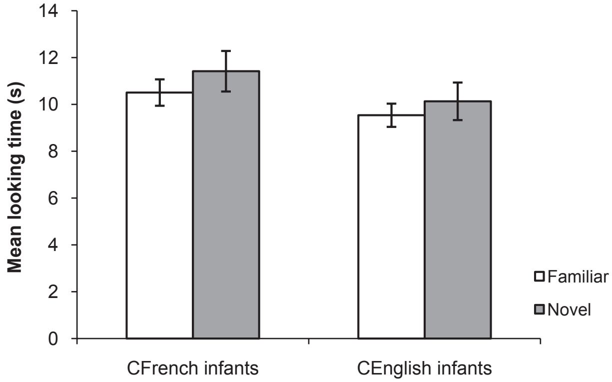

Figure 4 Cross-language segmentation.

Design

Same as in Experiment 1, except that CFrench infants were familiarized and tested on the CEnglish stimuli, and the CEnglish infants were familiarized and tested on the CFrench stimuli.

Results and discussion

Recall that all infants were familiarized with two word lists until they had heard each of the word lists for at least 30 sec. For the CFrench infants, there was no significant difference when familiarization times were analyzed using an independent sample *t* test with Familiarization Condition (doctor/candle versus hamlet/kingdom) as a between-subjects factor, $t(13) = -1.5$, $p = .15$.[5] For CEnglish infants, there was a marginally significant difference when familiarization times were analyzed using an independent sample *t* test with Familiarization Condition (devis/guitare versus beret/surprise) as a between-subjects factor, $t(14) = 2.1$, $p = .05$. This was due to higher familiarization times for three CEnglish infants who heard the French words "devis" and "guitare" during the familiarization stage. Given that CEnglish infants failed to segment the CFrench stimuli (see below) this longer familiarization did not facilitate performance in the test stage of the task. Thus, it is not discussed further.

Average looking times (*SE*) for 8-month-olds tested on the nonnative stimuli are shown in Figure 4. These values are reported separately for CFrench

[5]The familiarization time data was not available for one infant, thus only 15 infants are included in this analysis.

and CEnglish infants. Six out of 16 CFrench infants and seven out of 16 CEnglish infants listened longer to familiar compared to novel passages. Listening time was analyzed in a mixed model ANOVA with Group (CFrench versus CEnglish) as a between-subjects factor and Passage Type (familiar versus novel) as a within-subjects factor. Neither the main effect of Group, $F(1, 30) = 2.0, p = .17$, partial $\eta^2 = 0.06$, the main effect of Passage Type, $F(1, 30) = 1.7, p = .2$, partial $\eta^2 = 0.05$, nor the Group × Passage Type interaction, $F(1, 30) = 0.07, p = .8$, partial $\eta^2 = 0.002$, was significant.

Next, paired *t* tests were conducted separately for each group to confirm that CFrench and CEnglish infants failed to segment two-syllable words. For the CFrench infants, there was no reliable difference in listening times to the familiar ($M = 9.5$ sec; $SD = 2.0$ sec) and the novel passages ($M = 10.1$ sec; $SD = 3.2$ sec), $t(15) = -0.77, p = .45$. Likewise, for the CEnglish infants as well there was no reliable difference in listening times to the familiar ($M = 10.5$ sec; $SD = 2.3$ sec) and the novel passages ($M = 11.4$ sec; $SD = 3.5$ sec), $t(15) = -1.1, p = .31$. Thus, the CFrench as well as CEnglish infants failed to segment two-syllable words cross-linguistically.

To confirm the success in segmentation with native language stimuli and failure with nonnative language stimuli, we also analyzed the data from Experiments 1 and 5 in a three-way ANOVA with Group (CFrench versus CEnglish) and Stimuli (Native versus Nonnative) as between-subjects factors and Passage Type (familiar versus novel) as a within-subjects factor. Only the two-way interaction of Stimuli × Passage Type was significant, $F(1, 60) = 11.2, p = .001$, partial $\eta^2 = 0.16$. Next, a two-way ANOVA with Stimuli (Native versus Cross-language) as between-subjects factor and Passage Type (familiar versus novel) as a within-subjects factor was conducted for CFrench and CEnglish infants separately. For the CFrench-learning infants, only the interaction of Stimuli × Passage Type was significant, $F(1, 30) = 5.8, p = .02$, partial $\eta^2 = 0.16$. For the CEnglish-learning infants as well, only the interaction of Stimuli × Passage Type was significant, $F(1, 30) = 5.6, p = .02$, partial $\eta^2 = 0.16$. In both ANOVAs, the Stimuli × Passage Type interaction was due to the infants' success at segmenting native but not nonnative stimuli.

The failure in both language groups when tested with the nonnative stimuli confirms that infants rely on language-specific biases in their early word segmentation. The application of general processing schema to the acoustic stream is not sufficient to support word segmentation in natural speech utterances. Rather, by 8 months, word segmentation is already influenced by language experience. This specificity is apparent when infants face segmentation of word forms with a nonnative prosodic profile, in a rhythmically different language.

In earlier research, infants succeeded in cross-language segmentation task so long as the target words conformed to the typical, native language word stress pattern (Houston et al., 2000; Pelucchi et al., 2009). In our cross-language test conditions, both the rhythmic structure of the speech stream and the prosodic pattern of the target words were unfamiliar to the infant. In Jusczyk, Houston, et al. (1999), English-learning 8-month-olds failed to segment iambic words in English; this suggests that at this age infants cannot easily locate words with a less frequent stress pattern even in a familiar speech rhythm. Thus, familiarity with the prosodic structure of the word form appears to be an important element supporting early word segmentation. Overall, these findings show that infants, like adults, exploit the regularities of their native language in order to successfully segment words in natural speech.

GENERAL DISCUSSION

The present study was conducted to understand how infants segment word forms in natural speech utterances and the factors that shape the initial emergence of this skill in infancy, with a special focus on infants learning a syllable-timed language, CFrench. We conducted five experiments using natural speech stimuli to address two issues concerning the impact of language experience on word segmentation. First, are there systematic differences in the age at which word segmentation skills begin to emerge for infants acquiring languages in different rhythm classes? In Experiments 1, 2, and 3, we show that 8-month-olds acquiring either CFrench or CEnglish can segment bi-syllable words in their native language. Thus, we failed to find age differences in infants' ability to segment two-syllable words related to language rhythm class.

Our findings with CFrench infants demonstrate successful segmentation in a syllable-timed language within the first year of life. This finding is inconsistent with data reported by Nazzi et al. (2006) on infants acquiring EFrench. EFrench infants tested by Nazzi et al. segmented monosyllabic units only at 12 months; segmentation of bi-syllabic words emerged between 12 and 16 months. In contrast, we demonstrate that CFrench-learning infants successfully segment bi-syllabic words in CFrench and EFrench at 8 months.

There are three possible reasons for these discrepant findings. First, Nazzi et al. (2006) used adult-directed speech stimuli, whereas the stimuli used in our experiments were child directed. Cross-linguistically, there is evidence that child-directed speech is slower, has shorter utterances with more frequent pauses, and is exaggerated at the prosodic and phonetic level

(Burnham, Kitamura, & Vollmer-Conna, 2002; Fernald, 1992; Fernald & Mazzie, 1991; Fernald & Simon, 1984; Kuhl et al., 1997). Consistent with the differences between adult- and child-directed speech, the speaking rate for the EFrench stimuli (passages) used in Nazzi et al. (2006) was faster (~4.76 syllables per sec) than our EFrench stimuli (~3.0 syllables per sec). Research indicates that due to its prosodic properties, infants prefer child-directed speech to adult-directed speech (Cooper & Aslin, 1994; Fernald & Kuhl, 1987). Further, infants' are able to recognize a word 24 h after being exposed to it, when the words are introduced in child-directed speech but not when produced in adult-directed speech (Singh, Nestor, Parikh, & Yull, 2009). More directly, there is evidence using AL paradigms that infants are successful at segmenting words after hearing child-directed speech, but not adult-directed speech (Thiessen, Hill, & Saffran, 2005).

Second, there were also task differences in the implementation of the HPP procedure used to test segmentation in our study compared to Nazzi et al. (2006). Following the original segmentation studies with English-learning 8-month-olds by Jusczyk, Houston, et al. (1999), we familiarized infants with word lists for 30 sec; Nazzi et al. used a shorter familiarization period of 20 sec. Although the number of target word repetitions during familiarization was similar in the Nazzi et al. study and our study, the target words were produced at a slower speaking rate in our study. These task differences may also have made word segmentation more challenging for the EFrench infants tested in the Nazzi et al. study.

Finally, Canadian and European dialects of French differ in their prosodic and phonetic properties; thus, it is also possible that experience with each dialect may lead infants to weight segmentation cues differently so that segmentation abilities in infants learning different dialects does not emerge at the same time in development. Further cross-dialect experiments are needed to explain these age differences that have emerged across labs. Regardless of the reasons for the discrepancy, the performance of CFrench infants in the present study shows that segmentation in syllable-timed languages is not inherently more difficult than segmentation in stress-timed languages.

The second issue tackled in the present study concerns the role of language experience in shaping infant word segmentation. Do infants exploit their familiarity with their native language in word segmentation or are they relying on more general speech or auditory processing skills that are not language specific? Cross-dialect and cross-language comparisons were conducted to address this issue. These findings indicate that early word segmentation abilities are shaped by language experience. Our cross-dialect findings (Experiment 4) show that segmentation skills acquired by CFrench infants can be transferred to a rhythmically similar dialect of French while our cross-language findings (Experiment 5) show that segmentation skills acquired by 8 months of age cannot be applied to a rhythmically different language. These findings are consistent with Jusczyk, Houston, et al.'s (1999) rhythm hypothesis suggesting that segmentation skills can be readily transferred to rhythmically similar but not rhythmically different languages.

However, Pelucchi et al.'s (2009) results show that 8-month-olds learning English, a stress-timed language, were able to segment trochees in Italian, a syllable-timed language. These findings are clearly inconsistent with the rhythm hypothesis. In fact, their data show that with just short-term exposure, English-learning infants are able to segment bi-syllabic trochees in another language regardless of its phonetic, phonotactic, and most importantly, rhythmic difference from the infants' native language. Based on Pelucchi et al.'s results, it appears that infants are able to segment words even in a rhythmically different language provided the words have the prosodic structure that is most prominent in their native language. Our present findings are also consistent with this idea. In other words, CFrench infants are able to segment bi-syllabic words in EFrench because bi-syllabic words in both languages have a weak-strong pattern; CFrench infants fail to segment bi-syllabic trochaic words in CEnglish because these word forms have an unfamiliar strong-weak stress pattern. Future research is needed to adjudicate between Jusczyk, Houston, et al.'s (1999) rhythm hypothesis and the word-level prosodic mismatch hypothesis that emerges from Pelucchi et al.'s data.

The present study was undertaken to examine the extent to which infants exploit language-specific cues for segmentation and was not designed to identify *how* infants segment in their native language. Nevertheless, findings from Experiments 2 and 3 are informative with respect to the segmentation behavior of French infants. First, there are some parallels between our syllable and whole word findings and segmentation results reported by Nazzi et al. (2006). Recall, they found that EFrench-learning 12-month-olds could not segment a whole bi-syllabic word. However, EFrench 12-month-olds could segment the final syllable of the bi-syllabic word and could also segment the initial syllable when familiarized with the syllables that acoustically match the initial syllables in the passage words. In their EFrench infants, segmentation of the whole bi-syllabic word form was observed later (in 16-month-olds) but at this age infants no longer showed segmentation of the component syllables.

Putting aside the age differences between the present study and Nazzi et al. (2006), French infants in both studies show some ability to segment the component syllables of a bi-syllabic word. In Nazzi et al., the evidence for final syllable segmentation is stronger than the evidence for initial syllables segmentation. In the present study, the evidence for initial syllable segmentation is a stronger than evidence for final syllable segmentation. These differences in two studies are likely due to variation in how well the isolated syllables (used in the familiarization) match the acoustic/phonetic properties of the syllables in the passage words. This was evident in the Nazzi et al. study where infants could segment the initial syllable when familiarized with syllables that precisely matched (were spliced from) the passage words but failed when familiarized with syllables that were similar, but distinct isolated productions of the initial syllable. In the present study, it is difficult to gauge the acoustic similarity between the isolated syllables and the passage words since these natural syllables vary on multiple dimensions. Clearly, neither the initial, nor the final syllables presented during familiarization were an exact acoustic match to the passage syllables. However, it is likely that the initial syllables more closely matched the passage words because the initial syllables presented in familiarization were excised from a bi-syllabic word (rather than produced as isolated monosyllables) and thus contained the same prosodic and co-articulatory properties as the bi-syllabic words in the passage. In contrast, the final syllables were produced as isolated monosyllables and thus lacked the prosodic and co-articulatory cues found in the whole words occurring in the test passages.

It is also relevant to compare our findings with results obtained when English-learning infants were tested in similar conditions. Recall that in Jusczyk, Houston, et al. (1999), English-learning 8-month-olds were unsuccessful in segmenting iambic bi-syllabic words, but succeeded (showing the typical familiarity preference) when they were familiarized with just the stressed (final) syllable. However, English 8-month-olds were successful in segmenting trochaic bi-syllabic words, yet they failed when familiarized with just the stressed (initial) syllable from the trochaic word. These results, along with other findings, uncovered a segmentation strategy built around stress patterns. Specifically English 8-month-olds treat a stressed syllable as a word onset and display a bias to track trochaic units.

In the present study, CFrench 8-month-olds appear to segment each isolated syllable (the initial and, to some extent, the final) as well as a full iambic word, and show different listening preference patterns across syllable and word conditions. Thus, CFrench-learning 8-month-olds appear to retain some ability to track each syllable, along with segmenting the whole bi-syllabic word. A recent electrophysiological study by Goyet et al. (2010) shows this same pattern in EFrench-learning 12-month-olds. These findings may be pointing to a latent ability to track syllables (without regard to stress cues) in CFrench infants. However, this claim requires further investigation using behavioral and event-related brain potential measures with infants acquiring French and other syllable-timed languages.

It is important to note that the current evidence suggesting that French infants track both syllables and whole bi-syllabic words is based on tasks in which infants are first familiarized with a specific unit in isolation before testing them with passages of connected speech. It is not known whether French infants show the same segmentation patterns when they encounter connected speech, which characterizes much of their natural language input. Thus, research is needed to establish whether French infants spontaneously apply a syllable-based segmentation strategy in tasks that make no attempt to bias them to attend to a specific unit. Thus, an important next step is to familiarize infants with connected speech and assess their ability to segment out syllables versus bi-syllabic words.

Further research using more controlled language materials is also needed to establish the precise acoustic cues that support word segmentation in infants acquiring English or French, or other rhythmically different languages. The natural language approach, as implemented in the current study, typically relies on more complex natural speech materials and involves shorter exposure periods (and less target word repetition) than studies using ALs. Natural speech studies show us what infants are likely to do when they encounter speech in their everyday world, and what information they can readily access and use with the processing skills and biases they have acquired. Studies using this approach have identified a range of cues that support word segmentation in English-learning infants. These include, the use of familiar words at 6- (Bortfeld, Morgan, Golinkoff, & Rathbun, 2005) or 11-months (Shi, Cutler, Werker, and Cruickshank, 2006), prosodic boundaries as early as 7.5 months (Gout, Christophe, & Morgan, 2004; Seidl & Johnson, 2006), co-articulatory cues at 8 months (Johnson & Jusczyk, 2001), allophonic information between 8 and 10.5 months (Jusczyk, Hohne, & Bauman, 1999; Mattys & Jusczyk, 2001a), phonotactic information at 9 months (Mattys & Jusczyk, 2001b; Mattys, Jusczyk, Luce, & Morgan, 1999), and possibly pitch accent, lexical class, as well as the initial phoneme of the word to be segmented between 13 and 16 months (Nazzi, Dilley, Jusczyk, Shattuck-Hufnagel, & Jusczyk, 2005). Although natural speech studies can tap into processes that unfold in realistic speech communication contexts, the stimuli are typically less well controlled compared to AL studies making it difficult to determine what cues infants extract from the speech stream to support segmentation.

Studies using ALs not only have the potential to tell us what cues infants can extract from connected speech streams, but are also useful to test hypotheses about how infants may be integrating different types of word segmentation cues. However, it is unclear how far we can generalize from AL studies to more natural speech communication contexts. Some attempts to increase the complexity of AL materials have failed to show that these tasks can scale up to the complexity of natural language (Johnson & Tyler, 2010). Other studies have shown that statistical learning mechanisms identified using the AL method can be demonstrated with more complex and naturalistic materials (Pelucchi et al., 2009). Hybrid methods, similar to Pelucchi et al. (2009), that retain the richness of natural speech, but control critical stimulus elements, are needed to leverage the strengths of the artificial and natural language approaches.

In summary, the present study confirms that when infants are tested using natural samples of child-directed speech, native language word segmentation skills emerge around 8 months of age in infants acquiring a stress-timed (CEnglish) or a syllable-timed (CFrench) language. However, 8-month-olds who are acquiring CEnglish and CFrench do not segment speech in the same way; each depends on language-specific information to extract word forms from connected speech. Infants, like adults, rely on their familiarity with the native language—either with its rhythm structure or with the prosodic patterning of words—to perform rapid online word segmentation in natural speech.

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