On the role of frequency-based cues in the segmentation strategies of adult OV/VO bilinguals

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Keywords: frequency; bilingualism; speech segmentation; context language; artificial languages; OV/VO languages

Introduction

What cues do humans use to segment words and phrases out of speech? Are adult bilinguals able to deploy the segmentation cues of their two languages? The present paper seeks to determine the extent to which adult bilinguals use frequency-based cues related to their two languages when segmenting new input.

During the last decades, a substantial amount of research has investigated the cues that humans use to successfully segment the speech signal. This research has shown that statistical learning is a mechanism used by adults and infants to segment the input and extract the regularities present in it (Saffran, Aslin, and Newport 1996; Saffran, Newport, and Aslin 1996; Peña et al. 2002; Gervain et al. 2008; Weiss, Gerfen, and Mitchell 2009). Statistical learning is a domain-general capacity used also to discover regularities in non-linguistic auditory stimuli such as tone streams (Saffran et al. 1999) found across modalities, e.g., with visual stimuli (Fiser and Aslin 2001; Kirkham, Slemmer, and Johnson 2002), and not specific to humans but shared with other mammals such as cotton-top tamarins and rats (Hauser, Newport, and Aslin 2001; Toro and Trobalón 2005).

Computing the frequency of occurrence of certain properties of the input is a type of statistical learning performed by humans. Gervain et al. (2008, 2013) propose that one strategy used by adults and infants in speech segmentation involves computation of the frequency of occurrence of a specific type of elements of natural languages, i.e., functors. Functional elements are characterized by a series of properties that set them apart from content words (Morgan, Shi, and Allopenna 1996). Functors are closed-class elements that belong to a small set of functional categories (e.g., determiners, pronouns, prepositions, complementizers, verbal inflection: *the, this, he, it, where, on, if, that, walk-ed...)* but have a high frequency of occurrence in natural languages, whereas

content words are open-class elements (e.g., nouns, verbs, adjectives: *table, car, eat, beautiful, baby*...) that typically have a lower frequency of occurrence. Distributionally, functors tend to appear at the edges of phrases. Phrases are words organized into syntactic constituents. Every phrase (e.g., XP) contains a head (X), which determines the syntactic type of the phrase (i.e., the category) and can be accompanied by a complement and/or a specifier. Both content words and functors can be heads of syntactic phrases. The linear order of specifier and head, and complement and head are language-specific, as described by the Head-Directionality parameter (Baker 2001; Chomsky 1981). In head-initial, V(erb) O(bject) languages (Spanish, English) heads occur phrase-initially, whereas in head-final, O(bject) V(erb) languages (Basque, Japanese), heads occur phrase-finally. In turn, the order of heads and complements correlates with the order of functors and content words in natural languages (Greenberg 1963). In head-initial, VO languages, functors tend to appear at the beginning of phrases (head-initial languages typically have prepositions, auxiliaries precede the main verb, determiners precede nouns, e.g., English: *on the table, has gone, the woman*); in head-final, OV languages, functors typically appear at the end of phrases (head-final languages usually have postpositions, auxiliaries follow the main verb, determiners follow nouns e.g., Basque: *gizon-a-ren* man-the-possesive, *etorri da* come has, *emakume-a* woman-the).

Gervain et al. (2008) argue that, due to this correlation between the relative order of functors and content words and the relative order of heads and complements in phrases, computing the frequency distribution and relative order of functors and content words might enable infants to discover the basic word order of the surrounding language, before they have lexical knowledge. The particular properties of functors are indeed salient to infants from a very early stage in the development. Infants are

especially sensitive to the frequency of occurrence of the native language's functors and acquire first the most frequent functors present in the input (Shi, Cutler et al. 2006; Shi, Marquis, and Gauthier 2006).

Gervain et al. (2008) showed that by eight months of age infants are sensitive to the relative distribution of frequent and infrequent elements in the input and that they link these representations to the word order of their native language. In an experiment that tested the word order preferences of eight-month-old learners of Japanese (OV, head-final) and Italian (VO, head-initial) given an ambiguous artificial language, infants segmented the artificial language according to the relative order of frequent and infrequent elements (i.e., functors and content words respectively) characteristic of their native languages. The group of Japanese infants preferred a segmentation of the language in which frequent elements occurred at final position (i.e., frequent-final segmentation), whereas the group of Italian infants preferred a segmentation of the same language in which frequent elements appeared at initial position (i.e., frequent-initial segmentation). Infants exposed to languages with opposite head directionality/basic word order had therefore opposite preferences for the segmentation of a continuous string based on the relative order of frequent and infrequent elements.

This frequency-based bootstrapping mechanism appears to be available also in adulthood. Gervain (2007) and Gervain et al. (2013) examined whether adults also rely on the frequency and relative ordering of elements to segment novel input and found cross-linguistic differences in the segmentation preferences of an ambiguous artificial language. Comparing speakers of French and Italian (VO, head-initial languages) with speakers of Japanese and Basque (OV, head-final languages) and Hungarian (mixed order though predominantly head-final), Gervain (2007) and Gervain et al. (2013) found that speakers of the head-final languages displayed a significant frequent-final

segmentation preference, whereas speakers of the head-initial languages displayed a frequent-initial segmentation preference, though this frequent-initial segmentation preference did not significantly differ from chance. Hence, speakers of languages with opposite head directionality/basic word order showed different segmentation preferences for the ambiguous artificial stream.

Gervain (2007) and Gervain et al. (2013) argued that the non-significant frequent-initial preference found in French and Italian monolinguals might result from the amount of suffixation allowed in the inflectional morphology of these languages. Suffixation entails a frequent-final ordering, which might hence diminish the general frequent-initial representation of the French and Italian monolinguals. Indeed, the different segmentation preferences found between OV and VO speakers mirror the distributional data obtained by Gervain et al. (2013) in a corpus study. They examined the distribution of content words and functors at utterance edges in infant-directed speech corpora in Japanese, Basque, Italian, and French. Functors occurring both as bound and free morphemes were included, given that functors that appear as free morphemes in VO languages are often bound morphemes in OV languages. As expected, the two OV languages (Basque, Japanese) had a predominance of functor-final utterances, whereas the opposite distribution was found in the VO languages (Italian, French). No significant differences were found between the two VO languages, or between the two OV languages.

The group of Basque participants tested by Gervain et al. (2013) were bilingual speakers of Spanish, a head-initial language. Interestingly, this group showed the qualitatively strongest frequent-final preference. The frequent-final preference obtained in this group of Basque-Spanish bilinguals opens the ground for inquiring whether OV-VO bilinguals deploy only one segmentation strategy, determined by their L1, or

whether they can deploy both. Here we investigate the abilities of bilinguals to implement frequency-based cues in speech segmentation, and we do so by means of an artificial language learning experiment. Specifically, we examine whether the segmentation preferences of bilingual speakers of Basque (OV) and Spanish (VO) of a structurally ambiguous artificial language are modulated by the language of the context, i.e., the language (Spanish or Basque) in which participants are addressed and receive the instructions about the experiment.

Grosjean (1998; 2001) proposes that the language of the context is one of the factors that potentially influence the state of activation of the bilingual's languages and language processing mechanisms, by activating a particular base or main language. Few studies have examined the role of context language in bilingual language processing. Studies of voicing perception have examined whether presenting bilingual listeners with different perceptual sets—consistent of or including manipulation of the language of the instructions—led listeners to use different criteria to identify the same set of sounds (Caramazza et al. 1973; Elman, Diehl, and Buchwald 1977; Williams 1977; Flege and Eefting 1987; Bohn and Flege 1993; Hazan and Boulakia 1993). Language of the context—as either language of the instructions or as the language of the input presented to the bilingual participants prior to the experiment—has also been manipulated in lexical decision studies. Soares and Grosjean (1984) manipulated the language of the instructions as part of a language set that aimed to induce bilingual participants into a monolingual language mode (i.e., in which only one of the bilingual's languages is highly activated) prior to conducting a lexical decision task. In turn, Elston-Güttler, Gunter, and Kotz (2005) and Paulmann et al. (2006) presented the bilingual participants with 20 minute-long videos narrated in either their L1 or L2 before conducting a semantic-priming lexical decision task. However, no conclusion on the role of context

language could be drawn from these perception and lexical access studies, due to the divergent results obtained and the methodological differences across experiments.

Language of the context has therefore been largely unexplored in the literature on bilingual language processing. The present investigation aims to examine whether this factor exerts an influence on the choice of segmentation strategy by bilinguals.

Experiment

The present experiment investigates whether early and highly proficient bilingual speakers of Basque and Spanish, i.e., OV-VO bilinguals, deploy only the frequency-based segmentation strategy that characterizes their L1, or whether they can deploy the segmentation strategies of the two languages they command and use frequently. To that end, we examine the segmentation preferences of a structurally ambiguous artificial language of four groups of bilingual speakers of Spanish and Basque, which differ in their L1 and L2 (Basque-Spanish or Spanish-Basque) and in the language in which they were addressed and received the instructions of the experiment (i.e., context language: Basque or Spanish). Thus, this experiment investigates whether the context language modulates the bilinguals' segmentation preferences of the ambiguous language.

Regarding the potential differences in the segmentation preferences between speakers of OV and VO languages, a strong frequent-final segmentation preference similar to the obtained in Gervain et al. (2013) is expected to obtain in the group of native Basque speakers (OV, i.e., Basque-Spanish bilinguals) tested in a Basque context. A frequent-initial segmentation preference similar to the obtained in French and Italian (both VO) in Gervain et al. (2013) is predicted for native speakers of the previously unexamined VO language (i.e., Spanish-Basque bilinguals) when tested in a Spanish context.

If language of the context indeed modulates or determines the bilinguals' choice of a segmentation strategy, a smaller frequent-final preference is predicted for Basque-Spanish bilinguals tested in a Spanish context, as compared to Basque-Spanish bilinguals in a Basque context. Similarly, a stronger frequent-final preference is predicted in the group of Spanish-Basque context Basque bilinguals, as compared to the group of Spanish-Basque context Spanish bilinguals.

Methodology

Participants

One hundred and eleven highly proficient bilingual speakers of Basque and Spanish (75 females, mean age 22, range 18–35) took part in this experiment. Participants were sorted into four groups, depending on (a) their L1, Basque or Spanish, and (b) the context language, i.e., the language of the instructions, Basque or Spanish. Thus, 20 Basque-Spanish bilinguals (16 females, mean age 19.1, range 18–22) were tested in the Basque context condition, and 28 Basque-Spanish bilinguals (18 females, mean age 23.29, range 18–34) were tested in the Spanish context condition. Similarly, 32 Spanish-Basque bilinguals (21 females, mean age 21.84, range 18–33), a previously unexplored population, were tested in the Basque context condition, and another 31 Spanish-Basque participants (20 females, mean age 23.1, age range 18–35) were tested in the Spanish context condition.

Data concerning the linguistic background of the participants were collected by means of a questionnaire developed by members of the research group The Bilingual Mind at the University of the Basque Country (UPV/EHU) (see Appendix 1). All L1Spanish bilingual participants had been raised in Spanish-speaking homes at least until adolescence. Similarly, all L1Basque bilinguals had been raised in Basque-

speaking homes at least until adolescence. All bilinguals reported having acquired their L2 at around three to five years of age, had a bilingual education and thus formal knowledge in both their languages, and in order to access university education had taken a mandatory exam where they had to show a knowledge of both their languages equivalent to the monolinguals' knowledge of Spanish in other areas of Spain. Language dominance was established by measuring exposure to and use of the two languages in everyday life at three points of development: infancy, adolescence and adulthood. The participants rated the frequency of use of their two languages and reported using their respective dominant language approximately 75% of the time. All participants were naïve to the purpose of the experiment and received a four euro compensation for their participation.

Materials

The ambiguous artificial language used in this experiment was the one originally designed and used by Gervain et al. (2013). This language contained two types of categories, characterized by a different frequency of occurrence in the artificial language, mimicking the relative frequency of functional and content words in natural languages. Frequent categories consisted of three categories (*a, b, c*), where each category contained only one CV syllable token. Infrequent categories consisted also of three categories (*X, Y, Z*), but each category contained nine CV syllable tokens. The language comprised a total of three frequent tokens and 27 infrequent tokens, and frequent categories were therefore nine times more frequent than infrequent categories.

The language was constructed concatenating hexasyllabic units with the structure *aXbYcZ*, i.e., characterized by a strict alternation of frequent and infrequent categories. This basic unit was concatenated 540 times, resulting in a 17 minute and 30 second long

stream. The intensity of the initial 15 seconds of the stream was gradually increased and the intensity of the final 15 seconds gradually decreased, which rendered the stream ambiguous, allowing two possible segmenting schemas: (a) a frequent-initial segmentation (e.g., *aXbYcZaXbYcZ...: fiLUnuFEgeMU...*) that mirrored the relative order of frequent (i.e., functors) and infrequent (i.e., content words) elements in VO languages, or (b) a frequent-final segmentation (e.g., *XbYcZaXbYcZa...: LUnuFEgeMUfi*…), which mirrored the relative order of frequent and infrequent elements in OV languages.

Test stimuli consisted of 36 six-syllable long items, 18 items with a frequent-initial structure (e.g., *fiBAnuTAgeBI*), and 18 items with a frequent-final order (e.g., *DUnuPUgeKUfi*). Familiarization and test items were synthesized with the German male voice de6 of the MBROLA database (Dutoit 1997), a voice in a language unknown to all participants. The segments or phones had a constant duration of 120 milliseconds and a monotonous f0 of 100 Hz.

Procedure

Participants were tested individually in a quiet room at the Psycholinguistics Laboratory of the University of the Basque Country (UPV/EHU). The experimental input was displayed in a computer screen using DMDX software and participants were provided with high-quality Logitech headphones. Participants were told that they were about to listen to an unknown language for several minutes, after which they would listen to questions regarding the language they had heard. A short training familiarized participants with the procedure of the experiment. Participants heard six pairs of monosyllables and were asked to identify a target syllable by pressing one of two predefined keys in the keyboard, depending on whether the target had been heard first,

or second. After training, participants listened to the familiarization stream during 17 minutes and 30 seconds. Familiarization was followed by the test phase in which participants listened to 36 test trials. In each trial a pair of six-syllable long test sequences was presented, one sequence always being frequent-initial, the other frequent-final. The two sequences were separated by a 500 ms pause. Each test sequence appeared twice during the experiment, one time as the first member of a pair, and another time as the second member of a pair, but never in consecutive test trials. The participants' task consisted on choosing the sequence in each pair that they thought belonged to the language they had heard during familiarization, by pressing the corresponding key in a keyboard. The session had a total duration of around 30 minutes. The computer recorded the number of frequent-final responses per participant out of the 36 test trials.

Results

Figure 1 shows the percentage of frequent-final responses in the four groups. All groups of bilinguals showed a general preference for the frequent-final segmentation which differed significantly from chance (all $p < .001$). Mean percentage of frequent-final responses was: 78.06% in the group of Basque-Spanish bilinguals that received the instructions in Basque (28.1 out of 36, ±1.42 SE), 67.16% in the group of Basque-Spanish bilinguals addressed in Spanish (24.18 out of 36, ±1.26 SE), 73.26% in the group of Spanish-Basque bilinguals addressed in Basque (26.38 out of 36, ±1.03 SE), and 74.46% in the Spanish-Basque bilinguals that received the instructions in Spanish (26.81 out of 36, ±1.27 SE).

The present experiment aimed to determine whether the context language (i.e., the language in which participants were addressed during the experiment) influenced the

bilinguals' segmentation preferences of the ambiguous language. To that end, and given that the participants' responses are binomial in nature (i.e., two-alternative forced-choice between frequent-initial and frequent-final test-items), a binomial test was carried out on the stimuli as frequent-final among the different groups. Results revealed a significant difference between groups (χ^2 (3, N = 111) = 28, $p < .001$). Further pair-wise comparison of proportions (with Holm method for p-value adjustment) showed a significant difference between the responses of Basque-Spanish context Spanish bilinguals and Basque-Spanish context Basque bilinguals ($p < .001$). No significant differences were found in the responses of the two groups of Spanish-Basque bilinguals ($p = 0.548$). Thus, the context language significantly influenced the segmentation preferences of the Basque-Spanish bilinguals, but not the segmentation preferences of Spanish-Basque bilinguals.

Also, the responses of the Basque-Spanish context Spanish bilinguals significantly differed from the responses of the two groups of Spanish-Basque bilinguals (Basque-Spanish context Spanish vs. Spanish-Basque context Basque bilinguals: $p = .009$; Basque-Spanish context Spanish vs. Spanish-Basque context Spanish bilinguals: $p < .001$). The remaining pair-wise comparisons did not yield significant differences.

[Insert Figure 1]

Subject-by-subject responses (see Appendix 2) are shown in Figure 2. 85% of the group of Basque-Spanish context Basque bilinguals, and 60.71% of the Basque-Spanish context Spanish bilinguals chose the reported frequent-final segmentation in at least 24 of the 36 trials. On the other hand, 75% of the Spanish-Basque context Basque

bilinguals, and 67.74% of the Spanish-Basque context Basque bilinguals chose the reported frequent-final segmentation in at least 24 of the 36 trials.

[Insert Figure 2]

Last, an item-by-item analysis was conducted to observe for potential differences in the frequency of occurrence of frequent-final responses across test-trials. A chi-square test of goodness-of-fit was performed, which revealed no significant differences χ^2 (35, N= 80.9) = 33.97, p = .518).

Discussion

The present experiment aimed to investigate whether bilingual speakers of Basque (OV) and Spanish (VO) used the frequency-based segmentation strategies of the two languages they command, or preferred the segmentation strategy characteristic of their native language. The significant difference found between the two groups of Basque-Spanish bilinguals shows that the context language significantly influenced their performance: the group given instructions in Basque produced a greater number of frequent-final responses (78.06%), order associated to OV languages, than the group given instructions in Spanish (67.16%). No such difference was found in the responses of the Spanish-Basque bilinguals, i.e., the context language did not modulate the Spanish-Basque bilinguals' segmentation preferences. This context language effect obtained in the groups of Basque-Spanish bilinguals suggests that bilingual speakers can deploy the frequency-based segmentation strategies characteristic of their two languages.

In what follows, a series of potential accounts for the observed asymmetry in the segmentation preferences of Basque-Spanish and Spanish-Basque bilinguals are discussed, though the results obtained in the present experiment prevent us from adjudicating between these alternative hypotheses, at the current state of our knowledge.

Though unlikely, the observed asymmetry in the performance of Basque-Spanish and Spanish-Basque bilinguals might result from the inhibition of the Spanish-Basque bilinguals' L1 segmentation strategy. Implementation of the L2's segmentation strategy by both groups of Spanish-Basque bilinguals would thus result in the frequent-final preference observed, a preference that is similar to the one obtained in the Basque-Spanish context Basque bilinguals, which differs significantly from the preference found in the group of Basque-Spanish context Spanish bilinguals.[1] Simultaneous activation of the bilinguals' two languages has been well-established in research on lexical access (Costa, Caramazza, and Sebastián-Gallés, 2000), and models such as Green's (1998) have proposed that bilinguals inhibit the non-target language during lexical access. It is however unclear why the group of Spanish-Basque bilinguals would inhibit their L1 (Spanish) when presented with the Spanish context, i.e., why participants would perceive their L2 as the target language given the absence of any input in their L2 (Basque) during the experiment.

However, the frequent-final segmentation preference observed in the two groups of Spanish-Basque bilinguals might be due to causes other than inhibition of their L1 (which will be discussed below), and the asymmetry in the performance of Basque-Spanish and Spanish-Basque bilinguals might reflect that deployment of the L2's segmentation strategy is constrained, as shown by the absence of a context language effect in the preferences of the Spanish-Basque bilinguals. This constraint might stem from differences in proficiency and frequency of use of the two languages by the

[1] The authors wish to thank one of the reviewers for pointing out this possibility.

speakers of these two groups. Though all Spanish-Basque bilingual participants were highly proficient in their L2, Basque, it is nonetheless possible that the Basque-Spanish bilingual participants had higher proficiency in their L2, Spanish, due to the particular sociolinguistic situation of the Basque Country, an area in which Spanish is the prevailing language. The diglossic situation of the Basque Country demands frequent changes from Basque to Spanish in the group of Basque-Spanish bilinguals, as opposed to a more limited use of Basque in the group of Spanish-Basque bilinguals. The more balanced use of Basque and Spanish in the group of Basque-Spanish bilinguals might entail greater proficiency in the two languages, leading to a different processing of the artificial language, similar to what has been found in other areas of language processing such as lexical access (Costa and Santesteban 2004; Costa, Santesteban, and Ivanova 2006).

Alternatively, the absence of a context language effect in Spanish-Basque bilinguals could indicate that frequent-initial ordering of frequent and infrequent elements is the default or unmarked order, whereas frequent-final ordering is a marked order. However, the data obtained in the present experiment do not support this hypothesis, as discussed in what follows. Kayne (1994) proposes that natural languages have a universal structure in which specifiers precede heads, and, crucially, heads precede complements. Head-final, OV languages would thus result from the movement of the complement to a specifier position preceding the head. Langus and Nespor (2010) provide supporting evidence for this proposal in a speech comprehension task with monolingual speakers of an OV language (i.e., Turkish) and a VO language (i.e., Italian). When presented with sequences that instantiated the six possible orderings of subjects, objects and verbs (i.e., SOV, VOS, VSO, OSV, OVS and SVO) both groups of participants showed an advantage in sequences with VO orderings compared to

sequences with OV orderings. VO sequences seemed hence to have a processing advantage.

An asymmetry in speech segmentation strategies in bilingual populations has indeed been previously observed. Cutler et al. (1989; 1992) observed that while French dominant French-English bilinguals deploy a syllable-based segmentation strategy (i.e., characteristic in French) when presented with stimuli in French, but abandon this inefficient strategy when presented with stimuli in English (i.e., language characterized by stress-based segmentation), English-dominant bilinguals' performance was not affected by the language of the stimuli.

Following this hypothesis, the performance differences between Basque-Spanish and Spanish-Basque bilinguals observed in the present experiment would result from the fact that Basque-Spanish bilinguals, native speakers of an OV language, have acquired the marked ordering of heads and complements (i.e., head-final). Hence, they might be able to implement the two strategies characteristic of their two languages, i.e., the marked strategy characteristic of their L1 (head-final) and the unmarked strategy that characterizes their L2, Spanish (head-initial). Spanish-Basque bilinguals, on the other hand, would not have acquired the marked strategy of the L2, and could therefore be able to deploy only the segmentation strategy of their L1. However, this hypothesis leads to the prediction that Spanish-Basque bilinguals should present a frequent-initial segmentation preference. As mentioned above, this prediction is not met, given the clear frequent-final segmentation preference found in the Spanish-Basque bilinguals. We will address this issue below.

The difference found in the groups of Basque-Spanish bilinguals regarding the segmentation preferences of the ambiguous language shows that adult speakers are able to track the relative frequency of the elements in the artificial language and make use of

‘functor-like’ elements (in terms of frequency) to divide the input into phrase-like units. This finding provides supporting evidence for the claim that the salient frequency of functors in natural languages might lead learners to use them as anchoring points to acquire the grammar (Green 1979; Valian and Coulson 1988; Gervain et al. 2013).

Last, the frequent-final segmentation preference for the ambiguous language observed in Basque-Spanish bilinguals, who are native speakers of an OV language, replicates the preference obtained in Gervain et al. (2013). However, the Spanish-Basque bilinguals examined, who are speakers of a VO language, did not show the expected frequent-initial segmentation preference. By contrast, a similar significant preference for frequent-final segmentation was found both in OV and VO languages in the present experiment.

As mentioned in the Introduction, Gervain et al. (2013) argue that the non-significant frequent-initial preference found for Italian and French monolinguals might result from the amount of suffixation allowed in these two languages, which entails a frequent-final ordering that would diminish the preference of the native speakers for chunking a string according to the principle that a frequent unit is located at the beginning of a constituent. However, the frequent-final segmentation preference found in the VO language speakers is unlikely to have resulted from the relatively suffixing inflectional morphology of Spanish, as discussed below.

Unlike in Italian, in French suffixes are often only realized in liaison contexts. However, the corpus analysis conducted by Gervain et al. (2013) in French and Italian revealed no significant differences in the amount of suffixation between these two languages. Interestingly, though a predominance of frequent-initial items was found in the corpus corresponding to these VO languages, the difference between the number of frequent-initial and frequent-final items was only marginally significant in Italian ($p =$

.07) and not significant in French. This distribution mirrored the non-significant frequent-initial segmentation preference observed in French and Italian monolinguals. French, Italian and Spanish all have derivational suffixation (and prefixation) and exclusively suffixing inflections. Thus, in order for suffixation to account for the difference between the (non-significant) frequent-initial preference obtained in French and Italian by Gervain et al. (2013) and the strong frequent-final preference obtained in Spanish in the present experiment, suffixation should be much greater in Spanish than in French and Italian, so that Spanish had a predominance of frequent-final items, as found in Basque and Japanese by Gervain et al. (2013). This rather unlikely explanation could be put to test by comparing the results of corpus analyses that measure the frequency distribution of suffixes and prefixes in Spanish, Italian and/or French and Basque, and the amount of frequent-initial and frequent-final items that are found in Spanish, in a corpus analysis similar to Gervain et al.'s (2013).

As mentioned by Gervain et al. (2013), a VO and exclusively prefixing language such as Thai would be the perfect equivalent to the OV languages tested in Gervain et al. (2013) and the present experiment. If the amount of suffixation allowed in a given language modulates the speakers' representation of the frequency distribution of elements in the input, speakers of a VO and prefixing language should exhibit a strong frequent-initial segmentation preference.

Acoustic-phonetic properties of the input could alternatively have induced the general frequent-final segmentation preference observed in the present experiment. Materials and procedure in the present experiment were the same as those used in Gervain et al. (2013) with the exception of the voice used in synthesizing the stimuli. Instead of the Spanish-based voice (es1 voice, Spanish male, MBROLA software) used in Gervain et al. (2013), the current stimuli were synthesized with a German-based

voice (de6, German male, MBROLA software). German and Spanish stops differ significantly in their Voice Onset Times (VOTs), and these differences may have influenced the participants' performance. Studies on speech segmentation have shown that acoustic-phonetic cues play an important role, and that, indeed, adults rely on segmental cues such as acoustic-phonetic cues rather than on statistical cues in speech segmentation (Fernandes, Ventura, and Kolinsky 2007).

Conclusions

Bilingual speakers are able to deploy two segmentation strategies characteristic of the two languages they command, and can switch between these strategies as required by the input. As shown by the context language effect obtained in the groups of Basque-Spanish bilinguals, the language in which bilinguals are addressed during the experiment significantly influences their performance, i.e., their segmentation preferences of the ambiguous artificial language. The asymmetry observed between the Basque-Spanish and Spanish-Basque bilinguals might result from the Spanish-Basque bilinguals' inhibition of their L1. Alternatively, this asymmetry might result from limitations in the acquisition of the L2's strategy due to (a) differences in the bilinguals' language proficiency and language use, or (b) the possibility that frequent-final segmentation is a marked segmentation strategy, which can only be acquired as part of the L1's repertoire of processing strategies. Last, the frequent-final segmentation preference observed in native Spanish speakers might result from the amount of suffixation found in this language, or from acoustic-phonetic properties of the input. All these alternative hypotheses and their potential likelihood have been discussed above.

We may conclude that adult listeners track the frequency distributions of functor-like elements in an artificial language, elements which are used to segment the

input into phrase-like units, supporting thus the claim that the natural languages' salient frequency of functors leads listeners to treat these frequent elements as anchoring points to syntactic structure.

Figure captions

Figure 1. The figure shows the percentage of frequent-final responses per group. The error bars represent ±1SE.

Figure 2. The figure shows the number of frequent-final responses of each of the 111 participants, sorted by group.

Table captions

Table 1. Options given to the participants

Table 2. Options given to the participants

Table 3. Options given to the participants

Table 4. Options given to the participants

Table 5. To be filled by the participants

Table 6. Options given to the participants

Table 7. Options given to the participants

References

Baker, Mark. 2001. *The Atoms of Language: The Mind's Hidden Rules of Grammar.* New York: Basic Books.

Bohn, Ocke-Schwen, and James E. Flege. 1993. "Perceptual Switching in Spanish/English Bilinguals". *Journal of Phonetics* 21: 267–290. doi:10.1121/1.2025281

Caramazza, Alfonso, Grace H. Yeni-Komshian, Edgar B. Zurif, and Ettore Carbone. 1973. "The Acquisition of a New Phonological Contrast: The Case of Stop Consonants in French-English Bilinguals". *Journal of the Acoustical Society of America* 54(2): 421–428. doi:10.1121/1.1913594

Costa, Albert, Alfonso Caramazza, and Nuria Sebastián-Gallés. 2000. "The Cognate Facilitation Effect: Implications for Models of Lexical Access". *Journal of Experimental Psychology: Learning, Memory, and Cognition* 26(5): 1283–1296.

Costa, Albert, and Mikel Santesteban. 2004. "Lexical Access in Bilingual Speech Production: Evidence from Language Switching in Highly Proficient Bilinguals and L2 Learners". *Journal of Memory and Language* 50: 491–511. doi:10.1016/j.jml.2004.02.002

Costa, Albert, Mikel Santesteban, and Iva Ivanova. 2006. "How Do Highly Proficient Bilinguals Control their Lexicalization Process? Inhibitory and Language-Specific Selection Mechanisms Are Both Functional". *Journal of Experimental Psychology: Learning, Memory, and Cognition* 32(5): 1057–1074. doi:10.1037/0278-7393.32.5.1057

Chomsky, Noam. 1981. *Lectures on Government and Binding.* Dordrecht: Foris.

Cutler, Anne, Jacques Mehler, Dennis Norris, and Juan Segui. 1989. "Limits on Bilingualism". *Nature* 340(6230): 229–230. doi:10.1038/340229a0

Cutler, Anne, Jacques Mehler, Dennis Norris, and Juan Segui. 1992. "The Monolingual Nature of Speech Segmentation by Bilinguals". *Cognitive Psychology* 24(3): 381–410. doi:10.1016/0010-0285(92)90012-Q

Dutoit, Thierry. 1997. *An Introduction to Text-to-Speech Synthesis.* Dordrecht: Kluwer.

Elman, Jeffrey L., Randy L. Diehl, and Susan E. Buchman. 1977. "Perceptual Switching in Bilinguals". *Journal of the Acoustical Society of America* 62(4): 971–974. doi:10.1121/1.381591

Elston-Güttler, Kerrie E., Thomas C. Gunter, and Sonja A. Kotz. 2005. "Zooming into L2: Global Language Context and Adjustment Affect Processing of Interlingual Homographs in Sentences". *Cognitive Brain Research* 25: 57–70.

Fernandes, Tania, Paulo Ventura, and Régine Kolinsky. 2007. "Statistical Information and Coarticulation as Cues to Word Boundaries: A Matter of Signal Quality". *Perception & Psychophysics* 69(6): 856–864.

Fiser, József, and Richard N. Aslin. 2001. "Unsupervised Statistical Learning of Higher-Order Spatial Structures from Visual Scenes". *Psychological Science* 12(6): 499–504. doi:10.1111/1467-9280.00392

Flege, James E., and Wieke Eefting. 1987. "Cross-Language Switching in Stop Consonant Perception and Production by Dutch Speakers of English". *Speech Communication* 6(3): 185–202. doi:10.1016/0167-6393(87)90025-2

Gervain, Judit. 2007. "From the Richness of the Signal to the Poverty of the Stimulus: Early Mechanisms of Language Acquisition" PhD diss., SISSA.

Gervain, Judit, Marina Nespor, Reiko Mazuka, Ryota Horie, and Jacques Mehler. 2008. "Bootstrapping Word Order in Prelexical Infants: A Japanese-Italian Cross-Linguistic Study". *Cognitive Psychology* 57: 56–74. doi:10.1016/j.cogpsych.2007.12.001

Gervain, Judit, Nuria Sebastián-Gálles, Begoña Díaz, Itziar Laka, Reiko Mazuka, Naoto Yamane, Marina Nespor, and Jacques Mehler. 2013. "Word Frequency Cues Word Order in Adults: Cross-Linguistic Evidence". *Frontiers in Psychology* 4: 689. doi:10.3389/fpsyg.2013.00689

Green, Thomas R. G. 1979. "The Necessity of Syntax Markers: Two Experiments with Artificial Languages". *Journal of Verbal Learning and Verbal Behavior* 18: 481–496. doi:10.1016/S0022-5371(79)90264-0

Green, David W. 1998. “Mental Control of the Bilingual Lexico-Semantic System. *Bilingualism: Language and Cognition* 1: 67–81.

Greenberg, Joseph H. 1963. “Some Universals of Grammar with Particular Reference to the Order of Meaningful Elements”. In *Universals of Language*, edited by Joseph H. Greenberg, 73–113. London: MIT Press.

Grosjean, François. 1998. “Studying Bilinguals: Methodological and Conceptual Issues”. *Bilingualism: Language and Cognition* 1: 131–149. doi:10.1017/S136672899800025X

Grosjean, François. 2001. “The bilingual's language modes”. In *One Mind, Two Languages: Bilingual Language Processing*, edited by Janet Nicol, 1–22. Oxford: Blackwell.

Hauser, Marc D., Elissa L. Newport, and Richard N. Aslin. 2001. “Segmentation of the Speech Stream in a Non-Human Primate: Statistical Learning in Cotton-Top Tamarins”. *Cognition* 78: B53–B64. doi:10.1016/S0010-0277(00)00132-3

Hazan, Valerie L., and Georges Boulakia. 1993. “Perception and Production of a Voicing Contrast by French-English Bilinguals”. *Language and Speech* 36(1): 17–38. doi:10.1177/002383099303600102

Kayne, Richard. 1994. *The Antisymmetry of Syntax.* Cambridge: MIT Press.

Kirkham, Natasha Z., Jonathan A. Slemmer, and Scott P. Johnson. 2002. “Visual Statistical Learning in Infancy: Evidence for a Domain General Learning Mechanism”. *Cognition* 83: B35–B42. doi:10.1016/S0010-0277(02)00004-5

Langus, Alan, and Marina Nespor. 2010. “Cognitive Systems Struggling for Word Order”. *Cognitive Psychology* 60: 291–318. doi:10.1016/j.cogpsych.2010.01.004

Morgan, James L., Rushen Shi, and Paul Allopenna. 1996. “Perceptual Bases of Rudimentary Grammatical Categories: Toward a Broader Conceptualization of

Bootstrapping". In *Signal to Syntax: Bootstrapping from Speech to Grammar in Early Acquisition*, edited by James L. Morgan and Katherine Demuth, 263–283. Mahwah: Lawrence Erlbaum Associates.

Paulmann, Silke, Kerrie E. Elston-Güttler, Thomas C. Gunter, and Sonja A. Kotz. 2006. "Is Bilingual Lexical Access Influenced by Language Context?". *Neuroreport* 17(7): 727–731.

Peña, Marcela, Luca L. Bonatti, Marina Nespor, and Jacques Mehler. 2002. "Signal-Driven Computations in Speech Processing". *Science* 298: 604–607. doi:10.1126/science.1072901

Saffran, Jenny R., Richard N. Aslin, and Elissa L. Newport. 1996. "Statistical Learning by 8-Month-Old Infants". *Science* 274(5294): 1926–1928. doi:10.1126/science.274.5294.1926

Saffran, Jenny R., Elissa L. Newport, and Richard N. Aslin. 1996. "Word Segmentation: The Role of Distributional Cues". *Journal of Memory and Language* 35: 606–621. doi:10.1006/jmla.1996.0032

Saffran, Jenny R., Elizabeth K. Johnson, Richard N. Aslin, and Elissa L. Newport. 1999. "Statistical Learning of Tone Sequences by Human Infants and Adults". *Cognition* 70: 27–52. doi:10.1016/S0010-0277(98)00075-4

Shi, Rushen, Anne Cutler, Janet F. Werker, and Marisa Cruickshank. 2006. "Frequency and Form as Determinants of Functor Sensitivity in English-Acquiring Infants". *Journal of the Acoustical Society of America* 119(6): EL61–EL67. doi:10.1121/1.2198947

Shi, Rushen, Alexandra Marquis, and Bruno Gauthier. 2006. "Segmentation and Representation of Function Words in Preverbal French-Learning Infants". In Vol. 2 of *BUCLD: 30th Annual Boston University Conference on Language Development*, edited

by David Bamman, Tatiana Magnitskaia, and Colleen Zaller, 549–560. Boston: Cascadilla Press.

Soares, Carlos, and François Grosjean. 1984. "Bilinguals in a Monolingual and a Bilingual Speech Mode: The Effect on Lexical Access". *Memory and Cognition* 12(4):380–386.

Toro, Juan M., and Josep B. Trobalón. 2005. "Statistical Computations over a Speech Stream in a Rodent". *Perception & Psychophysics* 67(5): 867–875. doi:10.3758/BF03193539

Valian, Virginia, and Seana Coulson. 1988. "Anchor Points in Language Learning: The Role of Marker Frequency". *Journal of Memory and Language* 27(1): 71–86. doi:10.1016/0749-596X(88)90049-6

Weiss, Daniel J., Chip Gerfen, and Aaron D. Mitchel. 2009. "Speech Segmentation in a Simulated Bilingual Environment: A Challenge for Statistical Learning?" *Language Learning and Development* 5(1): 30–49. doi:10.1080/15475440802340101

Williams, Lee .1977. "The Perception of Stop Consonant Voicing by Spanish-English Bilinguals". *Perception and Psychophysics* 21(4): 289–297. doi:10.3758/BF03199477

Appendix 1. Background Questionnaire

Name:
Family name:
Gender:
Birth date:
E-mail address:
Telephone:
Place of residence (town and province):
Place of birth (town and province):
Have you ever lived in another town and/or province?
If so, where (town, province)?
From which date to which date?

• As an infant, in which language were you spoken to by...

...you mother?

...your father?

...your brother(s) and sister(s)?

...your grandparents?

[Insert Table 1]

• At what age did you start speaking...

...Spanish?

...Basque?

• If you have a language proficiency certificate on Basque, please specify which one:

• Which language and with which frequency do/did you use...

...as an infant, prior to going to school?

…during primary school, at school?

…during primary school, at home?

…during primary school, elsewhere?

...as a teenager, during secondary school, at high school?

...as a teenager, during secondary school, at home?

...as a teenager, during secondary school, elsewhere?

...at the moment, in adulthood, at the university/work?

...at the moment, in adulthood, at home?

...at the moment, in adulthood, elsewhere?

[Insert Table 2]

• In general, which language do you feel more comfortable in?

[Insert Table 3]

• With how much frequency do you read in Spanish/Basque?

[Insert Table 4]

• How do you get by in the following languages? Do you have any language proficiency certificates?

[Insert Table 5]

[Insert Table 6]

• Choose your preferred hand when carrying out the following actions:

write

draw

throw an object

cut with scissors

brush your teeth

cut with a knife

use the spoon

sweep (hand placed above)

play tennis (service)

open a tin (hand placed above)

[Insert Table 7]

Appendix 2. Subject-by-subject percentage of frequent-final responses

Basque-Spanish context Basque bilinguals

20 Participants, mean of frequent-final responses: 78.06%

Part.1: 77.78%; Part.2: 100%; Part.3: 83.33%; Part.4: 75%; Part.5: 83.33%; Part.6:97.22%; Part.7: 83.33%; Part.8: 88.89%; Part.9: 88.89%; Part.10: 91.67%; Part.11: 25%; Part.12: 94.44%; Part.13: 83.33%; Part.14: 69.44%; Part.15: 69.44%; Part.16: 61.11%; Part.17: 77.78%; Part.18: 83.33%; Part.19: 47.22%; Part.20: 80.56%.

Basque-Spanish context Spanish bilinguals

28 Participants, mean of frequent-final responses: 67.16%

Part.1: 61.11%; Part.2: 50%; Part.3: 36.11%; Part.4: 94.44%; Part.5: 58.33%; Part.6:88.89%; Part.7: 86.11%; Part.8: 63.89%; Part.9: 83.33%; Part.10: 50%; Part.11: 50%; Part.12: 91.67%; Part.13: 72.22%; Part.14: 66.67%; Part.15: 86.11%; Part.16: 72.22%; Part.17: 72.22%; Part.18: 25%; Part.19: 69.44%; Part.20: 33.33%; Part.21: 75%; Part.22: 69.44%; Part.23: 83.33%; Part.24: 88.89%; Part.25: 50%; Part.26:80.56%; Part.27: 55.56%; Part.28: 66.67%.

Spanish-Basque context Basque bilinguals

32 Participants, mean of frequent-final responses: 73.26%

Part.1: 83.33%; Part.2: 94.44%; Part.3: 72.22%; Part.4: 75%; Part.5: 72.22%; Part.6: 77.78%; Part.7: 83.33%; Part.8: 94.44%; Part.9: 58.33%; Part.10: 44.44%; Part.11: 69.44%; Part.12: 69.44%; Part.13: 91.67%; Part.14: 66.67%; Part.15: 100%; Part.16: 72.22%; Part.17: 69.44%; Part.18: 100%; Part.19: 88.89%; Part.20: 83.33%; Part.21: 63.89%; Part.22: 69.44%; Part.23: 80.56%; Part.24: 61.11%; Part.25: 61.11%; Part.26: 69.44%; Part.27: 44.44%; Part.28: 33.33%; Part.29: 88.89%; Part.30: 50%; Part.31: 80.56%; Part.32: 75.

Spanish-Basque context Spanish bilinguals

31 Participants, mean of frequent-final responses: 74.46%

Part.1: 66.67%; Part.2: 88.89%; Part.3: 86.11%; Part.4: 94.44%; Part.5: 88.89%; Part.6:91.67%; Part.7: 44.44%; Part.8: 94.44%; Part.9: 58.33%; Part.10: 97.22%; Part.11: 61.11%; Part.12: 83.33%; Part.13: 83.33%; Part.14: 88.89%; Part.15: 88.89%; Part.16: 50%; Part.17: 72.22%; Part.18: 52.78%; Part.19: 83.33%; Part.20: 55.56%; Part.21: 38.89%; Part.22: 97.22%; Part.23: 86.11%; Part.24: 55.56%; Part.25: 86.11%; Part.26: 94.44%; Part.27: 55.56%; Part.28: 97.22%; Part.29: 66.67%; Part.30: 72.22%; Part.31: 27.78%.

Table1

Only Spanish.
Mainly Spanish, albeit sometimes Basque.
Basque and Spanish with equal frequency.
Mainly Basque, albeit sometimes Spanish.
Only Basque.

Table2

Only Spanish.
Almost always Spanish, rarely Basque.
Mainly Spanish, albeit using Basque at least 25% of the time.
Basque and Spanish with equal frequency.
Mainly Basque, albeit using Spanish at least 25% of the time
Almost always Basque, rarely Spanish.
Only Basque.

Table3

Spanish
Basque
I feel comfortable in both languages.

Table4

Never
Little
Neither too much nor too little.
Quite a lot
Very much

Table5

	Speak	Understand	Read	Write	Certificate
Basque					
Spanish					
English					
French					
Other languages					

Table6

Not at all
Very bad
Bad
So-so
Quite
Well
Very well
Perfectly

Table7

Left hand
Right hand
Both hands

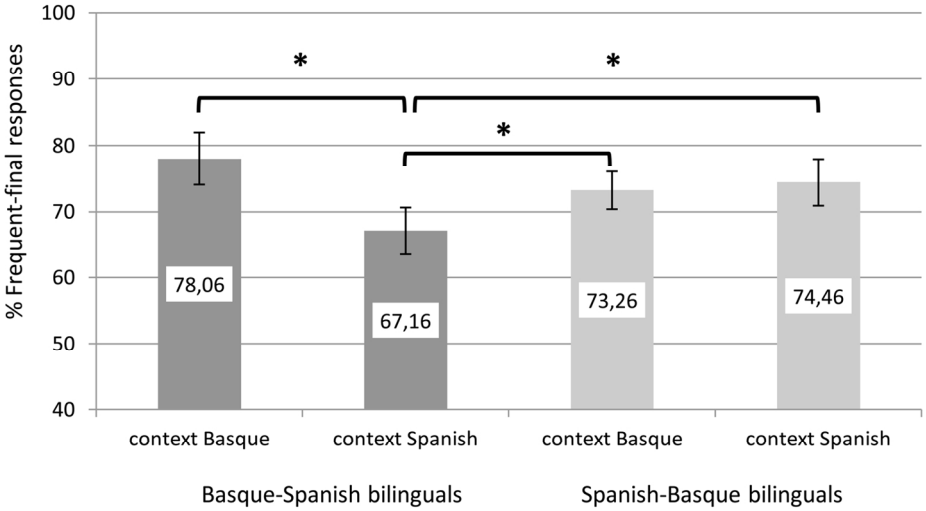

Figure 1. The figure shows the percentage of frequent-final responses per group. The error bars represent ±1SE.
141x77mm (300 x 300 DPI)

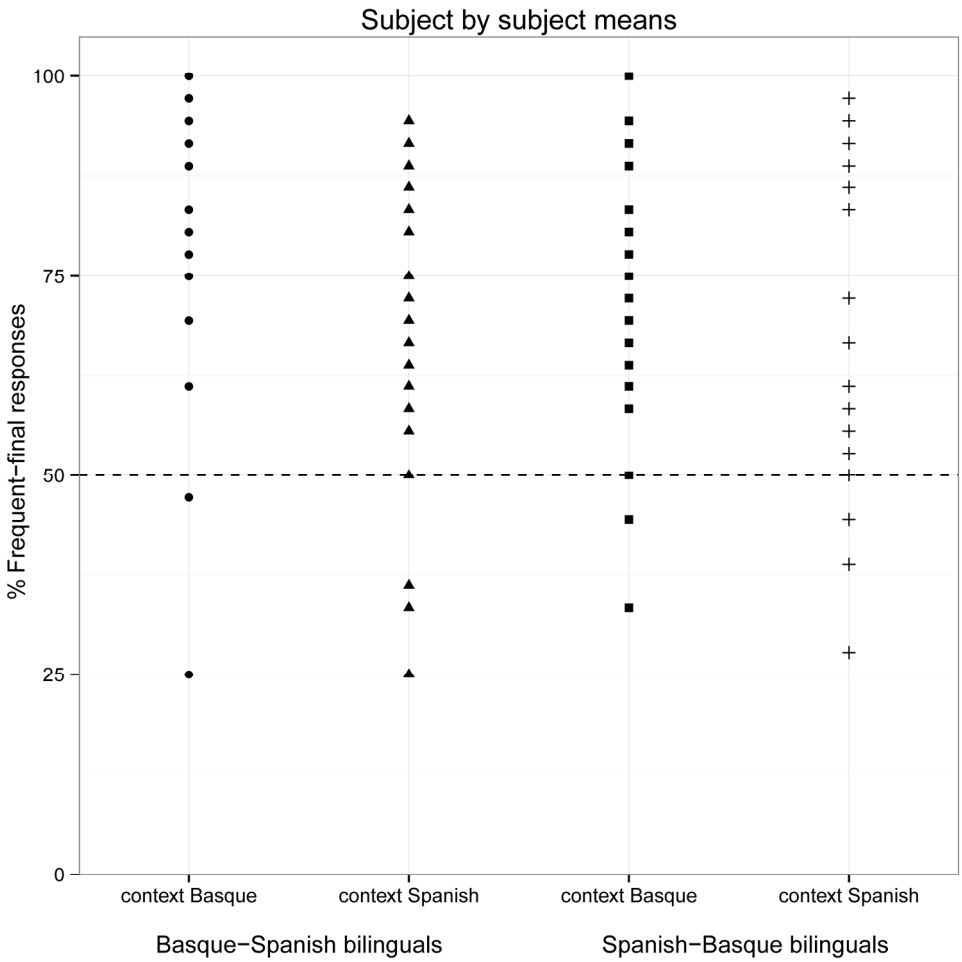

Figure 2. The figure shows the number of frequent-final responses of each of the 111 participants, sorted by group.
177x177mm (300 x 300 DPI)