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Segmenting words from fluent speech during infancy – challenges and opportunities in a bilingual context

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- A new dual-language task is used to assess infant word segmentation in two languages (French; English) within a single test session.
- Findings with the new task confirm that monolingual 8-month-olds acquiring either French or English segment bi-syllabic words in their native language, but not in a rhythmically-different language.
- For bilingual 8-month-olds acquiring French and English, segmenting words in both their native languages in the dual-language task poses a distinct challenge, providing a unique window into their word segmentation skills.

Abstract

Previous research shows that word segmentation is a language-specific skill. Here, we tested segmentation of bi-syllabic words in two languages (French; English) within the same infants in a single test session. In Experiment 1, monolingual 8-month-olds (French; English) segmented bi-syllabic words in their native language, but not in an unfamiliar and rhythmically-different language. In Experiment 2, bilingual infants acquiring French and English demonstrated successful segmentation for French when it was tested first, but not for English and not for either language when tested second. There were no effects of language exposure on this pattern of findings. In Experiment 3, bilingual infants segmented the same English materials used in Experiment 2 when they were tested using the standard segmentation procedure, which provides more exposure to the test language. These findings show that segmenting words in both their native languages in the dual-language task poses a distinct challenge for bilingual 8-month-olds acquiring French and English. Further research exploring early word segmentation will advance our understanding of bilingual acquisition and expand our fundamental knowledge of language and cognitive development.

Keywords: Word segmentation, Speech perception, Bilingualism, Language experience, Infancy

1. Introduction

The great challenge of *word segmentation* concerns the following question: how do naïve listeners know when words begin and end in a continuous stream of fluent speech? This can be a daunting task for young infants, as words are rarely produced in isolation (Aslin, Woodward, LeMendola, & Bever, 1996; Brent & Siskind, 2001); and unlike written language, words in spoken language are not reliably separated by spaces. Thus, young language learners must learn to extract discrete words from the speech stream. Indeed, their success in this task has been associated with better concurrent word-learning abilities (Graf-Estes, Evans, Alibali, & Saffran, 2007) and language outcomes (Cristia, Seidl, Junge, Soderstrom, & Hagoort, 2014; Newman, Rowe, & Ratner, 2015; Singh, Reznick, & Xuehua, 2012). An important consideration is how infants learning more than one language begin to segment words in both of their languages. Research in word segmentation has traditionally focused on infants raised in monolingual homes, while largely overlooking bilingual infants. However, word segmentation is a language-specific skill (Polka & Sundara, 2012), and thus bilingual infants face a different word segmentation challenge. Hence, the overarching goal of the present work is to explore how bilingual infants' language experiences might influence their word segmentation abilities. Specifically, we examined word segmentation in infants acquiring two rhythmically different languages: English, a stress-timed language, and French, a syllable-timed language.

Two decades ago, Jusczyk and colleagues conducted the ground-breaking research in early word segmentation by showing that English-monolingual infants are able to segment monosyllabic words between 6- and 7.5-months of age, and bi-syllabic words by 7.5 months of age (Jusczyk & Aslin, 1995; Jusczyk, Houston, & Newsome, 1999). Subsequent cross-linguistic studies have also shown segmentation skills to emerge between 6 and 12 months of age (e.g., *French*: Nazzi, Iakimova, Bertoncini, Fredonie, & Alcantara, 2006; *Dutch*: Houston, Jusczyk, Kuijpers, Coolen, & Cutler, 2000; *German*: Höhle & Weissenborn, 2003; *Spanish* and *Catalan*: Bosch, Figueras, Teixidó, & Ramon-Casas, 2013). Infants can track word boundaries by using a wide array of cues in the speech signal, such as syllable co-occurrence patterns (Saffran, Aslin & Newport, 1996), rhythmic units (Jusczyk et al., 1999; Nazzi et al., 2006), co-articulation (Johnson & Jusczyk, 2001), phonotactic sequences (Mattys, Jusczyk, Luce, & Morgan, 1999), and allophonic variation (Jusczyk, Hohne, & Baumann, 1999). The fact that different types of cues can be used to solve the segmentation problem has sparked a debate over which cue infants use to begin segmenting words, and how the integration or weighting of cues changes as infants gain native language experience. To date, much of the research has focused on syllable co-occurrence patterns and rhythmic units.

Evidence favoring syllable co-occurrence patterns comes from Saffran et al. (1996), who demonstrated that young infants can track transitional probabilities between adjacent syllables (i.e., the probabilistic odds that two syllables would appear adjacently). After being familiarized with a continuous stream of syllables from an artificial language for several minutes, 8-month-olds were able to recognize tri-syllabic word forms that occurred within the familiarization material. Subsequent research suggests that infants are able to use the domain-general learning mechanism of statistical learning to find word forms in connected speech (Aslin, Saffran & Newport, 1998; Thiessen & Saffran, 2003). Due to the artificial nature of the stimuli used in these tasks, some researchers have questioned the scalability of statistical learning for segmenting in natural speech (Johnson & Tyler, 2010). Nevertheless, evidence for statistical learning has been shown in many other aspects of language acquisition (see review in Erickson

& Thiessen, 2015), and with other languages (e.g., Mersad & Nazzi, 2012; Pelucchi et al., 2009), suggesting that this learning mechanism is language-general.

Evidence favoring the use of rhythmic units in early word segmentation comes from Jusczyk and colleagues (Jusczyk & Aslin, 1995; Jusczyk et al., 1999). Languages such as English and German are stress-timed, which include rhythmic patterns with both strong and weak syllables. By 6 months, infants are already sensitive to the prosodic pattern of words in their native language (Höhle, Bijeljac-Babic, Herold, Weissenborn, & Nazzi, 2009); and soon thereafter, they can use these sensitivities to segment words from the speech stream. Specifically, English-monolingual 8-month-olds treat a stressed syllable as a word onset to successfully segment bi-syllabic trochaic (strong-weak) words like "*KINGdom*"; however, they cannot segment words with the less frequently occurring iambic (weak-strong) stress pattern like "*guiTAR*" until 10 months of age (Jusczyk et al., 1999).

This idea is consistent with the prosodic bootstrapping hypothesis (Morgan & Demuth, 1996), and supported by findings showing that adults are biased to track the basic rhythmic unit of their native language (Cutler, Mehler, Norris, & Segui, 1986; Mehler, Dommergues, Frauenfelder, & Segui, 1981; Peretz, Lussier, & Béland, 1998; Vroomen, Van Zon, & De Gelder, 1996). Indeed, adults who speak stress-timed languages (e.g., English, German) are biased to track and segment based on stress, while adults who speak syllable-timed languages (e.g., French, Spanish) and mora-timed languages (e.g., Japanese) are biased to track units from their respective language's rhythmic class. Relevant to the current study, it should be noted that stress does not distinguish words in French, but it does mark phrase boundaries; thus, only the final syllable in a phrase will be stressed (e.g. "S`il vous PLAÎT"). In connected speech, French bi-syllabic words tend to have an iambic stress pattern, which is weakly marked unless the word is at the end of a phrase. Lexical stress is clearly not salient to French adults. Although they discriminate iambic and trochaic word stress patterns at above chance levels, their very weak performance compared to English or German adults is quite striking and has even been referred to as ‘stress deafness’ (e.g., Dupoux, Peperkamp, Sebastián-Gallés, 2001). Like French adults, French-monolingual infants track syllable units (Nazzi et al., 2006; Goyet, Nishibayashi & Nazzi, 2013) and are less sensitive to stress (Skoruppa et al, 2009).

Cross-language studies provide further support for the role of native language rhythm in early word segmentation. Studies show that 8-month-olds can segment bi-syllabic words that have their native language word stress pattern even when they are tested in a rhythmically-similar but unfamiliar language (e.g. English infants segmenting trochaic words in Dutch; Houston et al., 2000) or dialect (e.g., Canadian French infants segmenting iambic words in European French; Polka & Sundara, 2012). Consistent with this view, 8-month-olds did not segment words with an unfamiliar word stress pattern in a rhythmically-different language (e.g., French infants failed to segment trochaic words in English, and English infants failed to segment iambic words in French; Polka & Sundara, 2012). These studies show that infants implement different procedures that depend on the prosodic structure of their native language.

The language-specificity of word segmentation raises questions about how bilingual infants learn to segment words in each of their languages. There is little data to address this issue both in terms of developmental trajectory and the procedures they use. Compared to monolingual infants, bilingual infants face several added challenges in terms of word segmentation. First, it has been speculated that bilingual infants receive less input in each of their languages than monolinguals in their single language (e.g., Byers-Heinlein & Fennell, 2014), giving them less opportunities to learn about speech cues for segmentation. Further, bilingual infants are more likely to hear code-switching in their environment (i.e., two different languages being produced by the same person), making the distributions in the speech input less monolingual and thus more "noisy" and highly variable. These different factors may tax infants' cognitive resources for computing distributions in two separate systems, which in turn may make the process of word segmentation more challenging.

Second, bilinguals have to learn how lexical forms vary in two systems instead of one. Given that languages make different distinctions among word forms, infants must track speech and statistical information in each language separately. Certainly, bilingual infants are able to discriminate between their languages very early on, even when their two languages are rhythmically similar (Bosch & Sebastián-Gallés, 2001). Further, bilingual infants are able to exploit different prosodic cues to segment phrases in an artificial language task (Gervain & Werker, 2013), suggesting that bilingual infants can track prosodic cues in a context-specific way. Nevertheless, how bilingual infants apply these abilities to track word forms across languages when they encounter more complex speech streams in natural communication contexts is unknown. As an added complication, bilingual infants may encounter cue conflicts across their two native languages. For example, as previously mentioned, in stress-timed languages such as English and Dutch, segmentation of trochaic units is an effective way to locate word boundaries (Houston et al., 2000). However, this procedure will not aid segmentation in syllable-timed languages such as French (Nazzi, Mersad, Sundara, Iakimova, & Polka, 2014).

So, how might bilingual infants solve the word segmentation problem in two languages? Current research focusing on other aspects of speech perception (e.g., phonetic perception, language discrimination) suggest that bilinguals develop these skills at a rate similar to their monolingual peers with minor deviations in the overall developmental path (see Werker, 2012 for a review). Very few studies have examined the word segmentation abilities of bilingual infants. Polka and Sundara (2003) assessed segmentation of bi-syllabic words in a small sample (n=9) of French-English (FE) bilingual 8-month-olds. Infants were tested twice (once in each language) in separate sessions conducted one week apart using the standard 2word/4passage protocol introduced by Jusczyk & Aslin (1995). The trends in these data, at the group and individual level, suggest that 8-month-old FE bilinguals can segment in both languages. However, we must exercise caution in interpreting these data due to the small sample size and high subject attrition (i.e., many infants were uncooperative in the second session), which may have resulted in a selective sample of infants. The high attrition suggests that assessment of segmentation in two languages within a single session may be both efficient and informative.

Another study examined word segmentation in bilingual infants acquiring Spanish and Catalan – both syllable-timed languages (Bosch et al., 2013). Infants were familiarized with passages containing a target monosyllabic word, and tested on their recognition of that target word. Both 6- and 8-month-olds showed positive evidence of word segmentation: Spanish-dominant bilingual infants were able to segment Spanish words from Spanish passages; the same pattern was found with Catalan-dominant bilingual infants with Catalan materials. Like their monolingual peers, bilingual 6-month-olds showed the expected familiarity preference for the target words typically found in segmentation tasks, whereas 8-month-olds showed a novelty preference. This shift in preference direction may point to an increased efficiency in segmenting monosyllabic words with age (consistent with the model proposed by Hunter & Ames, 1988; but see Bergmann & Cristia, 2015). Overall, these findings indicate that bilingual infants follow the same developmental trajectory as monolingual infants, at least for their dominant language.

Nevertheless, to date, no study has comprehensively examined how bilingual infants segment in each native language. Yet, this is an important issue to address, as the language backgrounds of bilinguals are more heterogeneous than monolinguals. For instance, Bosch et al. (2013) did not test their bilingual infants in their non-dominant language. We addressed this issue by devising a new protocol for testing segmentation in two different languages within the same infant. Similar to Bosch et al. (2013), we implemented the passage/word version of the classic HPP protocol. In this task, infants are presented with two passages during familiarization and four words in the test phase[1]. To accommodate two languages within the same test session, we simplified the task by presenting one passage during familiarization and two words during the test phase and then combined the two simplified tasks (one for each language) into a single test session.

We used this new dual-language task to test segmentation of bi-syllabic words in Canadian French and Canadian English. The prosodic pattern of the target words followed the dominant stress pattern of words in each language (iambic words for French; trochaic words for English). In experiment 1, we validate this protocol by replicating previous findings with monolingual infants. We tested two groups of 8-month-old monolingual infants (French; English) in order to provide a baseline for the bilingual group tested in the later experiments. We predicted that, as in Polka and Sundara (2012), monolingual infants would segment words in their native language, but not in their unfamiliar language.

2. Experiment 1

2.1 Methods

Participants

[1] The two versions of the standard protocol, 2word/4passage and 2passage/4word, differ in which materials are presented during the familiarization and test stage. The same results have typically been observed across versions.

The subjects were twenty-four infants from French-speaking families (Mean age = 8;0, Range = 7;13 – 8;18, 12 boys), and twenty-eight infants from English-speaking families (Mean age = 8;7, Range = 7;15 – 8;25, 15 boys). All infants were recruited in Montréal, where many children grow up to be bilingual. Infants' language background was assessed using a detailed questionnaire and interview, which estimated each infant's language exposure via interactions with family and caregivers in a typical week. The criteria for monolingual group assignment was minimally 90% French or 90% English; however, the majority had 95-100% exposure levels. Thirty-one additional infants (12 French; 19 English) were tested but not included in the analysis due to fussiness or distraction (17), technical problems (9), falling asleep (2), diaper change (1) and segmentation index (test minus control) more than 2 SD above or below the group mean (2).

Stimuli

We used the same speech materials as Polka and Sundara (2012), produced by a female, simultaneous bilingual speaker of Canadian French and English. She acquired both languages from birth and has used both languages regularly throughout her life. The talker recorded four passages in each language (see Appendix). Each passage had six sentences containing a different bi-syllabic word produced 6 times; twice in three sentence positions (beginning, middle, end). The target words were '*beret*', '*surprise*', '*devis*' and '*guitare*' in French, and '*hamlet*', '*kingdom*', '*doctor*' and '*candle*' in English. The talker also produced repetitions of each bi-syllabic target word. Both passages and words were produced using a child-directed speaking style.

Overall durations were similar for passages (Mean = 21.6s; Range 20-23.9s and word lists (Mean = 22.1s; Range = 19.5-24.5s). Each word list included 12-16 repetitions of the target word. Detailed acoustic analyses of the target words are found in Polka & Sundara (2012); a summary is provided in the Appendix. These analyses confirm the expected differences in lexical prosody, which are consistently cued by duration differences. For English target words in the passages, the first syllable was longer and louder than the second syllable, consistent with a trochaic stress pattern; pitch differences were not reliable. For English target words in the word lists, the first syllable was longer than the second; amplitude and pitch differences were not reliable. For French target words in the passages, the second syllable was longer than the first syllable consistent with an iambic stress pattern; amplitude and pitch differences were not reliable. For French target words in the word lists, the second syllable was longer, louder, and higher in pitch than the first syllable.

Each infant was tested using only two of the four passage/word lists for each language. Specifically, for French, half of the infants were tested with the passage/word lists containing '*guitare*' and '*beret*', while the other half were tested with the word lists containing '*surprise*' and '*devis*'. For English, the two passage/word list conditions were '*doctor*' and '*kingdom*', and '*hamlet*' and '*candle*'. Within each passage/word list condition, the passage presented during familiarization was counterbalanced across infants.

Procedure

Following the standard headturn preference paradigm, the trials for both the familiarization and test phase follow the same procedure. The infant is 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 towards the center. Then, a light on one of the side panels flashed. When the infant turned and looked to the light, the trial was initiated and a speech file began to play through a loudspeaker located below the light, behind the pegboard. Termination of each trial was also infant-controlled. When the infants looked away from the side panel light (> 30 degrees) for more than two seconds, the speech stimuli stopped playing and the light on the center panel began flashing to start a new trial; however, if the infant look was less than two seconds, the sound continued to play, but this look away time was not included in their listening time. Infant's looking was recorded by a live observer seated outside the pegboard booth. The flashing light and speech were played on the right side on half of the trials, and on the left side on the other half. The assigned side varied randomly with the constraint that no more than three trials in a row were presented on the same side. The parent and experimenter listened to music over headphones to prevent influencing the infant's behavior.

In the standard 4passage/2word protocol, the trial process just described is repeated to implement a familiarization phase followed immediately by a test phase. In the familiarization phase, infants hear a passage play on each trial when they look at the side-panel light. Trials continue until the infant listens to each passage for 45 seconds providing 12 exposures to each target word in connected speech. During familiarization, the sentences within each passage are presented in the same order, but successive trials presenting the same passage start with a different sentence from the same passage. In the test phase, the trials include 2 familiar word lists containing the target words that were repeated throughout each familiarization passage, and 2 novel word lists containing two words from the same language that did not occur in the familiarized passages. There are 16 test trials; the 2 novel and 2 familiar word lists are presented 4 times in a block-randomized order.

To assess word segmentation in two languages within a single test session, we created a new dual language protocol in which infants encountered an alternation of Familiarization and Test phases (Familiarization 1, Test 1, Familiarization 2, and Test 2). Each familiarization/test phase sequence provided a short segmentation task in a different language; the language order was counterbalanced across participants in each language group. In the dual language protocol, each familiarization phase is identical to the standard version of the task, as described above, except that the infant is presented only one passage, not two. Each test phase also follows the standard protocol except that the infant is presented only 2 (one familiar; one novel) rather than 4 word lists and they complete 8 test trials in which the order of trial types is alternated (e.g. novel, familiar, novel, familiar…). The four phases occurred in a single, uninterrupted sequence (1 passage/2 word lists/1 passage/2 word lists), which lasted about ten minutes. For each test phase, listening time was averaged across the four familiar word trials and the four novel word trials. Maximum trial length was 22 seconds; minimum trial lengths were set (3 seconds for passages; 1 second for word lists) to ensure that the infant hears the target word twice on each trial. When the minimum was not met, the trial (i.e. the same passage or word list) was immediately repeated and the short trial was removed from the analysis.

2.2 Results

To determine whether infants were successful at segmenting bi-syllable words in their native and non-native language, we computed infants' looking responses to familiar and novel words during the test phase. The average listening times are shown in Figure 1.

-- INSERT FIGURE 1 HERE --

A mixed ANOVA with Group (French vs. English) and Order as between-subjects factors, and Language and Trial Type (Familiar vs. Novel) as within-subjects factors was conducted. There was a main effect of Group [$F(1,48) = 13.12$, $p = .001$, $\eta_p^2 = .22$], with English infants having longer listening times to words overall. There was also a main effect of Trial Type [$F(1,48) = 4.16$, $p = .047$, $\eta_p^2 = .08$], indicating longer listening times for familiar than for novel words – the pattern expected for successful segmentation. As expected, there was an interaction between Order and Language [F(1,48) = 32.12, p < .001, η_p^2 = .40], with overall longer listening times to both test and control trials in the language that infants were tested with first. There were no other main effects or 2-way interactions.[2]

Critically, there was a significant interaction between Group, Language and Trial Type [F(1,48) = 15.32, p < .001, η_p^2 = .242]. To understand this interaction, we conducted a mixed ANOVA with Language and Trial Type as within-subjects factors for each group. For French infants, there was a Language by Trial Type interaction [F(1,23) = 8.44, p = .008, η_p^2 = .268]: French-learning infants listened significantly longer to the familiar than the novel words when the tested language was French [t(23) = 2.88, p = .009, d = .565], but not when the tested language was English [t(23) = -.46, p = .650, d = -.093]. For English infants, there was also a Language by Trial Type interaction [F(1,27) = 7.34, p = .012, η_p^2 = .214]; they listened significantly longer to the familiar than the novel words when the test language was English [t(27) = 3.67, p = .001, d = .554], but not when the tested language was French, [t(27) = -.74, p = .464, d = -.074]. These results show that both monolingual groups – French and English - were successful in segmenting bi-syllable words in their native language, but not in their non-native language.

This pattern of results is robust: 18 out of 24 French infants and 20 out of 28 English infants listened longer to the familiar than the novel words in their native language. Binomial tests indicate that these proportions are higher than expected by chance (50; p = .023 and p = .036 respectively). In contrast, only 11 out of 24 French infants and 11 out of 28 English infants listened longer to the familiar than the novel words when tested in their non-native language, and

[2] To examine whether results were consistent across word list conditions, we also conducted a 3-wayANOVA with Language, Trial Type and Word List as factors for each language group. There was no main effect of Word List or interactions involving Word List in either language group.

binomial tests indicate that these proportions are not significantly different from chance (.50; p = .839, p = .345 respectively).

2.3 Discussion

Prior work has shown that monolingual infants use language-specific cues when segmenting words from connected speech (e.g., Jusczyk et al., 1999; Polka & Sundara, 2012). The findings from Experiment 1 clearly replicate these findings: as expected, 8-month-old monolingual infants were able to segment bi-syllabic words in their native language, but not in an unfamiliar and rhythmically-different language. Further, our experiment meaningfully extends previous research by showing this pattern of results in a modified version of the HPP paradigm. In an earlier study from our laboratory, we tested monolingual infants in the word-passage order (Polka & Sundara, 2012); here, we implemented the passage-word order, which is more analogous to how infants segment words in natural communication situations. Previous cross-linguistic work has also only shown the language-specificity of segmentation cues in a between-subjects design; here, we provide more direct evidence of this by testing the same infants in both their native and non-native languages (i.e., within-subjects design), indicating that this pattern is highly robust.

This is also the first study in which infants were tested on word segmentation in two languages within a single test session. The positive evidence of word segmentation in this experiment indicates that a dual-language, single test session version of the HPP paradigm is feasible. It is noteworthy that the critical effect sizes in our analyses were robust and very similar across both native language conditions. Further, performance was not modulated by the order in which languages were presented. These findings firmly establish the utility of this new protocol for future experiments. There are many aspects of infant word segmentation to be explored where repeated measures of segmentation performance within the same subjects is meaningful, e.g. bilingual development, and cross-language research, among others.

In Experiment 2, we implemented this new protocol to assess word segmentation abilities of FE bilingual infants to discover how their skills compare to their monolingual peers. As with monolingual infants, we expect that bilingual infants need to arrive at a language-specific solution. However, FE bilingual infants will not succeed in segmenting both languages if they simply applied just one of the procedures used by their monolingual peers. For example, bilinguals may use a trochaic template for segmenting English words, but they would fail to segment words in French if they used that same procedure. Hence, FE bilingual infants need a different solution.

If bilingual infants act as "two monolinguals in one" and follow the same developmental trajectory as monolinguals for word segmentation, then they should be able to segment bi-syllabic words from the speech stream in each of their languages. Indeed, some studies suggest that statistical learning abilities are unaltered by the experience of acquiring multiple languages (e.g., Yim & Rudoy, 2013), suggesting that bilingual infants should be able to use syllable-tracking or other speech cues for both languages at the same pace as monolingual infants. Further, previous research suggests that bilingualism promotes discrimination of lexical stress patterns, which is a precursor skill that should facilitate segmentation, at least in a stress-timed language like English (Bijeljac-Babic, Serres, Höhle, & Nazzi, 2012; Abboub, Bijeljac-Babic, Serres & Nazzi, 2015). Moreover, bilingual infants have been shown to have flexible learning of multiple speech structures (Kovács & Mehler, 2009; Graf-Estes & Hay, 2015), suggesting that bilingual infants may be able to keep track of different language-specific cues and use them for segmentation flexibly.

An alternative prediction is that bilingual infants may show differing patterns of word segmentation, compared to monolingual infants. Indeed, research with bilingual adults suggests that flexibility in using segmentation cues might be limited, and may in fact depend on the specific combinations of languages. Cutler, Mehler, Norris and Segui (1989) made strong claims that even highly fluent adult bilinguals, who have acquired rhythmically-distinct languages, resisted adapting their segmentation behavior when processing novel and non-meaningful speech samples. Rather, they typically apply the prosodic biases of their dominant native language (e.g., Tyler & Cutler, 2009). Indeed, an earlier study by Cutler, Mehler, Norris and Segui (1992) showed that French-English bilingual adults do not simply mirror the segmentation abilities of monolingual adults. When tested on their ability to segment words based on their syllabic structure, French-dominant bilinguals were only able to segment French stimuli and not English stimuli; and English-dominant bilinguals did not show any evidence of syllabic segmentation in either language. Thus, if this language-specific segmentation pattern emerges in infancy, then our FE bilingual infants should not segment stimuli in the same manner as their monolingual peers.

3. Experiment 2

3.1 Methods

Participants

Twenty-nine bilingual infants were recruited (Mean age = 8:06, Range = 7:14 – 8:24; 14 boys). As with Experiment 1, all infants were recruited in Montréal and language backgrounds were assessed using the same questionnaire. We included infants who were exposed to both English and French on a regular basis, with a minimum estimated input of 30% in each language, and no other language(s) contributing more than 5% to the child's input. Based on our input estimates, the final sample included 12 French dominant, 9 English dominant and 8 balanced (50% English/50% French) infants. Seventeen additional infants were tested but not included in the analysis due to fussiness or distraction (9), technical problems (3), stopping to feed (1) and segmentation index more than 2 SD above or below the group mean (4).

Stimuli

Same as in Experiment 1.

Procedure

Same as in Experiment 1.

3.2 Results

Mean looking times to the familiar and novel words were submitted to an ANOVA with Language and Trial Type as within-subjects factors and Order as the between-subjects factor. Similar to findings from Experiment 1, there was no main effect of Language or Order (both *ps* > .191), but there was an interaction between these two factors [$F(1,27) = 21.70$, $p < .001$, $\eta_p^2 = .446$], showing that overall listening times were longer to the language that infants were tested with first.

-- INSERT FIGURE 2 HERE --

Critically, there was a marginal interaction between Language and Trial Type, [$F(1,27) = 4.07$, $p = .054$, $\eta_p^2 = .131$]. Paired t-tests reveal that bilingual infants listened significantly longer to familiar words compared to novel words during the French block, [$t(28) = 2.50$, $p = .019$, $d = .483$]. Indeed, 21 out of 29 bilingual infants listened longer to the familiar than the novel words in French; binomial tests indicate that this proportion is higher than expected by chance alone ($p = .024$). However, during the English block, bilingual infants did not have significantly different listening times to the two types of trials [$t(28) = -.28$, $p = .783$, $d = -.029$]. Only 11 out of 29 bilingual infants listened longer to the familiar than the novel words in English; binomial tests indicate that this proportion is not significantly different from chance (*p* = .265). These results show that our group of bilinguals were successful in segmenting bi-syllable French words from their counterpart passages, but not English words.

Next, we examined whether the order of testing played a role in infants' listening behaviors. Although there was no three-way interaction between Language, Trial Type and Order [$F(1,27) = .70$, $p = .411$, $\eta_p^2 = .025$], there was an interaction between Trial Type and Order [$F(1,27) = 8.97$, $p = .006$, $\eta_p^2 = .249$]. To better understand how order of testing interacts with our main independent variables, we probed the effects of Trial Type and Language separately in each condition of order (i.e., French first condition vs. English first condition; see Figure 2). When French was tested first, infants listened significantly longer to familiar trials than to novel trials for the French words [$t(14) = 3.06$, $p = .008$, $d = .984$], but not for the English words [$t(14) = 1.05$, $p = .312$, $d = .113$]. However, when English was tested first, listening time was not significantly different between familiar trials and novel trials for either French words [$t(13) = .331$ $p = .746$, $d = .084$] or English words [$t(13) = -.95$, $p = .360$, $d = -.177$]. These analyses confirm that bilingual infants indeed showed successful segmentation only for French, and only when tested with French first.

-- INSERT FIGURE 3 HERE --

Next, we examined whether our group of bilingual infants showed different patterns of segmentation depending on their language dominance. Recall that our sample included twelve French-dominant, nine English-dominant and 8 balanced infants. The balanced infants were not included in this analysis. Listening times to the familiar and novel word during the two language conditions between the two sub-groups of bilinguals are graphed in Figure 3. We conducted a mixed ANOVA with Dominance (French-dominant vs. English-dominant) as between-subjects factor, and Language and Trial Type as within-subjects factors. There was an interaction between Language and Trial Type [F (1, 19) = 7.45, p = .013, η_p^2 = .282], with longer listening times to the familiar compared to the novel word during the French block [t(20) = 2.56, p = .019, d = .520], but not during the English block [t(20) = -1.05, p = .308, d = -.128]. However, there was no main effect of dominance [F(1,19) = .16, p = .692, η_p^2 = .008], nor any significant interaction between dominance and all other factors (all ps > .617)[3]. The inability to find a difference between the two sub-groups of bilinguals may be due to the reduced power associated with a smaller sample in the sub-groups; however, the pattern of results in Figure 3 shows that the two sub-groups of bilinguals showed similar patterns of listening times consistent with segmentation in the French condition but not in the English condition

3.3 Discussion

Experiment 2 shows that FE bilingual infants demonstrate segmentation of bi-syllabic French words from French passages, but only when tested on French materials first. They did not show successful segmentation of bi-syllabic English words from English passages. The same pattern was observed when the bilingual infants were divided into different language dominance subgroups, suggesting that performance was not modulated by the more prevalent language in their input. Taken together, performance in the dual-language task reveals that FE bilingual 8-month-olds are not yet able to deploy effective segmentation processes for each of their languages in a rapid and flexible way.

[3] The same results were found when the ANOVA was conducted after sorting the infants into dominance sub-groups based only on the mother's language use with their infant. With this criteria there were 15 French-dominant, 10 English-dominant and 4 balanced infants. Eight infants switched from balanced to a dominant group when maternal language was the basis for sorting.

These findings raise a number of issues. First, how do we reconcile the present findings with our earlier data, which suggested that FE bilingual 8-month-olds segment bi-syllabic words in both languages (Polka & Sundara, 2003)? One possibility is that FE bilingual 8-month-old infants can indeed segment two syllable words in English, but it is more difficult for them to display this skill when the language exposure during testing is reduced, as is the case in the dual-language task. We address this issue in Experiment 3.

4. Experiment 3

In Experiment 3, we tested FE bilingual infants' segmentation of bi-syllabic words in English using the same stimuli as Experiment 1 and the standard HPP task as described in Polka & Sundara (2003; 2012). If the FE bilingual 8-month-olds are simply unable to segment bi-syllabic words in English, they should also fail to segment in this task. However, if they succeed, it shows that the reduced exposure to the language during the dual-language task contributes to their failure to segment words in English.

4.1 Methods

Participants

Fourteen FE bilingual infants (Mean age = 7:24, Range = 7:15 – 8:15, 4 boys) were tested. The language exposure assessment and inclusion criteria were the same as Experiment 2. This sample included five French-dominant, four English-dominant and five balanced infants. Four infants were from the sample reported in Polka & Sundara (2003); they had been tested on English in their first test session. Nine additional Subjects were tested but not included in the analysis due to fussiness (1), very short looks during test trials (6), technical problems (1), and segmentation index more than 2 SD above or below the group mean (1).

Stimuli and Procedure

The stimuli were the same as experiments 1 and 2. Infants were tested using the 2word/ 4passage version of the standard HPP procedure. This task is identical to the standard task described in Experiment 1 except that two word lists were presented during familiarization until the infant listened to each word list for 30 seconds and then four passages were presented during the 16 test trials.

4.2 Results

Twelve out of fourteen infants listened longer to test passage than control passages; binomial tests indicate that this proportion is higher than that expected by chance alone (chance = .50; p = .013). As shown in Figure 4, listening time was significantly higher for the familiar passages than control passages, [t(13) = 2.76 p = .016, d = .628]. These findings show that FE bilinguals can segment bi-syllabic words in English when they have ample opportunity to process the speech stream.

-- INSERT FIGURE 4 HERE --

4.3 Discussion

Findings of Experiment 3 show that FE bilinguals can segment bi-syllabic words in English when the task affords them more opportunity to process the English speech stimuli. These data, together with Experiment 2, show that the task demands clearly modulate segmentation performance in FE bilingual 8-month olds. This is the first evidence that bilingual and monolingual infants differ in the early word segmentation performance.

5. General Discussion

In the present study, we examined the emergence of segmentation abilities in 8-month-old monolingual and bilingual infants using a dual-language task. Here, we provide some of the first insights into how dual-language input – particularly, languages from different rhythmic classes (i.e., French and English) – might affect word segmentation abilities. Overall, the present data shows that bilingualism alters the pattern of language acquisition from what is typically observed in monolinguals.

How might we reconcile our findings with those of Bosch et al. (2012), showing that Spanish/Catalan bilingual infants perform like their monolingual peers when segmenting words in their dominant language? Task demands may play a role. First, recall that Bosch et al. only tested their infants on their dominant language using the standard one-language word segmentation task; thus, their bilingual infants did not face the added challenge of processing two separate languages in a single task, like our bilingual infants in Experiment 2. Indeed, when we tested bilingual infants in a single language (Experiment 3), they were able to segment English words. The segmentation task in Bosch et al. (2012) was also possibly easier because they measured segmentation of simpler monosyllabic words, rather than bi-syllabic words in the current study. Further, because both Spanish and Catalan are syllable-timed languages, their bilingual infants may not need to adapt their processing procedure, at least with respect to rhythmic cues. Instead, they could exploit the shared property of their native languages for word segmentation. Indeed, even monolingual infants can segment words in an unfamiliar language with the same rhythmic structure (Houston et al, 2000). However, our FE bilinguals are acquiring two rhythmically different languages. The present findings suggest that the specific combination of languages being acquired may be a relevant factor in understanding how task demands modulate word segmentation performance in bilingual infants. Taken together with the results from Bosch et al. (2012), it appears that it is more challenging for infants to develop segmentation skills in two rhythmically-different compared to two rhythmically-similar languages.

Given the unique demands of dual-language segmentation, perhaps it is not surprising that FE bilingual 8-month-olds are not yet able to segment efficiently in both languages. At this age, infants' ability to segment multisyllabic word forms is just emerging: even monolingual infants this young are only able to recognize word forms when there is limited variability in voice, affect, speech rate and pitch between the familiarized and tested target word (e.g., Houston & Jusczyk, 2000; Morgan, 2002; Singh, White & Morgan, 2008). Perhaps coping with the additional variability associated with two languages presents an added challenge for bilingual infants, especially those acquiring two rhythmically-different languages.

The findings across Experiments 2 and 3 show that FE bilingual 8-month-olds can segment words in each of their native languages when the task is structured to expose these skills. The dual-language task is not adequate in this regard and instead reveals that FE bilinguals cannot yet apply their segmentation knowledge in a quick or flexible way to segment words in either language when they hear an unfamiliar talker. It is important to acknowledge what this entails. Along with acquiring the requisite schema to segment in each language, they need to select and apply the right schema, which depends on tagging the incoming language correctly and quickly. When encountering an unfamiliar talker, they may apply the wrong schema initially and will then need to switch; this may be difficult or at least take more time. The extra time needed to accurately tag the speech stream or to switch procedures if they implement the wrong one, as a default may be the main factor constraining their performance in our dual-language task. The success with English in the longer standard task in Experiment 3 but not with the truncated task in Experiment 2 supports this interpretation. Future studies are needed to assess whether bilingual infants are more successful in the dual-language task if the familiarization phase is lengthened.

The language switch also impeded bilinguals' segmentation performance. They failed to show successful segmentation in either French or English for the second language presented in the task. Recall that monolingual infants' performance was not modulated by the order of the language presentation: listening to the unfamiliar language first did not disrupt their ability to segment words in their native language when it came second. A possible reason for this could be that monolingual infants only have one segmentation procedure, which is compatible with their native language but not with other languages; thus, order of the language presentation does not hinder monolingual infants' segmentation performance. These findings are further evidence that the segmentation task facing the bilingual and monolingual infant is not the same and that this is already reflected in their behavior at 8 months.

Nevertheless, it is puzzling as to why bilingual infants' success in segmentation was limited to French. There was no evidence that this outcome is tied to the differences in their relative exposure to each language. Further, in Experiment 1 and in earlier work, we observed similar and robust effect sizes for each monolingual group tested in their native language. Thus, there is no evidence that French stimuli were easier to segment compared to the English stimuli.

There are two possibilities: infants were either applying a French-based procedure as a default and will switch once they recognize the speech as English, or they were employing another procedure that happens to works better for French than English. Research outlined above suggests that even proficient bilingual adults have difficulty tracking two different rhythmic units. From this perspective, it makes sense that, at least initially, the bilingual infants may favor a French-based schema of tracking syllables over the English-based schema of tracking trochaic units. This is because the syllable is a universal unit whereas the trochaic stress pattern is not; indeed, tracking transitional probabilities across syllables is a language-general mechanism (e.g., Mersad & Nazzi, 2012) and would interfere less in the segmentation process for bilingual infants. Nevertheless, although English infants are sensitive to syllable units (Jusczyk, Kennedy, & Jusczyk, 1995), the basic rhythm of English is not organized around syllables and syllable boundaries are often unclear in English. For example, in the word *balance*, the "*l*" seems to belong to both syllables. In French, syllabic units are clear - *balance* is produced with 2 distinct syllables, "*ba*" and "*lance*". Although stress is a prominent, reliable feature of words in English, stress is not a distinctive feature of French words. In fact, French adults have considerable difficulty discriminating word stress patterns (e.g., Dupoux et al, 2001). Thus, while tracking stress patterns is very efficient for segmenting English, it is ineffective for segmenting French.

Eight-month-olds may adopt syllable tracking as a default segmentation procedure, which works better for French than English, until they have learned to differentiate and exploit the relevant prosodic cues across their two native languages efficiently. By 6 months, monolingual infants acquiring German, a stress-timed language, show a listening preference for trochaic units, whereas French infants can discriminate between trochaic and iambic stress patterns but fail to show a stress pattern preference (Höhle et al, 2009). It is unknown whether FE bilingual 8-month-olds can discriminate iambic and trochaic stress patterns. Further research on stress pattern discrimination and preference in FE bilinguals could provide further insight into their acquisition of segmentation skills.

The present study highlights some of the methodological issues that arise in bilingualism research. We have a long tradition of research developed from a monolingual mindset. One of the challenges of exploring bilingual acquisition is devising methods that are efficient to assess performance in two languages within the same individual. This is important, not just for efficiency sake, but because bilinguals experience their languages in a wide variety of ways and we often want to know how this impacts their performance as bilinguals. It is difficult to construct language tasks that present the same processing demands to a bilingual and a monolingual, even when you present identical stimuli in the same test protocol. In the present study, we devised an efficient protocol to assess language processing in French and English, yet the demands of this new task are not the same for monolingual and bilinguals.

When assessing bilinguals, we also need to consider the language exposure that we introduce in the lab. In the present study, both languages were spoken during interactions with the parent prior to the testing session. It is unknown whether exposure in the lab or even several hours prior to the testing session can impact infant word segmentation in bilingual infants. This is an important issue to consider and explore in future research.

The present findings also reveal how research on bilingual acquisition can lead to a more principled understanding of language and cognitive development. Segmenting words from connected speech is an important step in building lexical knowledge. Supporting this notion, several studies show that early segmentation performance in monolingual infants is predictive of later language abilities (Newman et al, 2015; Singh et al, 2012). At this point, there are no data to address whether this prediction also holds for bilingual infants. Moreover, the causal connection between early word segmentation and later language skills remains unclear. It may be that early segmentation is a good language predictor because segmentation is a critical precursor to many subsequent skills. In that case, segmentation may be a kind of bottle-neck or rate-limiting skill that sets the pace for further progress in language acquisition. Alternatively, early segmentation may be a good predictor because it is correlated with more general cognitive abilities that are tied to faster language development. With bilingual infants, we have the opportunity to disambiguate these alternative accounts by comparing how well early segmentation skill predicts later language competence within and across their two native languages. Thus, further research exploring word segmentation in bilingual infants can provide new insights into the language acquisition process in general.

Finally, bilingualism has been linked to enhanced executive function in adults and infants (Kaushanskaya & Marian, 2012) and has opened up a mechanistic debate. One view is that learning to switch rapidly between two language systems – in comprehending and speaking – promotes enhanced executive function in bilinguals (e.g., Verreyt, Woumans, Vandelanotte, Szmalec, & Duyck, 2014). Segmenting words in a context where the talker is switching between languages provides one such opportunity for bilingual infants. The current findings show that segmenting speech in a bilingual context increases the processing load for the bilingual infant. Future research into the relationship between word segmentation in the context of language switching and other cognitive skills may provide further insights into the connection between bilingualism and enhanced executive function.

In summary, learning to segment words is challenging for bilingual infants acquiring two rhythmically-different languages. Understanding the impact of bilingualism on language acquisition also introduces added complexities for researchers. Thus, bilingualism offers unique opportunities for learning and growth that are well worth the extra investment.

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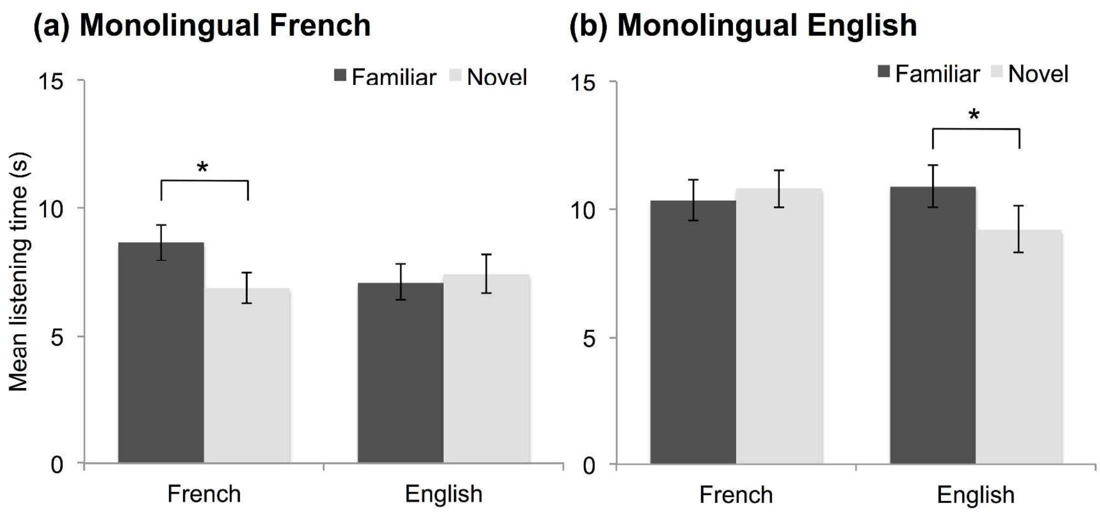

Figure 1. Average listening times to Familiar and Novel trials for (a) Monolingual French infants (b) Monolingual English infants. Error bars represent standard error.

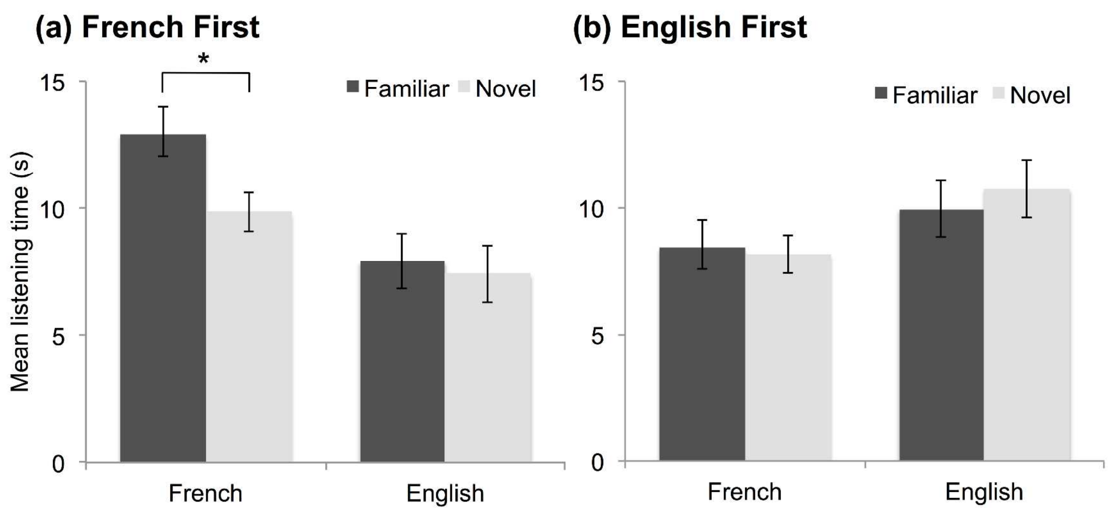

Figure 2. Average listening times to Familiar and Novel trials for Bilingual-learning infants in the (a) French-first, English-second condition and (b) English-first, French-second condition. Error bars represent standard error.

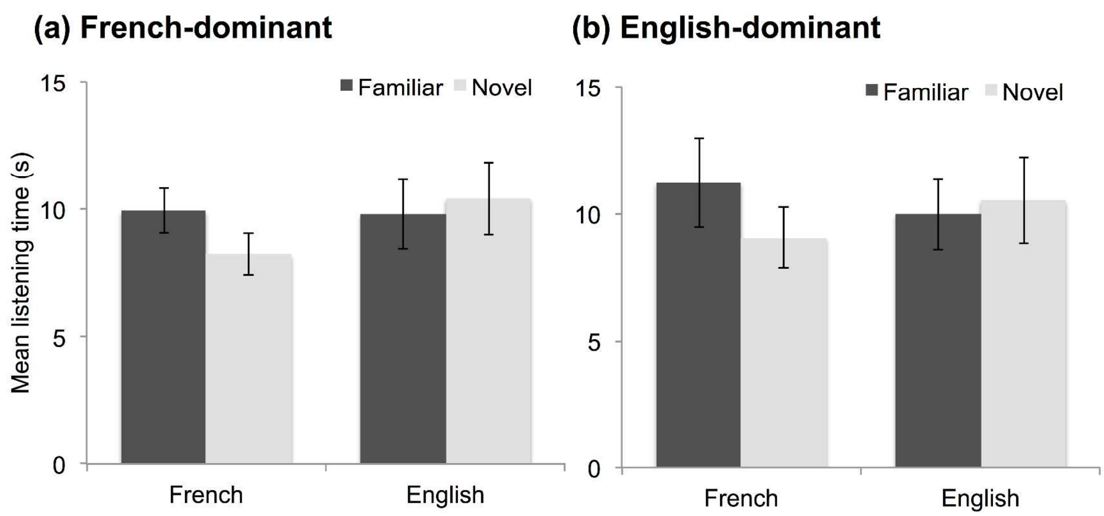

Figure 3. Average listening times to Familiar and Novel trials for (a) French-dominant infants (n=12) and (b) English-dominant infants (n=9). Error bars represent standard error.

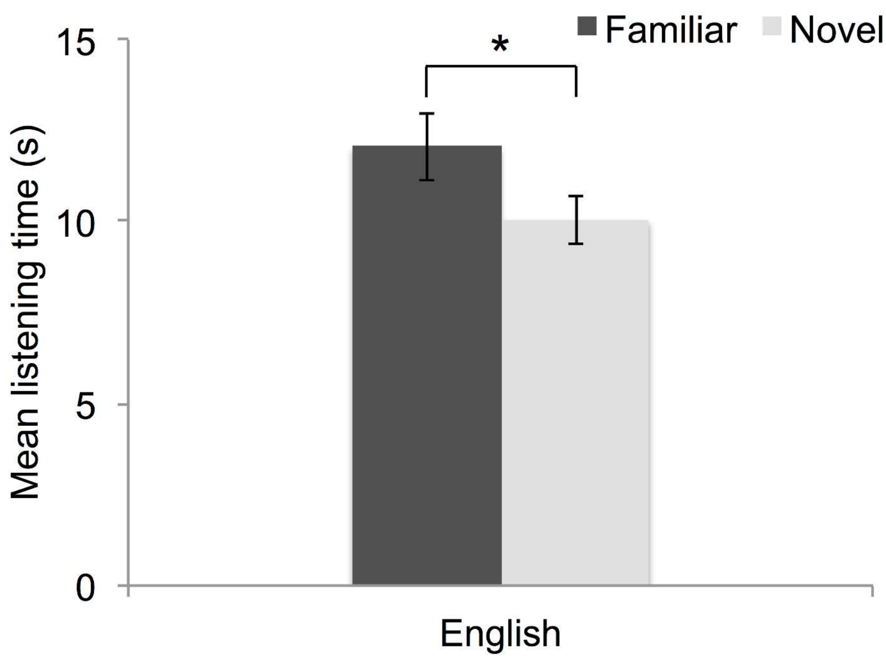

Figure 4. Average listening times to Familiar and Novel trials for bilingual infants. Error bars represent standard error.

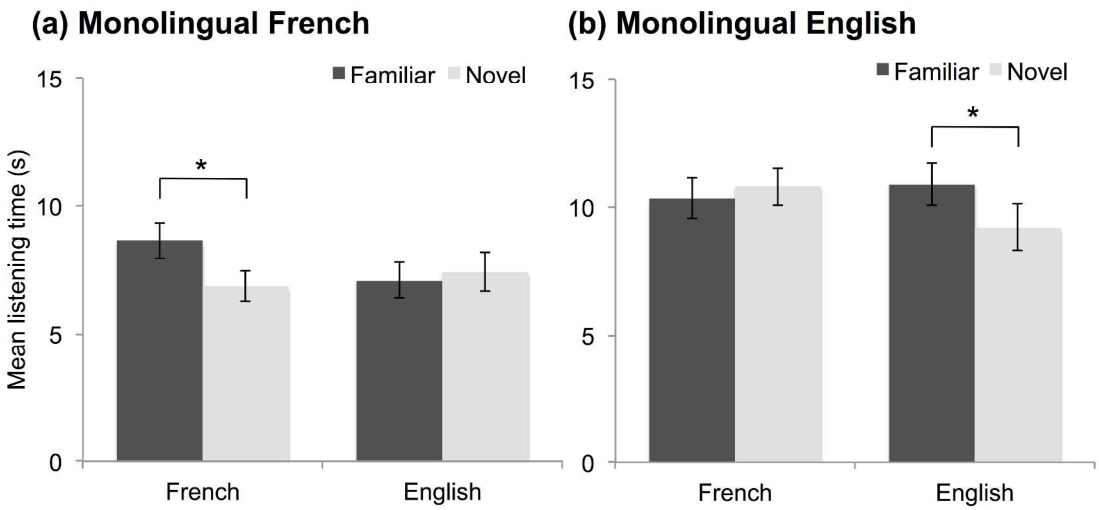

Figure 1. Average listening times to Familiar and Novel trials for (a) Monolingual French infants (b) Monolingual English infants. Error bars represent standard error.

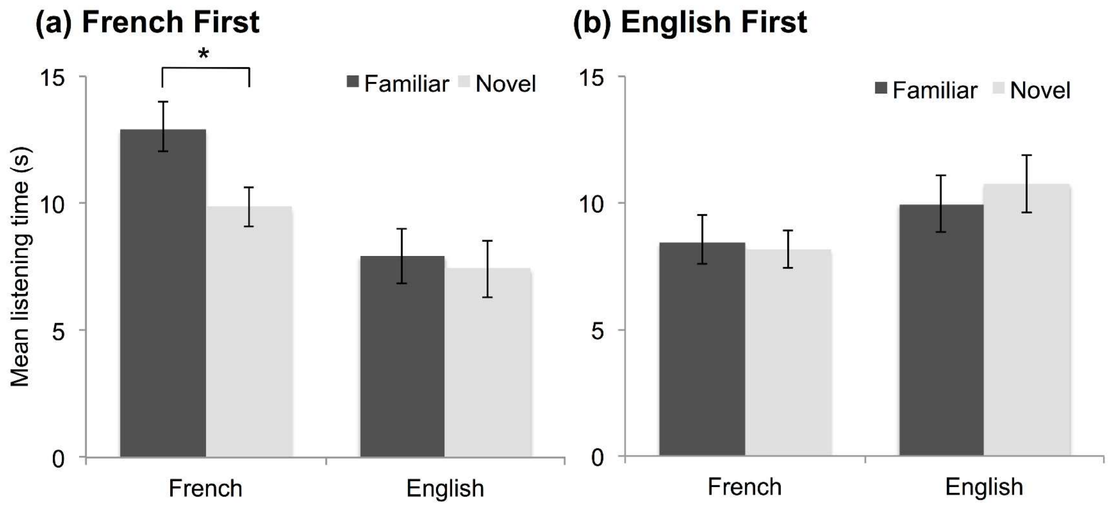

Figure 2. Average listening times to Familiar and Novel trials for Bilingual-learning infants in the (a) French-first, English-second condition and (b) English-first, French-second condition. Error bars represent standard error.

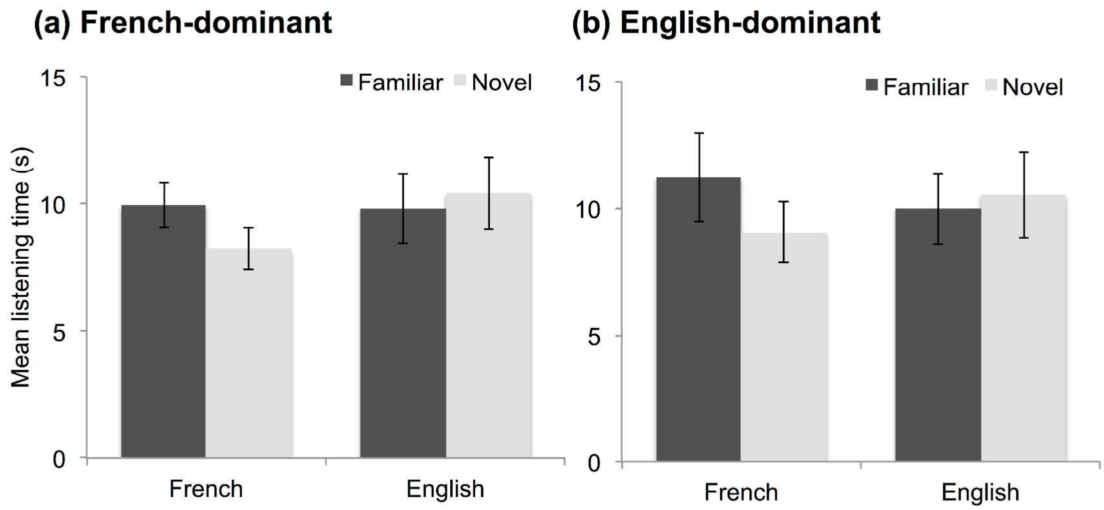

Figure 3. Average listening times to Familiar and Novel trials for (a) French-dominant infants (n=12) and (b) English-dominant infants (n=9). Error bars represent standard error.

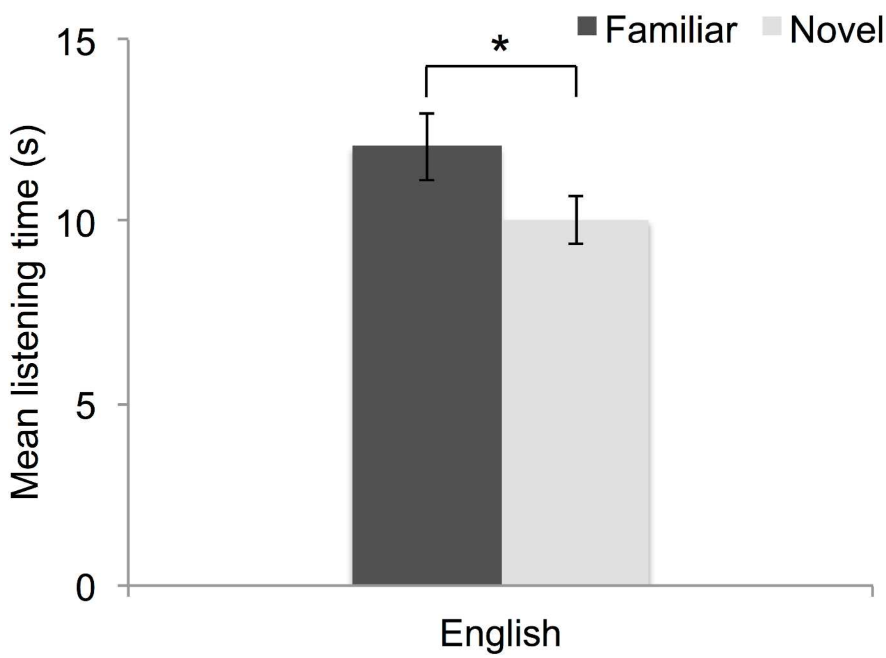

Figure 4. Average listening times to Familiar and Novel trials for bilingual infants. Error bars represent standard error.