*Title*: Speech perception in bilingual contexts: neuropsychological impact of mixing languages at the inter-sentential level.

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**Abstract**

The neuropsychological impact of processing naturalistic speech streams containing code switches at the inter-sentential level was studied in fluent bilinguals who frequently switch between languages. To this end, electroencephalographic recordings (EEG) and a behavioral recall test were used to address speech perception while processing pieces of information conveyed in a single- or mixed-language speech carrier. Measurements of spectral power in the continuous EEG signal accompanying perception of speech were directly compared between conditions. The direction of the switch was also assessed. Our principal finding was a reduced oscillatory power in the beta frequencies when bilinguals are attentively listening to informative speech streams in which the two known languages are intermixed. The memory recall test showed equivalent performance across the different language conditions. These results suggest that the cognitive cost of processing speech containing inter-sentential language switches is reflected at a neural level but that it has no measurable impact on the recall of long streams of information. Listening speech in which the two languages known to a bilingual are mixed at a sentence level, may have no clear behavioral drawback, but implies some neural processing cost.

Keywords: Bilingualism; Speech perception; Codeswitch; Language mixing; EEG

## 1. Introduction

Alternating between processing of two different languages is a common situation in bilingual environments. If two languages are ubiquitous (e.g. in the Basque Country: Basque and Spanish), mixing them at word-to-word and sentence-to-sentence level is a natural (expected) phenomenon (Poplack, 1978). Nevertheless, even though mixing languages occurs in everyday life, it is sometimes actively avoided in circumstances where transmission and acquisition of long streams of information are required in a structured context. These could be the cases of news in the media, classes at the school and written language in general. To avoid mixing languages seems to be an intuitive idea given the well-known fact that language switching is cognitively demanding and incurs an increased cognitive load and higher attentional demands (Branzi, Martin, Abutalebi, & Costa, 2014; Costa & Santesteban, 2004; Verhoef, Roelofs, & Chwilla, 2009). However, most of the evidence on the mutual interference between two different language systems and the cognitive cost that overcoming this interference implies, comes from studies in which isolated-item switching (e.g. one word) paradigms are used. In contrast, other forms of naturalistic language mixing situations such as voluntary switching conditions in word naming experiments suggest that alternating between languages does not necessarily imply a generalized cost (see de Bruin, Samuel, & Duñabeitia, 2018; Gollan, Kleinman, & Wierenga, 2014). Nonetheless, while the number of studies exploring ecologically valid language switching at the word level is increasing, studies exploring meaningful utterances such as sentences are still very scarce (for a review, see van Hell, Lifcosky, & Ting, 2015).

A study by Litcofsky and Van Hell (2017) examined the cost of mixing languages using naturalistic sentences and collecting self-paced reading measures as well as electroencephalographic (EEG) recordings. Importantly, switching was an intra-sentential manipulation, and Spanish-English bilinguals were presented with sentences that in some conditions could include a switch to the dominant or to the weaker language (e.g., "Next week, the young waiter will begin his trabajo con gran entusiasmo"). This way, the study addressed language switching between coherent language expressions looking beyond intra-sentential single-word switches. From the behavioral results of the study they concluded that, even for highly proficient bilinguals, intra-sentential language switching involves a cost that can be observed in the form of longer reading times. Furthermore, the EEG results demonstrated significant differences between switching directions in the event-related potential (ERP) analysis and in the time-frequency analysis. The ERP data showed an enhanced effortful processing as indexed by an increased late positive component (LPC) for codeswitches from the first to the second language (L1→L2) as compared to codeswitches from the second to the first language (L2→L1). The analysis of the oscillatory activity also showed differential effects depending on the switching direction, with a power decrease in the lower beta frequency band for L1→L2 switches, and a power increase in the theta band for L2→L1 switches. Interestingly, similar results have been recently reported by the same group in a study that presented participants with intra-sentential codeswitches in the auditory modality (Fernandez, Litcofsky, & van Hell, 2019). Listening to sentences that included L1→L2 switches has been associated with a power decrease in the upper beta frequency band and also with ERP (N400 and LPC) effects.

As seen, the processing of sentences that include a switch to a different language is associated with a distinctive neural pattern as compared to non-switching conditions. However, despite the existence of certain amodal mechanisms underlying language processing (as evidenced by the similar results reported by Litcofsky and Van Hell, 2017, in the visual domain, and by Fernandez et al., 2019, in the auditory domain), serial processing of consecutive words in a rapid serial visual presentation reading task or in an auditory sentence processing task is fundamentally different from speech perception of long utterances from which the listener has to extract meaning. Moreover, as compared to intra-sentential language switching, codeswitching between sentences is delimited by suprasegmental features (e.g. phonology) that provide a stronger link between languages and ideas or contexts and occurs sparser in time. In other words, in contrast to intra-sentential language switches, inter-sentential switches involve language alternations over long functional units with semantic and syntactic congruency in its inner elements and allow for an easier prediction of switching occurrence. Hence, the processing of speech with inter-sentential language switches allows the listener to integrate the meaning of clauses containing phonological, lexical, and syntactic consistency, in an otherwise reduced probabilistic context (i.e. less frequent and more easily predicted). Thus, inter-sentential language switches may represent a more straightforward language-switching situation as compared to other types. In fact, results of studies using experimental manipulations partially resembling inter-sentential codeswitching support the idea of their reduced cognitive demands as compared to other types of switches (Bultena, Dijkstra, & van Hell, 2015; Gullifer, Kroll, & Dussias, 2013).

In addition, in line with the adaptive control hypothesis (Green & Abutalebi, 2013), highly proficient bilinguals that are frequent switchers and that use both languages in multiple social contexts are expected to show enhanced cognitive control capacities allowing for high tolerance to task switching. This is due to their training in inhibiting and activating representations and codes from two languages that are mutually interfering (Yang, Hartanto, & Yang, 2016). With this in mind, we considered the possibility that for highly proficient bilinguals immersed in dual language contexts, the processing of inter-sentential language switches during natural conversation incurs no significant additional processing efforts as compared to non-switching situations. The current study aims to provide electrophysiological evidence on the manner in which bilinguals process natural speech containing code-mixing at the inter-sentential level, but also on the neuropsychological consequences of this. To this last end, we also included a behavioral memory recall test. Recent behavioral studies have demonstrated that bilingual children and young adults learn and remember concepts equally well in single-language contexts (namely, upon presentation of the pieces of information in one of their known languages) and in mixed-language contexts (namely, when the two known languages are mixed during the learning phases; Antón, Thierry, & Duñabeitia, 2015; Antón, Thierry, Goborov, Anasagasti, & Duñabeitia, 2016).

We designed an experiment in which proficient Spanish-Basque bilingual participants attentively listened to long streams of speech presenting information that could be in one language only or a mixed-language fashion at a sentence-to-sentence level. EEG signal was recorded and used for quantifying the oscillatory brain activity associated with each language condition in the frequency spectrum from 1 to 40 Hz. The assessment of rhythms from induced brain activity is methodologically well suited for studies addressing slow neural dynamics that take place in naturalistic setups (Ding, Melloni, Zhang, Tian, & Poeppel, 2016) and neural oscillations play a key role in auditory perception of verbal input (Pérez, Carreiras, Gillon-Dowens, & Duñabeitia, 2015; Riecke, Formisano, Sorger, Baskent, & Gaudrain, 2018; Zoefel, Archer-Boyd, & Davis, 2018). Specifically, different frequency bands have been linked systematically to diverse neurolinguistic phenomena. In the context of speech perception, theta (4-7 Hz) oscillatory activity has been linked to lexical retrieval processes (Bastiaansen, Oostenveld, Jensen, & Hagoort, 2008) and to semantic working memory processes (Bastiaansen & Hagoort, 2006; Bastiaansen, van der Linden, Ter Keurs, Dijkstra, & Hagoort, 2005). Similarly, alpha (8-12 Hz) has been found to co-vary with listening effort (Obleser, Wostmann, Hellbernd, Wilsch, & Maess, 2012) and speech intelligibility (Obleser & Weisz, 2012). Finally, changes in beta (approximately 13-30 Hz) and gamma (>30 Hz) power have been associated with a predictive coding framework (i.e. the generation of top-down and bottom-up predictions during language processing; Arnal & Giraud, 2012; Arnal, Wyart, & Giraud, 2011; Lewis & Bastiaansen, 2015). Here, we investigated the continuous neural encoding of speech perception in a situation of relatively natural inter-sentential codeswitching and compared it to no-switching situations, seeking differences in the neurophysiological activity by conducting a direct statistical comparison between these conditions. The existence of differential underlying neural oscillatory patterns during single-language and mixed-language conditions would indicate different processing demands depending on the situation, and the precise frequency ranges encompassing these differential effects could allow for a better characterization of the mechanisms associated with the processing of language switches.

In addition to investigate the generalized differences between single-language and mixed-language speech perception, the current study also allowed for exploratory analysis of the oscillatory patterns associated with each switching direction (i.e. the impact of the switches occurring from L1➞L2 versus those occurring from L2➞L1). In non-balanced bilinguals, the presence of asymmetric language switching effects (e.g., Costa & Santesteban, 2004; Litcofsky & Van Hell, 2017) is explained by the larger switching costs from L1➞L2 as compared to L2➞L1 switches due to the need of inhibiting the stronger and more readily available L1 representations (see also Dijkstra & Van Heuven, 2002; Grainger, Midgley, & Holcomb, 2010). As reviewed above, recent EEG studies using visual and auditory presentation of intra-sentential codeswitches have also claimed for an enhanced cognitive cost linked to L1➞L2 switching both at the ERP level (with larger N400 and LPC) and at the oscillatory level (with a power decrease in the beta band; see Fernandez et al., 2019; Litcofsky & Van Hell, 2017). In this line, we tentatively predicted a differential neural cost associated with the processing of auditory input including codeswitches (e.g., in a mixed-language condition), as compared to a single-language condition.

In summary, here we present an exploratory study on the electrophysiological and behavioral consequences of mixing languages at the sentence level to a group of highly proficient yet non-balanced Spanish-Basque bilinguals. Finding similar oscillatory patterns would indicate that any processing difference between mixed-language and single-language speech conditions is subtle if not nonexistent. In contrast, the presence of differences in the oscillatory patterns would be interpreted in line with a functional distinction between purely monolingual and mixed-language speech processing. Also, the behavioral results will show the extent to which language mixing, oscillatory patterns, and memory recall are related. Hence, the results of this study were expected to extend our knowledge about the impact of code-switches in naturalistic speech processing.

## 2. Methods

### 2.1. *Participants*

The study included data from twenty-eight participants (18 females; $M_{Age}$=23.4 years, $SD_{Age}$=3.8). All were right-handed as assessed by an adapted version of the Edinburgh Handedness Inventory, and reported normal visual and hearing acuity and no history of psychiatric or neurological disorders. All of them had acquired both languages before the age of 6 ($M_{Spanish}$= 0, $SD_{Spanish}$= 0; $M_{Basque}$= 1.4, $SD_{Basque}$= 1.6) and lived immersed in a bilingual environment where alternating between the two languages is fairly common. They were fluent and relatively balanced Spanish-Basque bilinguals, as assessed by the BEST, a battery of tests consisting of an individual interview by a native bilingual linguist, a multilingual picture naming test, and two lexical decision tests (de Bruin, Carreiras, & Duñabeitia, 2017) (see Table 1). The study was carried out by the principles laid down in the Declaration of Helsinki. The BCBL Ethics Committee approved the experimental procedure.

*Table 1. Means and standard deviations (in parentheses) of the language skills of the participants in Spanish and Basque (see de Bruin, Carreiras, & Duñabeitia, 2017, for additional information).*

| | Interview (max=5) | Picture Naming (max=65) | Lexical Decision (percentage of errors) |
|---|---|---|---|
| Spanish | 5 (0) | 64.3 (1.1) | 5.7% (3.5) |
| Basque | 4.5 (0.7) | 56.2 (9.8) | 11.2% (6.6) |

## 2.2. *Materials and Procedure*

### 2.2.1. Task

The participants had to complete a questionnaire (*i*) followed by listening to speech tracks (auditory input) (*ii*) containing the information needed to respond correctly to all the questions included in the questionnaire. They were informed that the purpose of the experiment was "to asses how the brain learns the new material needed for a test through EEG."

(*i*) *Questionnaire*: Contained 36 items about the characteristics and peculiarities of a country that they most probably did not know beforehand (Guyana, Belize, or Surinam). Participants had to respond in a forced choice manner by choosing the correct answer from three possible options. They were warned that they would not know the answers, but they had to respond to all the questions 'intuitively.' The questionnaire presented all the questions and answer options in the two languages to avoid any potential interaction between the language of the questionnaire and the language of the audios.

(*ii*) *Auditory input:* Consisted of continuous speech, lasting for approximately 10 minutes. It contained plenty of information about the country previously presented in the questionnaire. Participants were told to pay careful attention to the speech since the information in this audio will provide the correct responses to all of the questions presented in the questionnaire. EEG data were collected during this phase.

Three blocks were presented, each one corresponding to one experimental condition: Spanish, Basque and Mixed Languages. In the Spanish and the Basque conditions, all sentences in the questionnaire and the audio were only in Spanish and Basque, respectively. In the Mixed Language condition, for the questionnaire, all the questions and the responses were presented in both languages; and for the audio, the number of sentences in each language were balanced, intermixing sentences in Spanish and Basque.

After finishing the three consecutive blocks (conditions), participants were asked to return to the lab two days later. They all thought they were returning only to receive payment since the learning of the new material was supposed to be evaluated using the EEG signal. They were not aware they would be asked about the information contained in the audio listening phases on the first day. When they returned, they were asked to complete the same questionnaires again. This manipulation was implemented to assess the amount of information that participants still held in memory two days after the audio listening phase. Previous studies exploring immediate recall have consistently demonstrated that mixing languages does not hinder learning at the behavioral level (Antón et al., 2015, 2016). However, it is still unclear whether language mixing during explicit or implicit learning has any drawback effect after memory consolidation. For this reason, the current study re-tested participants two days after the initial presentation of the information. It is important to note that, when debriefed, none of the participants reported any further search on the learned topics during the two-day gap.

The presentation order of the three different types of blocks was counterbalanced across participants. The specific material contained in the audios (namely, the information about the countries) was also counterbalanced across language conditions. The *questionnaires* were presented in the same order in the first day as the second day.

#### 2.2.2. Stimuli

Presentation of all instructions and stimuli was controlled by a custom-written program created and compiled with Experiment Builder© software (SR-Research, Ontario, Canada) that was run on a PC. The questions with the possible answers were presented visually and in a random order on a monitor, using black font over a white background. Participants responded by pressing the number that corresponded to the option they considered as correct (1, 2 or 3) on the computer keyboard. Supplementary Material 1 provides the original questions and answers choices for each country material.

Auditory stimuli delivered by headphones were created from expository texts about the mentioned countries. These texts contained a similar type of information and equivalent narrative structure. A team of bilingual Basque-Spanish linguists carefully controlled for the versions in the two different languages having (as much as possible) a parallel semantic and syntactic structure in the sentences, similar word and phoneme rate, and equal number of paragraphs. These texts are provided in Supplementary Material 2. A female bilingual speaker recorded the speech stimuli, which were equivalent in length ($M_{length}$=10’23”, $SD_{length}$=16”) and in the underlying power spectra patterns ($p>0.05$, for all frequencies).

### 2.3. *EEG Recording and Analysis*

Participants were seated comfortably in a sound-attenuated room with a monitor positioned in front of them. They were instructed to remain quiet, avoiding body movement. Electrophysiological data were acquired using an elastic cap with a 32-channel BrainAmp system (Brain Products GmbH). The left earlobe was used as reference. Eye movements and blinks were monitored with four additional electrodes providing recordings of the horizontal and vertical EOG. Inter-electrode impedances were set below 5 kΩ at the beginning of the experiment. Data were acquired at a sampling rate of 500 Hz. EEG markers were time-locked to the beginning of each 10-minute audio block.

EEG signal processing and analysis were performed using EEGLAB (Delorme & Makeig, 2004) and custom programs run in MATLAB (version 2014b, The MathWorks Inc.). First, the recorded signal of each participant was re-referenced off-line to the average of the left- and the right-earlobe electrode, and a high-pass filter (FIR) at 1 Hz was applied. Bad channels, identified with the PREP toolbox (Bigdely-Shamlo, Mullen, Kothe, Su, & Robbins, 2015) and through visual inspection of the power spectra, were removed from the dataset. An Independent Component Analysis (ICA, runica method, EOG channels included) was performed and those components identified as mainly containing ocular movements (i.e., blinks, saccades), by examining the components' topographies, frequency spectra and time courses, were removed from the data (up to 4 components; $M_{components}$=3). The bad channels were re-created by spherical interpolation. Next, the signal was segmented. Two different segmentations were done, each corresponding to a specific analysis. For the first analysis assessing for differences between mixed and non-mixed language conditions, the signal was segmented in 10-minute epochs from the onset of each audio block. The first 5 sec were removed, resulting in three epochs of 9 minutes and 55 seconds, each corresponding to one condition, that were further analyzed. For the second analysis investigating the differences as a function of the switching direction, only the recordings associated with the Mixed Languages condition were used. The signal was segmented in 4-seconds epochs from the onset of each sentence-level language switch. This way, an equivalent amount of Basque-to-Spanish (L2➞L1) and Spanish-to-Basque (L1➞L2) switch epochs or 'trials' were generated (namely, 22 per condition, each including the first 4 seconds of the sentence representing a language switch). Note that this procedure allowed for an analysis of the switching effects independent of the duration of the sentences. Finally, for each Language condition (<u>Mixed, Spanish only and Basque only</u>) and Switching condition (L1➞L2, L2➞L1), the power spectral density was estimated for each channel in the frequency range from 1 to 40 Hz using non-overlapping Blackman-Harris window type of a length of 250 milliseconds. The obtained values were collapsed across corresponding conditions for each subject.

A nonparametric permutation-based one-way repeated measures ANOVA (rm-ANOVA) and *t*-test methods from the Resampling Statistical Toolkit of EEGLAB assessed differences between Language and Switching conditions in the channel-frequency power spectra data (number of surrogate data copies=10,000). This distribution-free test does not require any assumption about the correlation structure of the data. *Post-hoc* nonparametric permutation-based *t*-tests were conducted for all pairwise comparisons when a significant effect of Language was found.

### 2.4. *Behavioral Analysis*

The data containing the percentage of errors for each participant in the questionnaires administered on the first and second test days were submitted to a two-way rm-ANOVA including the factors Language (Spanish, Basque and Mixed Language conditions) and Day (Day 1 and Day 2) to identify differences in recall across language conditions and to ascertain that learning had effectively occurred.

## 3. Results

### 3.1. *Behavioral Results*

As expected, performance differed as a function of the day (Day 1 vs. Day 2) when the questionnaires were administered (Day effect: $F(1,27)=467.53$, $p<0.01$). The mean percentage of errors decreased from the first ($M_{Error}$=47.06%) to the second administration of the questionnaires ($M_{Error}$=32.74%), thus showing a healthy learning effect despite the fact that the second questionnaire was administered on a different day. More importantly, the mean accuracy of the participants on both days did not significantly differ across language conditions (Language effect: $F(2,54)=0.03$, $p=0.97$). There was no interaction between Language and Day ($F(2,54)=0.82$, $p=0.45$). In general terms, these results indicate that there is similar behavioral performance in the memory tests regardless of the language(s) used in the presentation of the information.

### *3.2. Power spectra analysis: Language conditions*

The EEG power spectral density associated with listening to auditory stimuli in Spanish, Basque and Mixed Language were compared for each channel (27) and frequency (1-40 Hz). Figure 1 shows the exact channels/frequencies at which there was a significant effect of Language. Supplementary Material 3 contains the statistics from this test, with all the exact F and p-values. Statistically significant differences between conditions were found in 11 (mostly) posterior electrodes in the 13–17 Hz range, and widely distributed differences were evident for most of the electrodes in the 19-24 and 29-33 Hz range, approximately. There were also differences at higher frequencies (up to 40 Hz) in parietal electrodes.

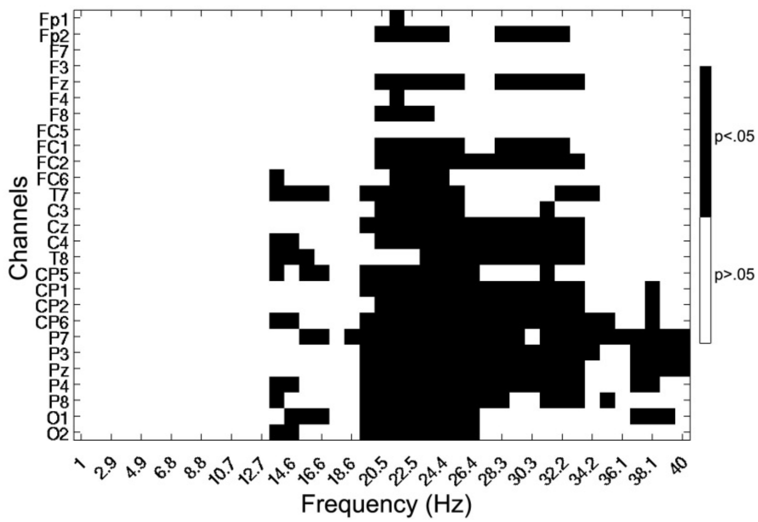
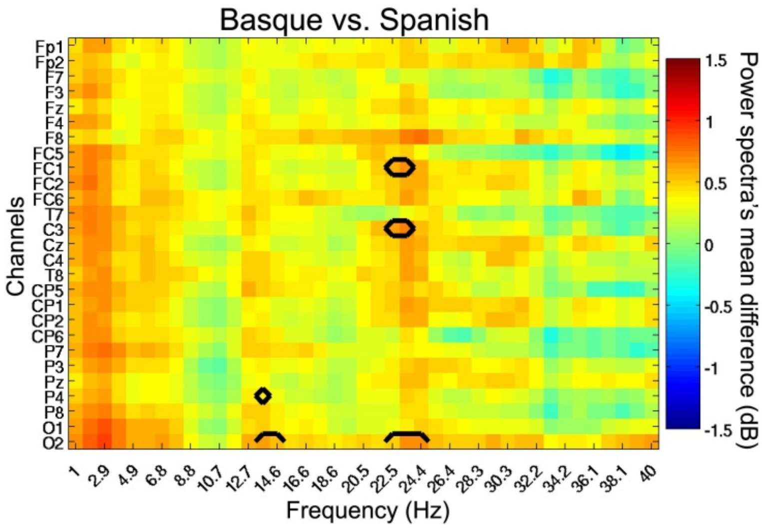


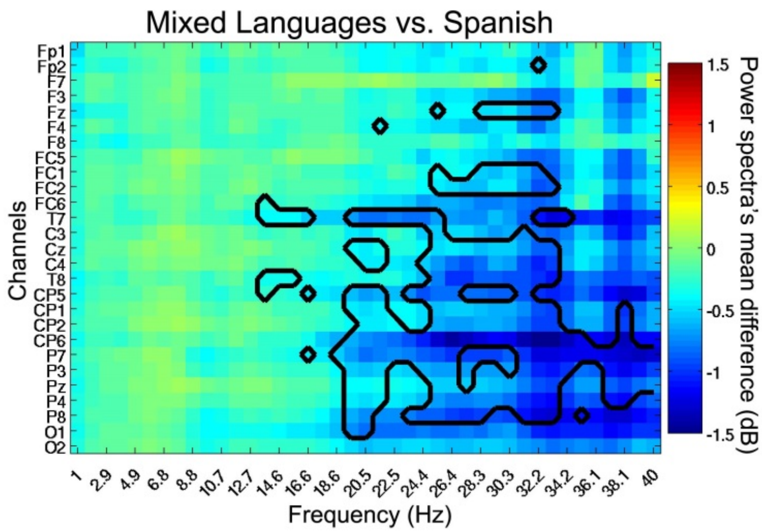

*Figure 1. Channel-frequency representation of the output from the nonparametric permutation-based one-way rm-ANOVA assessing differences between language conditions. In black are those channels and frequencies showing statistically significant power differences (p<0.05) when participants were listening to auditory stimuli in Spanish, Basque and Mixed Languages.*

Figure 2 shows the results of the *post hoc* pairwise comparisons for all channels and frequencies at which a significant ($p<0.05$) effect of Language was obtained.

*Basque vs. Spanish*: The mean power spectra obtained from these two conditions showed a similar pattern, with a minimal increase in the power spectra for the Basque only condition as compared to the Spanish only condition.

*Mixed Language vs. Spanish/Basque*: These comparisons showed significant differences in the beta and gamma band range, mainly driven by the relative reduced spectral power associated with the Mixed Language condition as compared to listening to Spanish-only or Basque-only versions of the auditory stimuli. These differences are especially evident in the 19-33 Hz frequency range, and to a lesser extent at frequencies between 13 and 18 Hz. This is in line with the usual subdivision of beta band in low-beta and high-beta (Buzsáki, 2006). There is also spectral power reduction for frequencies over the 33 Hz in the gamma band range at parietal electrodes. In summary, an overall pattern of reduced power associated with the Mixed Language condition was found mainly in the beta frequency band, and this effect is clearer in the high-beta band.


Basque vs. Spanish
Channels
Fp1 Fp2 F7 F3 Fz F4 F8 FC5 FC1 FC2 FC6 T7 C3 Cz C4 T8 CP5 CP1 CP2 CP6 P7 P3 Pz P4 P8 O1 O2
1 2.9 4.9 6.8 8.8 10.7 12.7 14.6 16.6 18.6 20.5 22.5 24.4 26.4 28.3 30.3 32.2 34.2 36.1 38.1 40
Frequency (Hz)
1.5 1 0.5 0 -0.5 -1 -1.5
Power spectra's mean difference (dB)


Mixed Languages vs. Spanish
Channels
Fp1 Fp2 F7 F3 Fz F4 F8 FC5 FC1 FC2 FC6 T7 C3 Cz C4 T8 CP5 CP1 CP2 CP6 P7 P3 Pz P4 P8 O1 O2
1 2.9 4.9 6.8 8.8 10.7 12.7 14.6 16.6 18.6 20.5 22.5 24.4 26.4 28.3 30.3 32.2 34.2 36.1 38.1 40
Frequency (Hz)
1.5 1 0.5 0 -0.5 -1 -1.5
Power spectra's mean difference (dB)

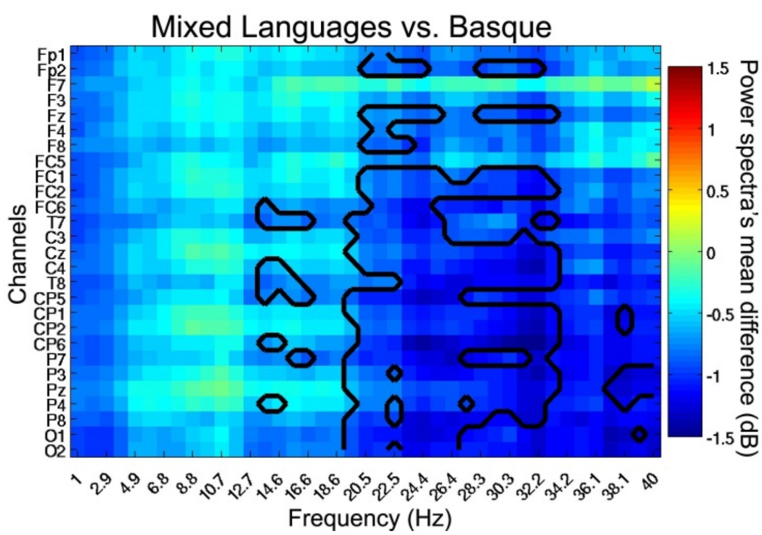

Mixed Languages vs. Basque
Channels
Fp1 Fp2 F7 F3 Fz F4 F8 FC5 FC1 FC2 FC6 T7 C3 Cz C4 T8 CP5 CP1 CP2 CP6 P7 P3 Pz P4 P8 O1 O2
1 2.9 4.9 6.8 8.8 10.7 12.7 14.6 16.6 18.6 20.5 22.5 24.4 26.4 28.3 30.3 32.2 34.2 36.1 38.1 40
Frequency (Hz)
1.5 1 0.5 0 -0.5 -1 -1.5
Power spectra's mean difference (dB)

*Figure 2. Post-hoc pairwise comparisons between conditions. The color scale represents the mean power spectra differences between conditions, i.e., the subtraction of the spectral power average (in dB) corresponding to first condition minus the second condition declared in the title. Black contour lines are outlining those exact channels and frequencies showing statistically significant differences (p<0.05) on power.*

### 3.3. Power spectra analysis: Switching conditions

The EEG power spectral density associated to listening mixed-language speech switching from Basque-to-Spanish (L2➞L1) and switching from Spanish-to-Basque (L1➞L2) was compared. Figure 3 shows the exact channels/frequencies at which a significant effect of switching direction was found. Supplementary Material 4 contains the exact statistics from this test (*t* values and uncorrected p-values). Statistically significant differences ($p_{FDR}$<.05) between conditions were most evident in the 4–6 Hz range containing almost all (15) fronto-central electrodes. These results indicate that the switching direction asymmetrically impacts theta band power, which is significantly increased after a L1➞L2 switch as compared to a L2➞L1 switch.

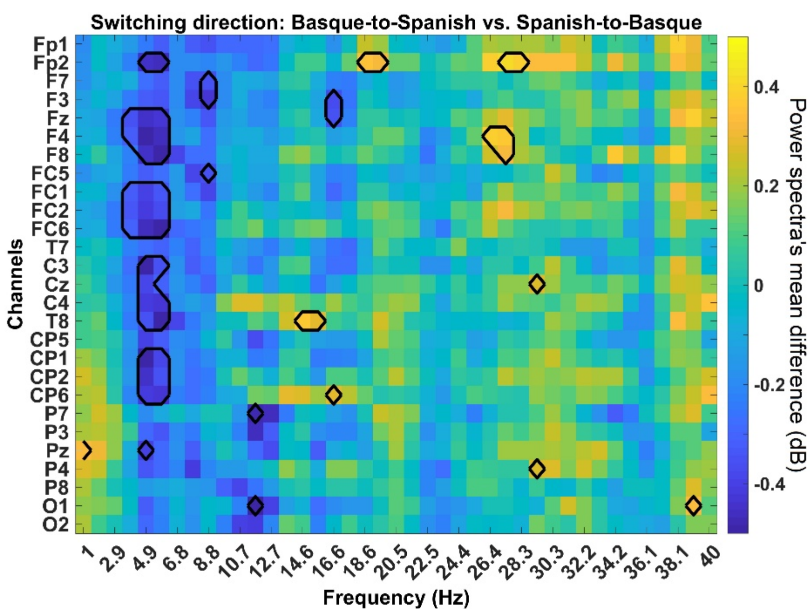



*Figure 3. Power spectra comparison between the two switching directions that includes all electrodes and frequencies. The color scale represents the mean power spectra differences (subtraction) between Basque-to-Spanish (L2➞L1) and Spanish-to-Basque (L1➞L2). Black contour lines are outlining exact electrodes and frequencies showing statistically significant differences ($p_{FDR}$<0.05) on power.*

### 3.4. Correlation between power spectra and behavior

The relationship between the behavioral and electrophysiological measures were assessed by Pearson's linear correlation tests. Specifically, the learning effect (namely, the mean difference between the percentage of errors in the second administration of the questionnaire and that from the first session) was correlated to the power spectra for each condition. No statistically significant correlations were found.

## 4. Discussion

The present study addresses the question of whether inter-sentential language switches are associated with different oscillatory and/or behavioral patterns as compared to situations of no language switch. Inter-sentential language switching implies alternating between full coherent messages produced in different languages, allowing the processing of semantic and syntactic information from both languages to be integrated as part of complete clauses. Here we used speech stimuli that somewhat mimics a common bilingual conversation from a dense switching context (Green & Abutalebi, 2013), thus partially resembling a naturalistic language-use situation in some bilingual societies. Also, participants were highly proficient bilinguals who were habitual code switchers. Our results highlighted several differences at the neural level between single-language and mixed-language speech perception (but not in the memory recall), indicating a not equivalent underlying neurophysiological activity in switching and non-switching contexts. In other words, the current study shows a measurable impact at a neural level for language mixing, despite of using inter-sentential language switches and proficient bilinguals, two circumstances that are supposed to ameliorate the impact of mixing languages. These effects, however do not involve a parallel counterpart of differential effects at the behavioural level.

The first finding that should be discussed corresponds to a by-product of the statistical comparison done between the two single-language contexts. Bilinguals showed equivalent neural oscillatory activity underlying speech processing in their two languages, Spanish and Basque, in spite of the proficiency differences. Although the participants were not balanced bilinguals, their high proficiency level in both languages dissipated possible differential oscillatory patterns such as the ones described before for foreign languages (Pérez, Carreiras, Gillon-Dowens, & Duñabeitia, 2015). These results support the existence of a tight relationship between the proficiency in a given language and the underlying oscillatory activity associated to its processing. However, and as a cautionary note, it should be considered that even highly proficient bilinguals may exhibit language-independent neuroanatomical and semantic representations (García-Pentón, Fernández García, Costello, Duñabeitia, & Carreiras, 2016). Future research should explore if other analyses allowing the assessment of network dynamics and/or more precise anatomical locations of the signal could unveil subtle language-specific differences (Pérez et al., 2015).

The second finding to highlight is that mixing two well-known languages yields a desynchronization of the oscillatory activity mainly in the beta band as compared with a seemingly pure 'monolingual' context. Beta band (13-30 Hz) activity has been related to the construction and representation of the current sentence-level meaning during unification (Lewis & Bastiaansen, 2015). In other words, beta-band frequencies seem to be closely linked to the maintenance and update of the neural network configuration responsible for the construction of sentence-level meaning (Lewis, Schoffelen, Schriefers, & Bastiaansen, 2016). We argue that the computation of the combinatorial semantics is more demanding in a language-switching context, and so getting to the assembly of a general meaning might be more circuitous, resulting in differences in beta-band synchronization. However, it should be noted that in a more general framework, beta band activity is considered to be associated with the so-called 'signalling of the status quo', which implies that beta oscillations are more strongly present when the maintenance of the current processing set (cognitive or sensorimotor) is intended or predicted (Engel & Fries, 2010). Thus, it could be more generally interpreted that in the case of speech containing inter-sentential code switches, the decreased beta oscillatory power as compared to single-language scenarios is expressing the need for assembling and updating information from two different sources (languages) within the same cognitive set (discourse processing). Expressed more succinctly, beta power decreases because the ongoing process is disrupted. These two interpretations are closely intermixed since the detection of novel stimuli or pieces of information, is an essential process for language perception and processing (Weiss & Mueller, 2012). This finding and interpretation is in line with the results reported by Litcofsky and Van Hell (2017) and by Fernandez et al. (2019) in their visual and auditory intra-sentential codeswitching study, respectively, given that they also found a beta power decrease for switches from the 'dominant' to the 'weaker' language. It should be noted, however, that in the current study, this difference was somewhat larger and spread to the gamma frequency band when the comparison involved the Basque-only condition. Despite their high proficiency level in Basque, participants were more skilful in Spanish than in Basque and had also acquired Basque slightly later than Spanish. While it is difficult to draw strong conclusions on the basis of this effect given that the statistical results did not unambiguously show language-specific effects, this could tentatively suggest the presence of underlying differences between both languages related to phonemic and prosodic awareness, given that precise speech-tracking of attended natural speech is closely related to processing its fine-grained structure (Rimmele, Zion Golumbic, Schroger, & Poeppel, 2015).

The third finding that may be worth discussing is the theta activity increase for switches into the 'weaker' language (Basque; L1➞L2) as compared to switches into the 'stronger' language (Spanish;

L2➞L1). More precisely, the direct statistical comparison between the two possible switching directions showed an increment in theta power at least during the first 400 ms of speech processing in the weaker language when it was preceded by a sentence in the stronger language. Oscillatory studies of language processing suggest that lexico-semantic processing elicits power increases in theta (and gamma) band (Bakker, Takashima, van Hell, Janzen, & McQueen, 2015; Bastiaansen & Hagoort, 2006, 2015). Moreover, theta activity has been linked to the word-level suppression of the L1 in isolated-item language switching paradigms using picture naming tasks (Liu, Liang, Zhang, Lu, & Chen, 2017). Results here of an increased theta activity, if speech perception take place after a L1➞L2 codeswitch, could be reflecting the suppression of the first language schema and the dominant-language word-level inhibition engaged during the processing of their weaker language (see the Bilingual Interactive Activation plus model, BIA+, for a theoretical account; van Heuven & Dijkstra, 2010). In other words, we interpret that the theta enhancement found here could be linked to the neural reanalysis of the more difficult to interpret second language speech material, and the inhibition of the native language. But importantly, it seems clear that the language switching direction has an asymmetrical neural impact, showing differential effects when perceiving input in a mixed-language condition as compared to single-language contexts.

Finally, the fourth finding that we would want to address is the lack of impact of inter-sentential language switching during spoken language perception of new information on long-term memory recall. This suggests that mixing languages during the presentation of new pieces of information has little if any negative measurable behavioural consequence as it does not harm memory retrieval. The current findings are in line with recent studies showing that bilingual children and young adults learn and remember concepts equally well in single-language contexts as compared to mixed-language contexts (Antón, Thierry, & Duñabeitia, 2015; Antón, Thierry, Goborov, Anasagasti, & Duñabeitia, 2016). Thus, it is probable that bilinguals with a sufficiently high level of proficiency in both languages could efficiently face the transmission of knowledge using multilingual speech, regardless of the number of languages used in the input.

In sum, here we extended previous studies on intra-sentential language switching (e.g., Litcofsky & Van Hell, 2017) to inter-sentential language-mixing situations where the separation between languages is emphasized. In particular, we analysed the neuropsychological impact of perceiving long utterances including language alternations between sentences, a code-switching context of the sort in which some bilinguals frequently engage (e.g., dual-language contexts and dense code-switching contexts; see Green & Abutalebi, 2013). We conclude that mixing languages between sentences imposes no significant costs affecting memory retrieval, but it results in an impact on the underlying neurophysiological oscillatory patterns. These differences are mainly evident in the beta band, and they most probably relate to the construction of a sentence-level meaning representation its processing (namely, to syntactic unification; Bastiaansen & Hagoort, 2015). Still, further studies are needed to better understand the extent to which mixing languages can influence speech comprehension of code-switched utterances, specifically comparing intra- and inter-sentential switching. The complexity of language mixing and its practical implications for real-life situations will be only be correctly understood by integrating findings from studies addressing language switching at different levels (i.e., intra- and inter-sentential, behavioural and physiological) in more naturalistic experimental scenarios.

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