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Neural correlates underlying linguistic and non-linguistic switching tasks in high-proficient bilinguals: An ERP study

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NOTA DE PREMSA

Porqué don't we talk así?

A study from the Autonomous University Barcelona investigates why blinguals don't mix their two languages.

Have you ever posed yourself the aforementioned question – how do bilinguals control their two languages? Previous research has shown that when bilinguals speak in one language, the other language is also activated; thus making the question rather intriguing: shouldn't we all be mixing up our two languages in everyday life then? How are we able to control over two languages?

Researchers at University College in London have argued that a general system in the brain that allows us to read the newspaper while talking to your friend, or listen to music while driving, is also able to control your non-mixing of languages in mundane situations. Researchers at Harvard, however, argue that this control is done by a system in the brain that's specific to language. Who is right? A student from the Autonomous University of Barcelona researching at the Centre for Brain and Cognition in Universitat Pompeu Fabra decided to use the special population in Catalonia, where most bilinguals learn both Catalan and Spanish very early in their lives, in order to address this question. Twenty-four Catalan-Spanish bilinguals were asked to complete a task that involved naming pictures and a similar task that did not involve any kind of language; all of this while connected to an electroencephalogram – a machine that allows us to see what your brain is doing in every millisecond.

Results based on the responses of participants diverged from results from the brain responses, each one supporting a different theory.

Interestingly enough, while the results from the tasks completed by the participants showed that there seemed to be no relation in the manner in which the participant was processing the two tasks, the electroencephalogram results narrated another story: both tasks were being processed in the same manner in the brain. These compelling results thus show us two things: firstly, the tell-tale brain functions in unexpected ways. Secondly, **being able to talk in Catalan and in Spanish in different contexts seems to be processed by our brain just like any other task** such as driving while listening to music.

The implications of these findings are staggering: if everything is processed in the same manner, **are bilinguals in advantage when it comes to controlling tasks other than language?** Previous research seems to suggest so; yet much more has to be done in the future. Until the mysteries of the bilingual brain are being unveiled, let's just be thankful que no hablamos switching languages todo el tiempo.

RESUM EXECUTIU

UNDERSTANDING BILINGUAL'S CONTROL OVER LANGUAGE PRODUCTION

Introduction

The number of bilinguals in the world outnumbers that of monolinguals, making its study of utmost relevance in actuality. The study of how bilingualism is processed in the brain is especially pertinent to policy-makers in governments presiding over bilingual communities who want to ground their policies bearing in mind the differences in the functioning of the bilingual brain. These involve governments across the globe as varied as the Generalitat de Catalunya, the Ministère de l'Éducation, du Loisir et du Sport in Quebec, or the Department of Education in the Government of Jammu and Kashmir, India, to name a few.

Moreover, parents of bilingual children or future parents who seek to understand what differences a bilingual brain from that of a monolingual before bringing their children up in a bilingual environment may also interested in the research presented here, the presence of groups such as the Multilingual's Children Association reaffirming this notion.

This precise study seeks to answer questions about the manner in which early bilinguals so efficiently control their two languages.

Research Background

Research has shown that when bilinguals speak in one language, the other language is concurrently activated; making the accuracy in language production by bilinguals particularly striking. Two opposing theories explain this control over the languages by different mechanisms. Dr. Green, from University College of London, has argued that general executive functions, which are responsible for our ability to multitask, among other things, are responsible for it. On the other hand, Dr. Caramazza, from Harvard University, argues that a mechanism that is specific to language is responsible for this control.

Main Objective

This study sought to understand the mechanisms behind bilingual language control, using both behavioral and neuroimaging techniques in order to test which one of the aforementioned hypothesis was correct.

Research Methods

The task-switching paradigm was employed in both a linguistic and non-linguistic task. The linguistic switching tasks consisted in naming eight different objects in Catalan and Spanish, alternatively, depending on the cue. The non-linguistic switching task consisted in classifying with a keyboard eight different objects according to their shape or color, depending on the cue given. Cues in both tasks were presented 500msec before the picture, giving the 24 Spanish-Catalan bilinguals tested some time to prepare.

While the task was being completed, a 64-electrode-cap recorded the participant's neural activity, allowing us to see how the brain responded to the cue and the image

Hypotheses

The switching from one language to another, or one classification to another in the linguistic and non-linguistic task respectively yields "shifting costs", which can be compared across tasks. The neural recording allows us to observe components – i.e. positive or negative peaks.

If general executive functions control for language, the "shifting costs" found in the linguistic task will correlate with those in the non-linguistic task; with the neural correlates recorded in both tasks also having similar components. However, none of the above should be true if a mechanism specific to language controls bilingual language production.

Results

There was a clear dissociation between the "shifting costs" results and the neural ones. While the "shifting costs" from the linguistic and the non-linguistic task did not correlate, similar components were found in the neural data. More precisely, 300 msec after the cue was presented a positive peak was observed in both tasks, which has been previously interpreted by researchers as the brain updating the context. On the other hand, 200 msec after the image to be named or classified in the linguistic and non- linguistic task respectively was presented, a negative peak was observed. This has previously been interpreted as indexing the inhibition of the task not being produced.

Conclusions

The previous results show us thus, that, as Dr. Green hypothesized, bilingual speakers use domain-general mechanisms during language production. These results help answering the aforementioned theoretical debate and also raise questions about the tangible implications of bilingual language production being controlled by a general mechanism. Would this mean that, because bilinguals are well trained in using their executive functions as they constantly switch between the two languages in their everyday life, they rip the benefits of this constant controlling in non-linguistic events as well? Previous research by Dr. Bialystok at York University seems to suggest that bilingualism is advantageous in several ways, such as delaying the offset of Alzhemier by 3 years in comparison to monolinguals. However, more research is needed in order to fully understand the exact impact of constant domain-general control in every-day life.

INFORME FINAL

Neural correlates underlying linguistic and non-linguistic switching tasks in high-proficient bilinguals: An ERP study.

KEY WORDS: bilingualism, language switching, task switching, ERP components

ABSTRACT

During language production in bilingual speakers, both languages are simultaneously activated (Costa et al, 2000), making the everyday accurate bilingual language control (bLC) rather striking. A language specific and a language non-specific hypothesis have been put forth to explain bLC. Among the behavioral measures employed in order to test both hypotheses, one finds the switching task paradigm wherein when switching between two tasks of different difficulty, dominant tasks show a greater switch cost (Meuter & Allport, 1999). These tasks can be done both with linguistic (Costa et al, 2006) and non-linguistic (Allport et al, 1994) trials; yet, no correlation has been found between these two costs (Calabria et al, 2013). As electrophysiological data provides information that behaviorally may go unnoticed (McLaughlin et al, 2004), we looked for ERP effects underpinning language and task switching that may support one hypothesis over the. Twenty high-proficient Spanish/Catalan early bilinguals were tested. Behavioral results show no correlation between linguistic and non-linguistic switch costs. Cue-locked ERPs show a P3 component, indicating context updating (Jost, Mayr, & Rösler, 2008), while stimulus-locked ERPs show an N2 component, indexing inhibition (Swainson & Cunnington, 2003) both common to the linguistic and non-linguistic task. Thus, the results support the language non-specific hypothesis.

1. INTRODUCTION

Bilinguals, broadly defined as the individuals who have the ability to use more than one language (Butler, 2006), outdo the number of monolingual speakers in this world (Grosjean, 1989). Thus, the study of how bilinguals process both languages seems of great relevance given the demographics.

A series of studies show that when performing a language production task in solely one of their languages, be it the more-dominant L1 or less-dominant L2, bilingual speakers activate both languages (Costa, Caramazza, & Sebastian-Galles, 2000; Costa, Miozzo, & Caramazza, 1999). Given this parallel activation during bilingual speech production, it is rather striking how proficient bilinguals are able to control both languages in order to avoid producing errors during speech production. The cognitive processes behind this seemingly effective selection of one language over the other have been named as 'bilingual language control' (Abutalebi & Green, 2007; Costa & Santesteban, 2004). In order to explain how this selection takes place, two main hypotheses have been put forth: the language non-specific selection hypothesis (Abutalebi & Green, 2007) and the language specific selection hypothesis (Costa & Caramazza, 1999).

The language non-specific hypothesis postulates that lexical information and words are activated across and within the two languages, competing for production. The words most activated are thus selected. This process requires an inhibitory mechanism that suppresses the unintended language and allows for the word to be produced in the target language (Green, 1998).

While the language specific hypothesis concedes that lexical information is simultaneously activated in both languages, it proposes a lexical selection mechanism wherein linguistic cues allow the candidates in the target language to be selected (Finkbeiner, Almeida, Janssen, & Caramazza, 2006; Finkbeiner, Gollan, & Caramazza, 2006). Thence, the difference between the language non-specific and the language specific hypotheses is the presence and absence of inhibitory processes.

Costa & Santesteban (2004) tried to reconcile these two seemingly diverging hypothesis, arguing that low-proficient bilinguals use the former, whilst high-performing bilinguals use the latter.

The motive behind our study, hence, is to further investigate whether there is an overlap between the domain-specific bilingual language control and the domain-general executive control (Abutalebi & Green, 2007).

In a bid to test these different accounts of language selection, both behavioral as well as neuroimaging measures can and have been employed. In the former, three different approaches can be discerned from the literature; namely, looking into picture-word interferences, language-specific properties and language switching costs. As far as the neuroimaging methodologies are concerned, both changes in structure as well as processing differences have been studied; fMRI and ERP being the main imagining techniques used in these studies, respectively. (Kroll, Bobb, Misra, & Guo, 2008) This study will build up on the language switching costs literature and the ERP literature, hence the need to discuss both in detail.

1.1 The switching task paradigm

Meuter and Allport (1999) first introduced the switching paradigm in the literature on bilingualism in a groundbreaking study that had the Task Set Inertia at its heart. In this task, which had first been developed as a non-linguistic task (Allport, Styles, & Hsieh, 1994), it is observed that when switching among tasks of different difficulty, the dominant task shows a greater switch cost than the non-dominant one. The authors explained this somewhat paradoxical result arguing that the switch cost indexed suppression. In other words, in a bid to avoid interference with the non-dominant task, the dominant task had to be actively suppressed. In the aforementioned study carried out by Meuter and

Allport (1999), a linguistic task was employed. The results show a similar pattern as the non-linguistic one: the switch cost was higher in the participant's first language (L1) than the second one (L2). The explanation given for these results is that inhibition is required in order to suppress one task while performing the other. The stronger the task, the stronger the inhibition required in order to suppress it, thus resulting in a larger cost. This pattern, which is asymmetrical, was found in participants who were less proficient in their L2. In highly proficient bilinguals, however, this pattern is symmetrical, as the L1 did not seem to be suppressed more than the L2 (Costa, Santesteban, & Ivanova, 2006).

It is of paramount importance to understand how the switching paradigm works, and the variables implied and studied in such tasks.

As the name suggests, the switching paradigm entails changing from one language to a second one – and sometimes even a third one – in different trials in the linguistic task. In the non-linguistic task, the participant switches from classifying the trial presented in some dimension or the other. A clear example of such a task would be the one used in Calabria, Branzi, Marne, Hernández and Costa (2011), wherein participants were presented with objects made of a combination of shapes and colors and were asked to classify them either according to their shape (task A) or their color (task B). The switch cost obtained when resolving the interference in the preceding trial is called the "n-1 shift cost" (Wylie & Allport, 2000). This cost is calculated by looking at the response time (RTs) of the subject in the switch trials (BA) versus the RTs in the non-switch trials (AA). The "n-1 shift cost" is thought to index a series of components of Executive Control, such as goal retrieval, attention, shifting, reconfiguration processes and inhibition of the prior task set (Branzi et al, in preparation).

Studies that have looked at the correlation between the linguistic and non-linguistic tasks in early bilinguals, have not found any correlation among the two (Calabria, Branzi, Marne, Herández, & Costa, 2013)

1.2 ERP correlates of switching tasks

The ERP data mirrors the behavioral literature in that both languages seem to be active to a certain extent even when only one of them is intended to be used for speech production (Guo & Peng, 2007). However, the literature concerning until where this parallel activation is maintained has been inconsistent (Christoffels, Firk, & Schiller, 2007). Hence, the question on whether inhibition is necessary during bilingual speech production has not yet been answered by looking at the neural processing data.

In language switching studies, an N2 component over the frontal and central scalp seems to be sensitive to language switching (Jackson, 2001), as switch trials show a non-transient increased negativity when compared with non-switch trials. This increased negativity is further modulated by preparation intervals, i.e. the time allowed to prepare to name a picture (Verhoef, Roelofs, & Chwilla, 2009). However, the sensitivity of the N2 component to language switching is not a compelling one, as this findings has not been replicated (Swainson & Cunnington, 2003). Nevertheless, the N2 component has otherwise been found to modulate the inhibitory processes required in go/no-go tasks (Folstein & Petten, 2008) and thus has been, and will be interpreted in the current study, as an evidence for the need of inhibitory processes in bilingual speech production.

On the other hand, non-linguistic switching tasks have looked mainly at the response-cue interval (RCI) and the cue-stimulus interval (CSI) and have found that they both modulate the parietal positivities and central negativities found in switch-trials (Li, Wang, Zhao, & Fogelson, 2012).

1.3 The present study

Given that no correlation has been found between linguistic and non-linguistic tasks on a behavioral task (Calabria et al., 2013), it would be interesting to see whether there are any underlying common processes that occur during linguistic switching and non-linguistic switching tasks. For simplicity's sake, only the "n-1 shift cost" will be studied.

Given that the electrophysiological data sometimes provide information that behaviorally goes unnoticed (McLaughlin, Osterhout, & Kim, 2004), turning to the ERP recordings of non-linguistic and linguistic switching tasks could provide us with information about whether there are any similar processes underpinning linguistic switching and non-linguistic switching. Previous studies have looked at the neural correlates of linguistic switching tasks or non-linguistic switching tasks separately; only one study reportedly studied both tasks at the same time (Magezi, Khateb, & Mouthon, 2012), although the stimuli used in the non-linguistic task of this latter study included numbers and letter, thus potentially tapping into linguistic systems as well. This will be avoided in the current study by using a non-linguistic task that is devoid of language.

2. METHODS

2.1 Participants

Twenty-four Spanish/Catalan early high-proficient bilinguals participated in return for payment. All participants were right-handed and had normal or corrected-to-normal vision. All participants were dominant in Catalan. Two participants were excluded from the study group; one participant made too many errors (three standard deviations above the average number of errors across participants) in one of the tasks whilst the other participant's responses in the questionnaire indicated that he was Spanish-dominant. Table I provides with information about the linguistic profile of included participants.

Linguistic Profile of Participants			
		Mean Years	**Standard Deviation**
Catalan	Age of Acquisition	0,65	0,96
	Proficiency	6,90	0,29
Spanish	Age of Acquisition	1,86	2,16
	Proficiency	6,33	0,75
English	Age of Acquisition	6,36	2,62
	Proficiency	4,87	1,06

Table 1: Linguistic profile of included participants

2.2 Material and apparatus

All participants completed both a linguistic and a non-linguistic task (which will be henceforth referred to as LS and TS respectively) in one experimental session that lasted approximately 120 minutes. Both tasks were presented in the same day, with the order of the tasks being counterbalanced. In all tasks, blocks of 64 trials were used.

Both tasks were divided in two conditions: a blocked condition and a mixed condition. The blocked condition consisted of two blocks of repeat trials: one block where naming had to be done in Catalan and another one in Spanish in LS; and one block where a figure had to be classified according to the color and another block according to the shape in TS. The order of presentation was counterbalanced. The mixed condition consisted of six blocks of switch and repeat trials, wherein switch trials were trials where the language or classification task required from the participant was different from the previous trial, and repeat trials were trials where the participant was required to name or classify the object like in the previous trial. Thus, there were 384 trials in total, comprised by 288 repeat trials and 76 switch trials. The order of the blocks was counterbalanced. A smaller block of 32 trials preceded these six blocks in order to familiarize the participant with the task.

2.2.1 Linguistic Switching Task

The linguistic switching consisted of an object-naming task, where the object that appeared on the center of the screen had to be named either in Spanish or Catalan, depending on the cue. All images displayed non-cognate words, i.e. words that are phonetically different in the two languages. The images were taken from Branzi et al (in preparation). The cues consisted of the Spanish flag when objects had to be named in Spanish, and the Catalan flag when the object had to be named in Catalan. They were placed in the four corners of the screen, around the central image. All images from LS can be consulted in Appendix I.

The LS trials consisted of the presentation of the cue, while the picture appeared in the center of the screen after 500mse. The Cue-Stimulus Interval was that of 500msec. Once the response was triggered by the voice onset, a fixation-cross appeared in the center of the screen. If the Stimulus-Response

Interval was higher than 5000 msec, a message "miss!" appeared on the center of the screen instead of the fixation-cross.

2.2.2 Non-Linguistic Switching Task

The non-linguistic switching task consisted was formed by a classification task, where the figure displayed on the center of the screen had to be classified according to its color or shape, depending on the cue. The cue consisted of images taken from (Prior & Gollan, 2013). All images used for TS can be consulted in Appendix II.

The TS trials consisted of the presentation of the cue, while the picture appeared in the center of the screen after 500mse. Keys 1,2,9 and 0 from the upperside of the keyboard acted as correct responses. The keys that acted as correct responses were counterbalanced across participants. The Cue-Stimulus Interval was that of 500msec. The pressing of the key triggered the response, a feedback message appeared in the center of the screen: if the correct key had been pressed, "good!" appeared on the center of the screen, if it was an incorrect key, "oops!" would appear and if the participant took more than 5000msec to respond, "miss!" appeared.

2.3 Procedure

Participants were tested individually in an electrically shielded and sound-attenuated chamber. They sat in front of a computer screen, placed approximately 100cm away from their face. The keyboard was placed on the participant's lap, with the help of a stand.

While the ERP cap was being prepared, all participants were requested to complete the Speech Production and Bilingualism Language Switching Questionnaire.

Participants were first given instructions about the blocked condition, which allowed them to familiarize themselves with the task. Once the blocked condition was completed, participants were given instructions about the mixed condition. During the LS, a microphone was placed in front of the participant's mouth and set so that the voice onset of the participant triggered the response in the program used for programming the experiment, i.e. 'Presentation® software (Version 0.70, www.neurobs.com); once LS was over, the aforementioned microphone was taken away for the comfort of the participant.

2.4 Electroencephalogram (EEG) Recordings

The EEG recordings were be done from 64 scalp sites using thin electrodes mounted in an ACTIcap. Electrode impedance was kept below 10kΩ. Online referencing was done on the tip of the nose. A bipolar montage were placed on the left and lower orbital ridge, monitoring eye blinks and vertical eye movement.

3. DATA ANALYSES

3.1 Behavioral Data Analysis

The reaction time (RT) was calculated in the linguistic and the non-linguistic trials from the time the stimulus was presented, until the onset of the verbal response or the key press was registered, respectively.

In LS, a response was considered incorrect if the picture was named in a different language (cross-language interferences), if it was named incorrectly in the same language (within-language interference) or if the voice key was triggered incorrectly. All these responses were invalidated and excluded from data analysis.

In TS, a response was considered incorrect if the key pressed did not correspond to the one required for the classification task.

Trials with RTs three standard deviations higher or lower than the average of the participant's RT in the task were also excluded. As were trials where artifacts were observed in the ERP recordings.

Aside from RTs, the "n-1 shift cost" was also calculated; this was done by subtracting the RTs of switch trials from those of repeat trials.

3.1 ERP Data Analysis

Off line processing involved rejection of vertical eye movements and blinks. Segmentations of 600msec in length were made from markers that indicated when cue and stimulus were presented, thus creating segments that were cue-locked and stimulus-locked, respectively. These segmentations included a100-ms pre-stimulus baseline. Rejected artifacts included segmentation with a frequency higher than 20Hz and lower than 0.01Hz.

4. ETHICAL CONSIDERATIONS

While there were no inherent risks in doing this experiment, other than getting slightly stressed while performing the task, as it is quite demanding, there were a few ethical considerations taken into account. Firstly, all data was and has been kept confidential and consent forms were signed. Moreover, economical compensation was given to participants, who were paid 10 euros per hour spent in the lab. In case of feeling any kind of discomfort with the procedure at any point, participants were allowed to disrupt the experiment and leave. Had that scenario taken place, they were still economically rewarded for the time spent in the lab.

Aside from the monetary compensation, participants have not benefitted directly from taking part of this study. Nonetheless, the data provided by all participants is useful in the study of bilingualism and could further its study, potentially leading to conclusions and tangible implications pertinent to the bilingual population and thus impacting the participant in an indirect manner.

5. RESULTS

5.1 Behavioral Results

The overall RT in LS was 787ms in switch trials and 800ms in repeat trials. The overall "n-1 shift cost" was 13 msec. A t-test was performed, the outcome being a value of $t(21) = 1.838$, $p=.08$. This means that "n-1 shift cost"

cost in LS is not statistically significantly different from zero, but it has a tendency towards significance.

The overall RT in TS was 614ms in switch trials and 804ms in repeat trials. The overall "n-1 shift cost" was 190 msec. A t-test was performed, the outcome being t(21) = 9.228, p >.001. Thus, the "n-1 shift cost" cost in TS is significantly different from 0.

No correlation were found between LS and TS "n-1 shift costs" (R=.219, p = .328)

Figure 1 shows the "n-1 shift cost" in both LS and TS as well as the correlation between these two tasks. Overall reaction times can be consulted in Figure 2. Graphs for overall "n-1 shifting costs" in LS and TS independently can be found in appendix III.

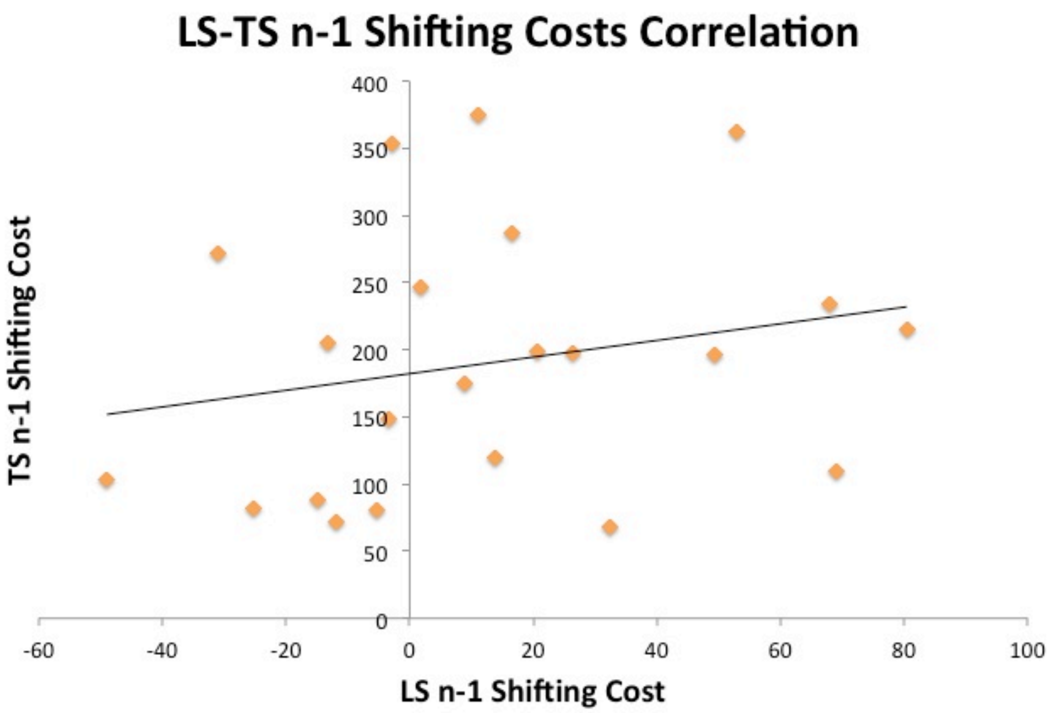


Fig 1. Correlation between "n-1 shift cost" in LS and TS

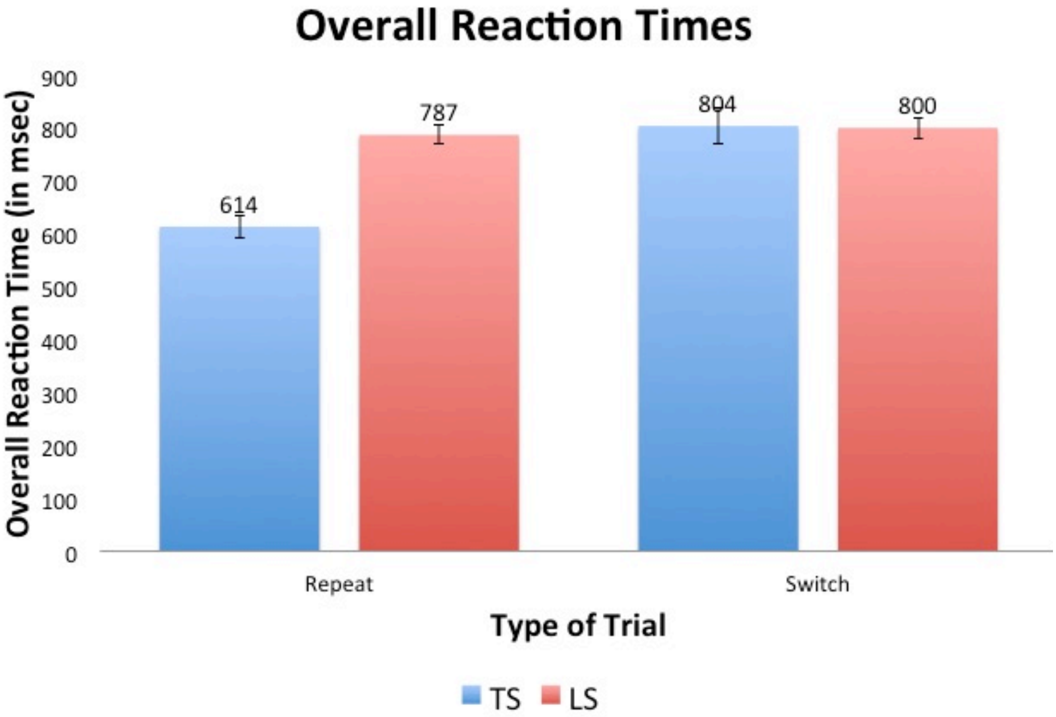


Fig 2. Overall reaction times in LS and TS

5.2 Electrophysiological Data

5.1 Cue-locked Waveforms

The grand average waveforms of cue-locked switch and repeat trial waveforms for electrode CZ are displayed in Fig 3 for LS and Fig 4 for TS. The waveforms of other electrodes can be consulted in appendix IV. The N1 complex usually elicited by visually presented material was present. Ocular inspection shows a P2 component, more positive for switch trials. This P2 positivity in switch trials is observed in both LS and TS. A second positivity, the P3 component, is observed from 400msec onward in LS whilst in TS it seems to start slightly earlier, from 400msec onwards.

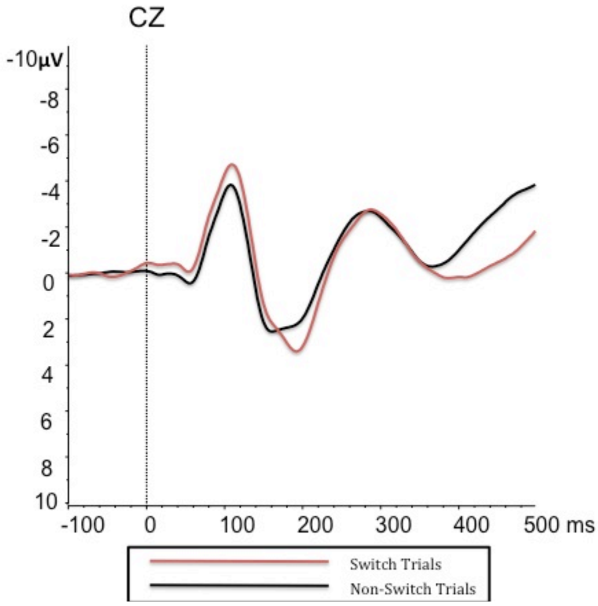


Fig 3: Cue-locked waveform for LS

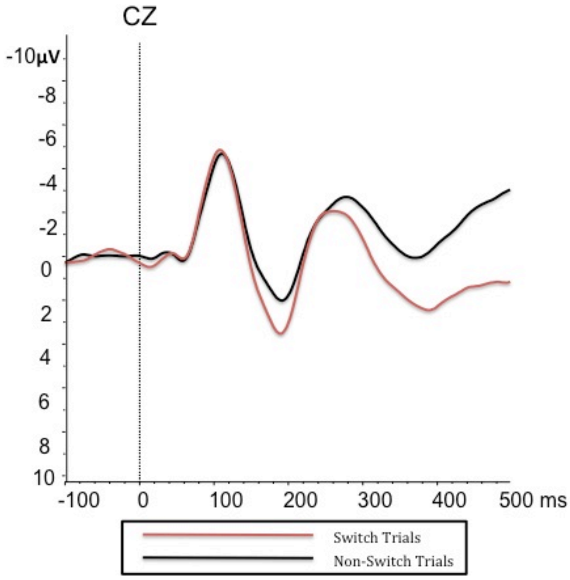
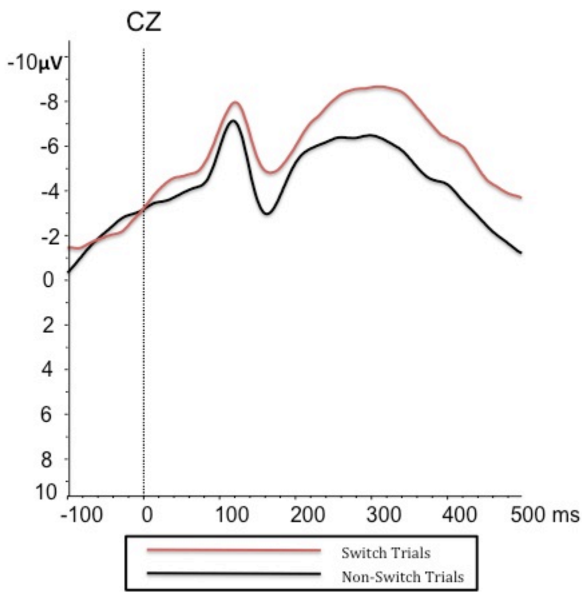


Fig 4: Cue-locked waveform for TS

5.2 Stimulus-locked Waveforms

The grand average waveforms of stimulus-locked switch and repeat trial waveforms for electrode CZ are displayed in Fig 5 for LS and Fig 6 for TS. The waveforms of other electrodes can be consulted in appendix IV. The N1 complex elicited by visually presented material was also present. Ocular inspection shows a N2 component present, wherein switch trials are more negative than repeat trials. This component is present in both LS and TS. This component seems to be clearly an N2 component given the distribution of its negativity in the frontal and central areas from 200ms onwards, as depicted in Fig 7.



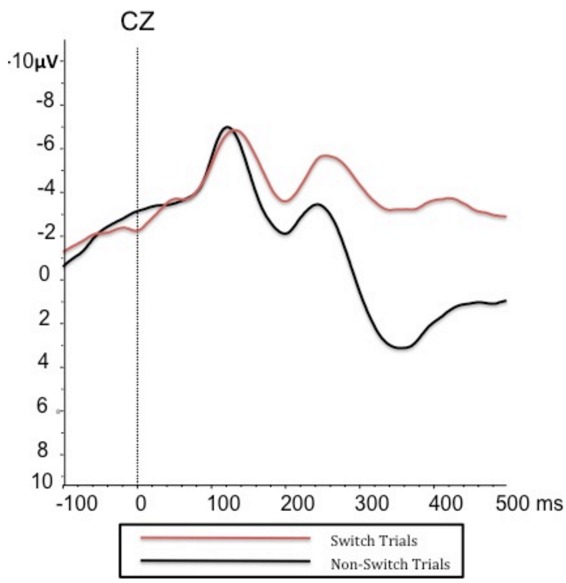


Fig 5: Stimulus-locked waveform for LS

Fig 6: Stimulus-locked waveform for TS

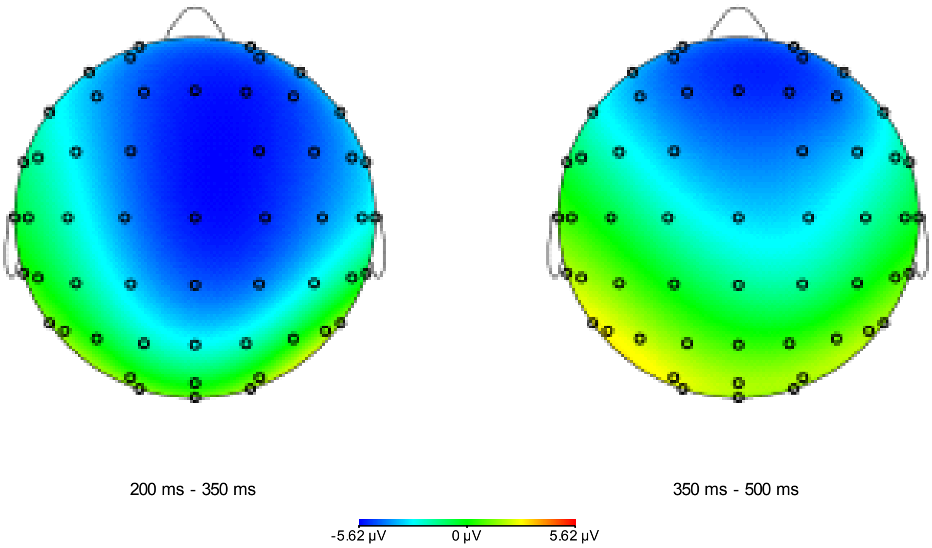


Fig 7. Frontal and central distribution of negativity from 200ms onwards

6. DISCUSSION

This study intended to investigate behavioral and electrophysiological correlates of bilingual language control. It addressed the on-going debate regarding bilingual language control and whether it is dependent on language-specific selection or a language non-specific selection. This was done by carrying out a switching task with linguistic and another one with non-linguistic trials, whilst recording both behavioral and electrophysiological data in order to monitor for components that may or may not be similar in both tasks.

6.1 Behavioral Data

Behavioral data show a large switching cost ($p>0.001$) in the non-linguistic trials, while no switching cost ($p>0.08$) was found in the linguistic trials. The latter results are inconsistent with previous findings (Costa & Santesteban, 2004; Verhoef, Roelofs, & Chwilla, 2009). However, there might be a reason why this is the case. In Costa and Santesteban (2004)'s study, where a switch cost of 20ms was found, no cues were used; the task was indicated by the color of the image. And while Verhoef, Roelofs, & Chwilla (2009) use a short cue of the exact length as the one used in the present study, participants were unbalanced bilinguals, as opposed to the early high-proficient bilinguals of the current study. One could surmise that the absence of switch cost could be due to slower overall reaction times; however the overall reaction time was 787msec in repeat trials and 800 msec in switch trials; contrasted with 950ms and 925ms respectively (Verhoef, Roelofs, & Chwilla, 2009). Thus, participants in this study were fast and reaction times can not explain the absence of a language "n-1 shift cost".

6.2 Electrophysiological Data

In cue-locked ERPs we find two positivites, namely a P2 and a P3 component. The P2 component may be considered part of the N1-P2 complex, which indicates processing of visual stimuli; the positivity may be larger in switch trials as the image displayed is different from the previous trial. At 200msec it is difficult to be able to speak about cognitive processes given the earliness of its timing. However, the P3-like component that can be observed both in LS and TS does give us indications about underlying cognitive processes. Previous research indicates that the P3 component reflects endogenous or cognitive aspects of context updating (Jost et al., 2008). We see, thus, that in switch trials context updating occurs when the cue is different from the previous cue observed by the participant, i.e. in switch trials.

On the other hand, in stimulus-locked ERPs a clear N2 component is observed, which is more negative in switch trials. The N2 component has been widely recognized to index inhibition (Jackson, 2001; Swainson & Cunnington, 2003). Therefore, results indicate us that during switch trials participants inhibit more the language not intended to be produced. The fact that in LS an N2 component is found during a CSI of 500msec is remarkable given that Verhoef et al (2009) do not observe this component. They argue that this lack of N2 is due to the fact that the costs obtained are asymmetrical during the 500msec interval. In our case the LS cost is in symmetrical in both languages, thus supporting Verhoef et al (2009)'s argument of the N2 component being sensitive to symmetry. Nonetheless, one needs to note that both the costs obtained in our study are not significantly different to 0, despite its tendency towards significance. The difference in the results found could also be due to the fact that Verhoef et al (2009) used unbalanced bilinguals in their study, whilst our participants are early and high proficient bilinguals, as can be seen in Table 1.

It is of paramount importance to mention that all the aforementioned components are observed in both LS and TS.

6.3 Discussion

Taken all together, these results show us that while behaviorally it seems that there is no correlation between costs found in the linguistic and non-linguistic task, as found previously (Calabria, Branzi, Marne, Herández, & Costa, 2013) hinting at different mechanisms processing linguistic and non-linguistic tasks; the neural components that correlate with these tasks are identical, with direct evidence of inhibitory processes taking place in both linguistic and non-linguistic trials, as evidenced by the N2 component in stimulus-locked waveforms. Thus, while behavioral results in the literature regarding bilingual language control may have thus far supported a language-specific selection hypothesis (Costa & Caramazza, 1999), the results found in this study clearly support a language non-specific selection hypothesis (Abutalebi & Green, 2007).

Despite the compelling results, one must bear in mind that the cost found in language switching is not significantly different from zero. Thus, one should either include more participants in the study in order to obtain a language switching cost that is statistically significant or future research should control for variables that may elicit a larger switching cost in language switching.

Moreover, in stimulus-locked waveforms we observe that the segmentations from the linguistic task tend to be more negative than those from the non-linguistic task, despite the P3 component being present in both segmentations. This is due to the fact that the linguistic task involves overt speech production, the motor preparation required for it causing the waveforms to be more negative. As the P3 component is still present in both segmentations, this negativity should not be a cause of concern in the interpretation of results. Nonetheless, future research that would like to address this issue could employ a linguistic task where overt speech production is not required.

Despite these shortcomings, this study provides compelling evidence that the neural correlates underpinning language and task switching are similar.

7. ACKNOWLEDGEMENTS

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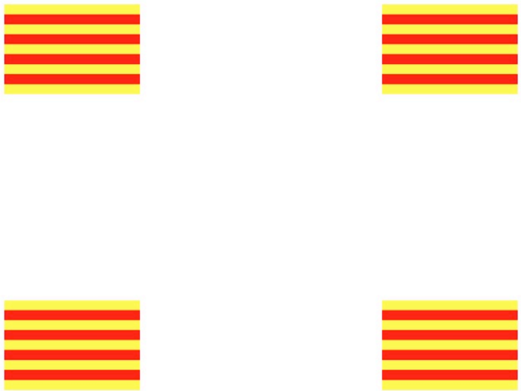
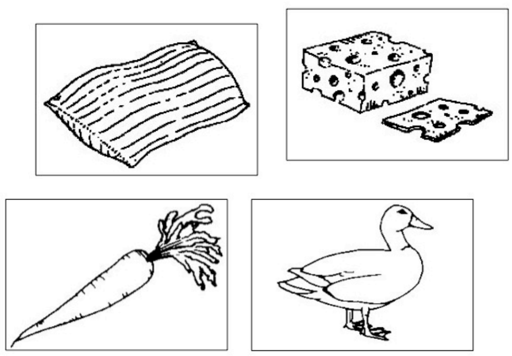
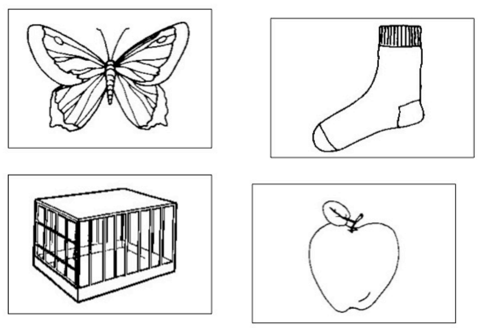
**APENDIX I - **Images used during the Linguistic Switching Task



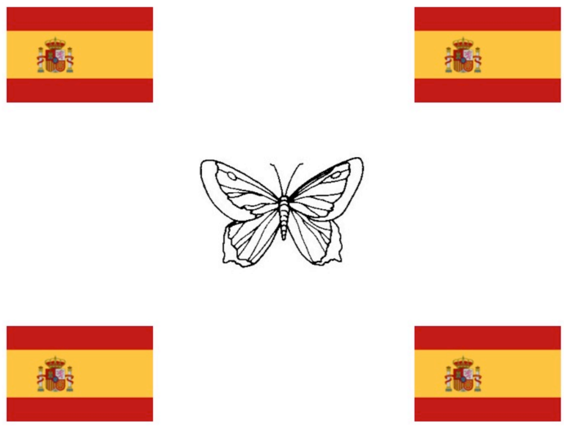
Cue Stimulus for the Catalan Task

Cue Stimulus for the Spanish Task





Images of the objects that had to be named

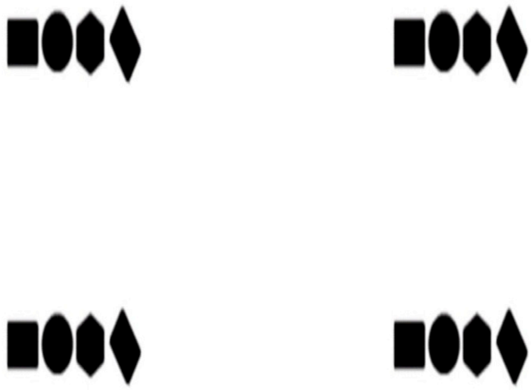


Example of a Catalan Task Stimulus

Example of a Spanish Task Stimulus

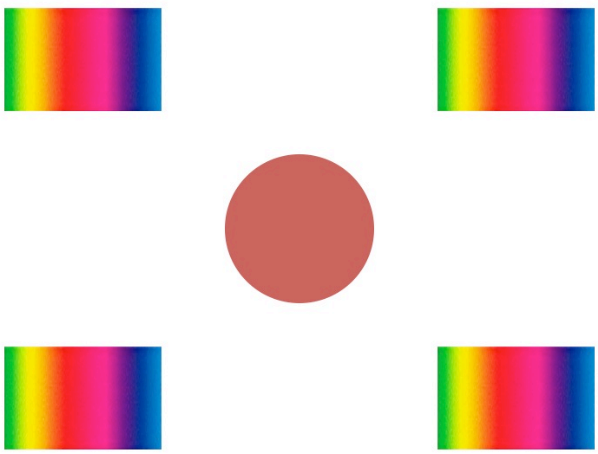
APENDIX II - Images used during the Non-Linguistic Switching Task

Cue Stimulus for the Color Task

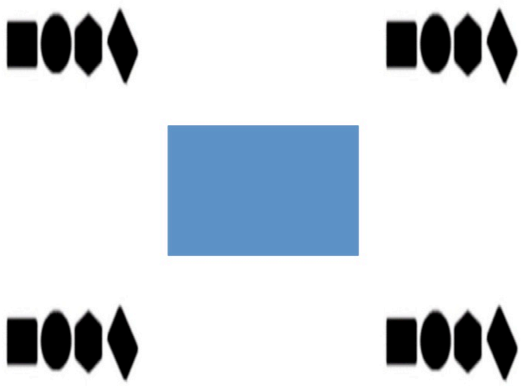


Cue Stimulus for the Shape Task

Images of the objects that had to be classified

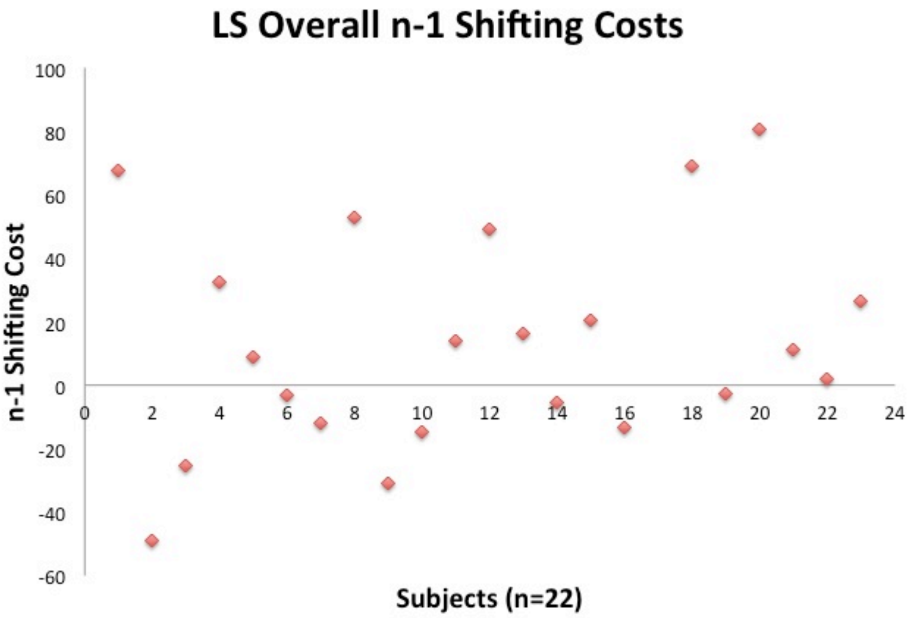


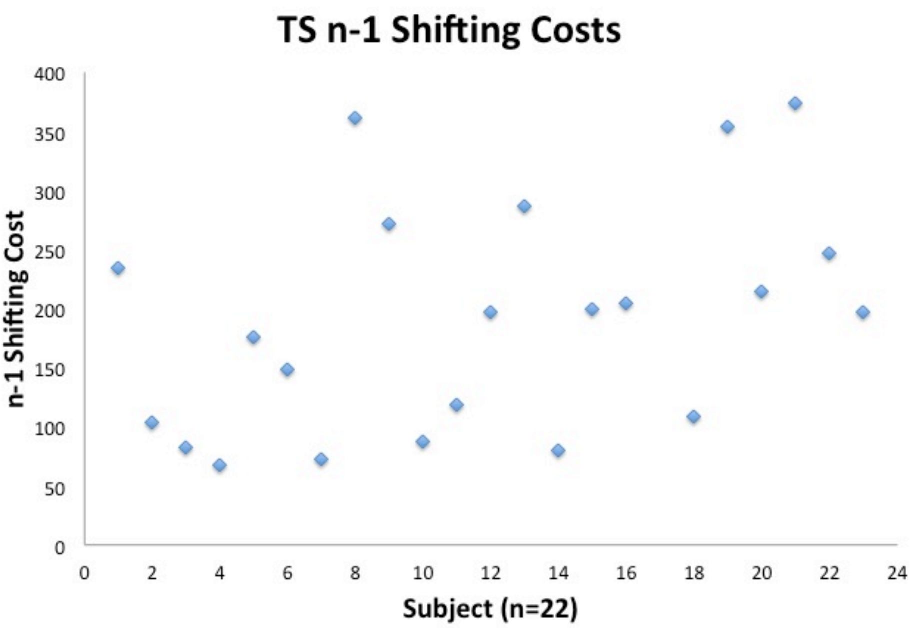
Example of a Color Task Stimulus



Example of a Shape Task Stimulus

APENDIX III **-** Overall n-1 Shifting Costs in LS and TS





APENDIX IV – ERP COMPONENTS

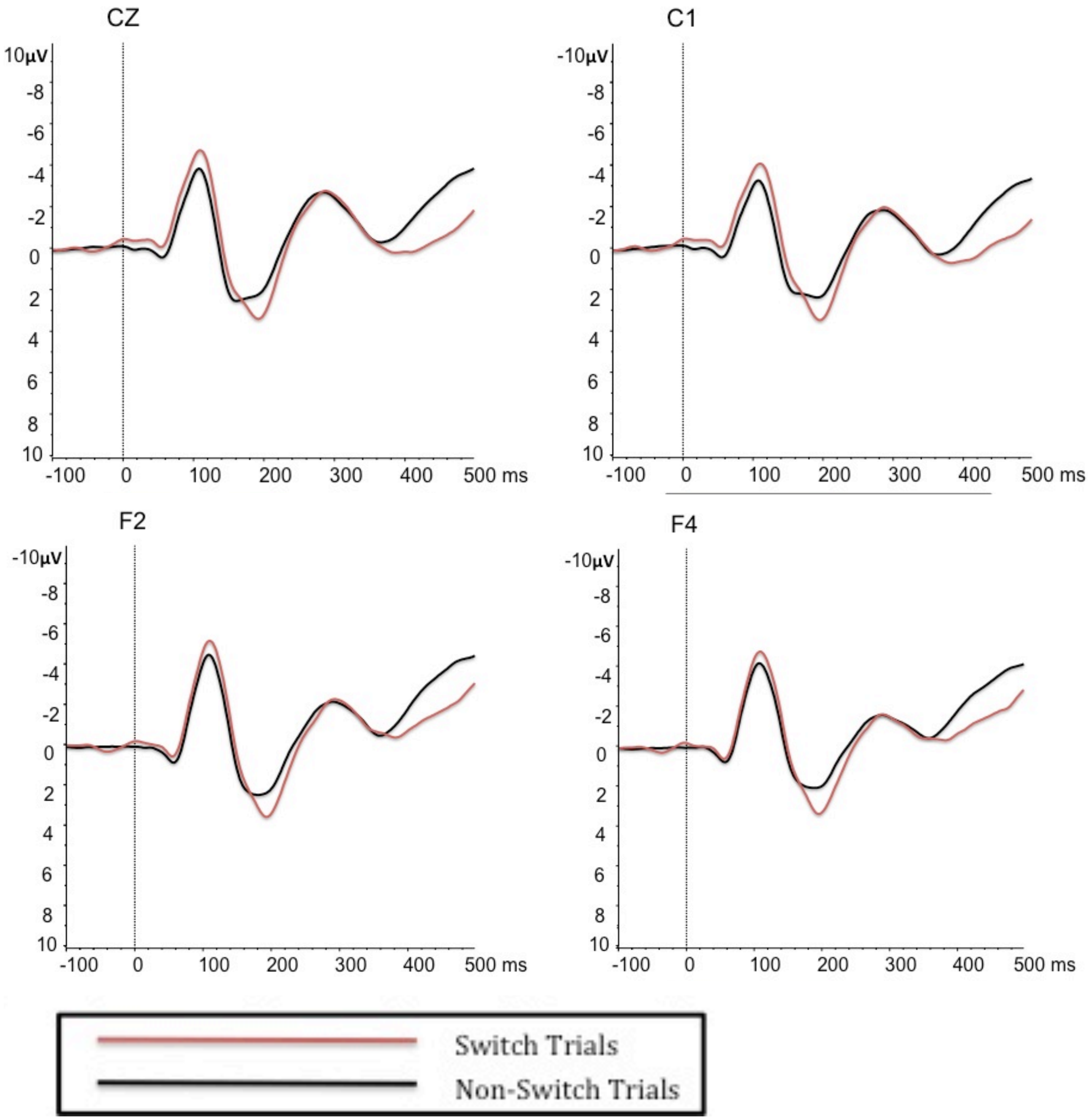


Image IV.I: Cue-locked waveform for LS in electrodes C1, CZ, F2 and F4.

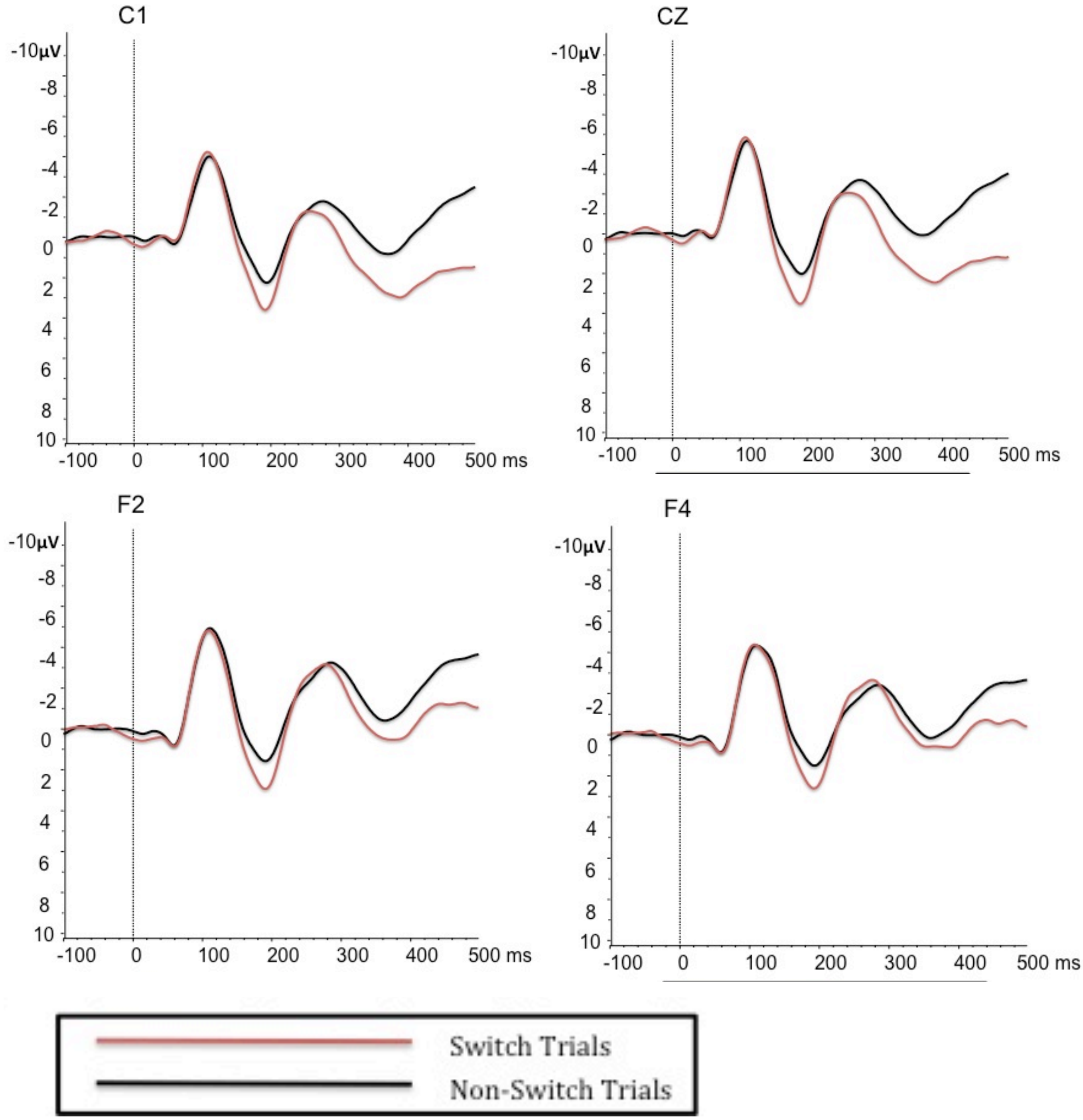


Image IV.II Cue-locked waveform for TS in electrodes C1, CZ, F2 and F4.

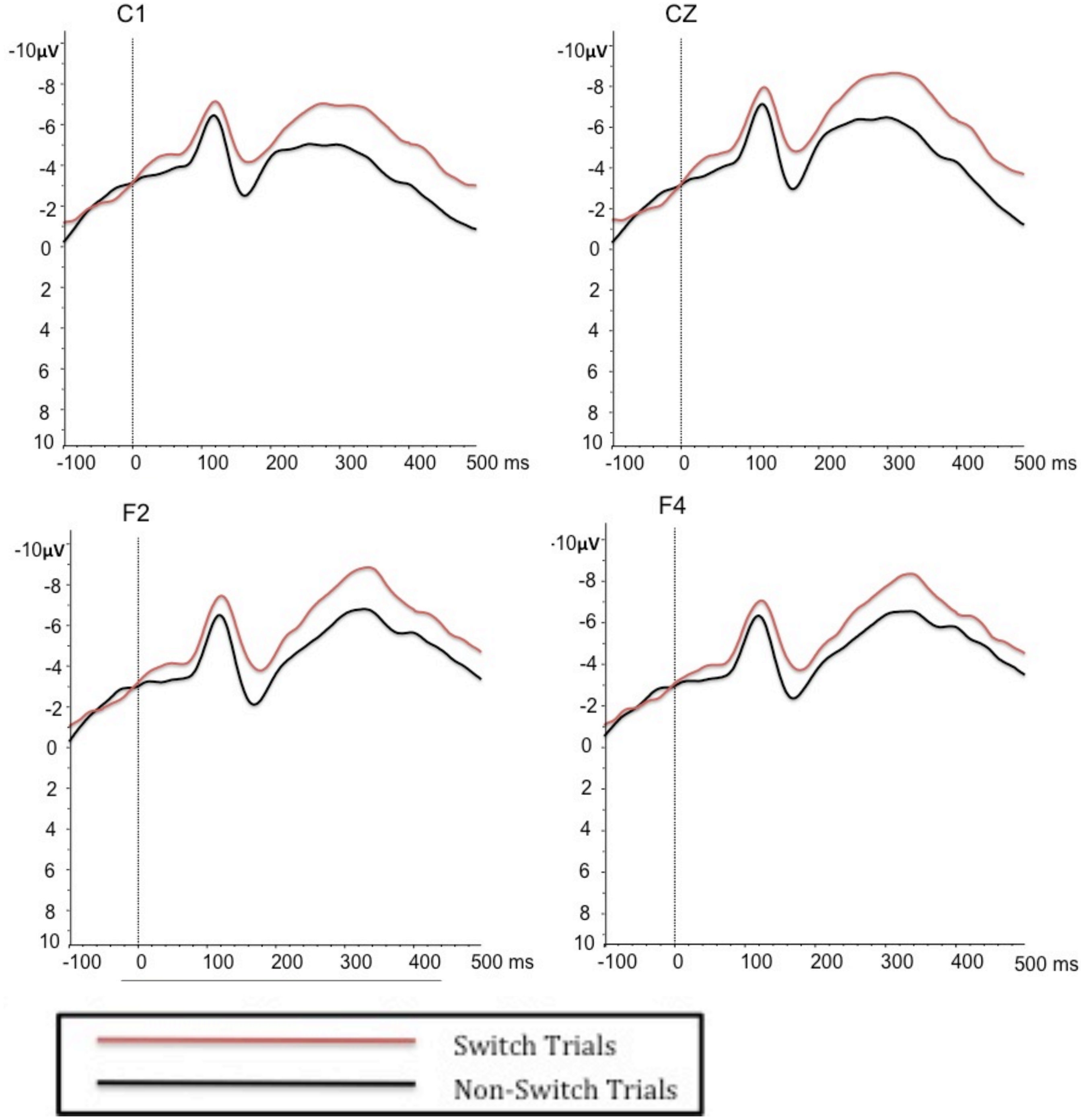


Image IV.III: Stimulus-locked waveform for LS in electrodes C1, CZ, F2 and F4.

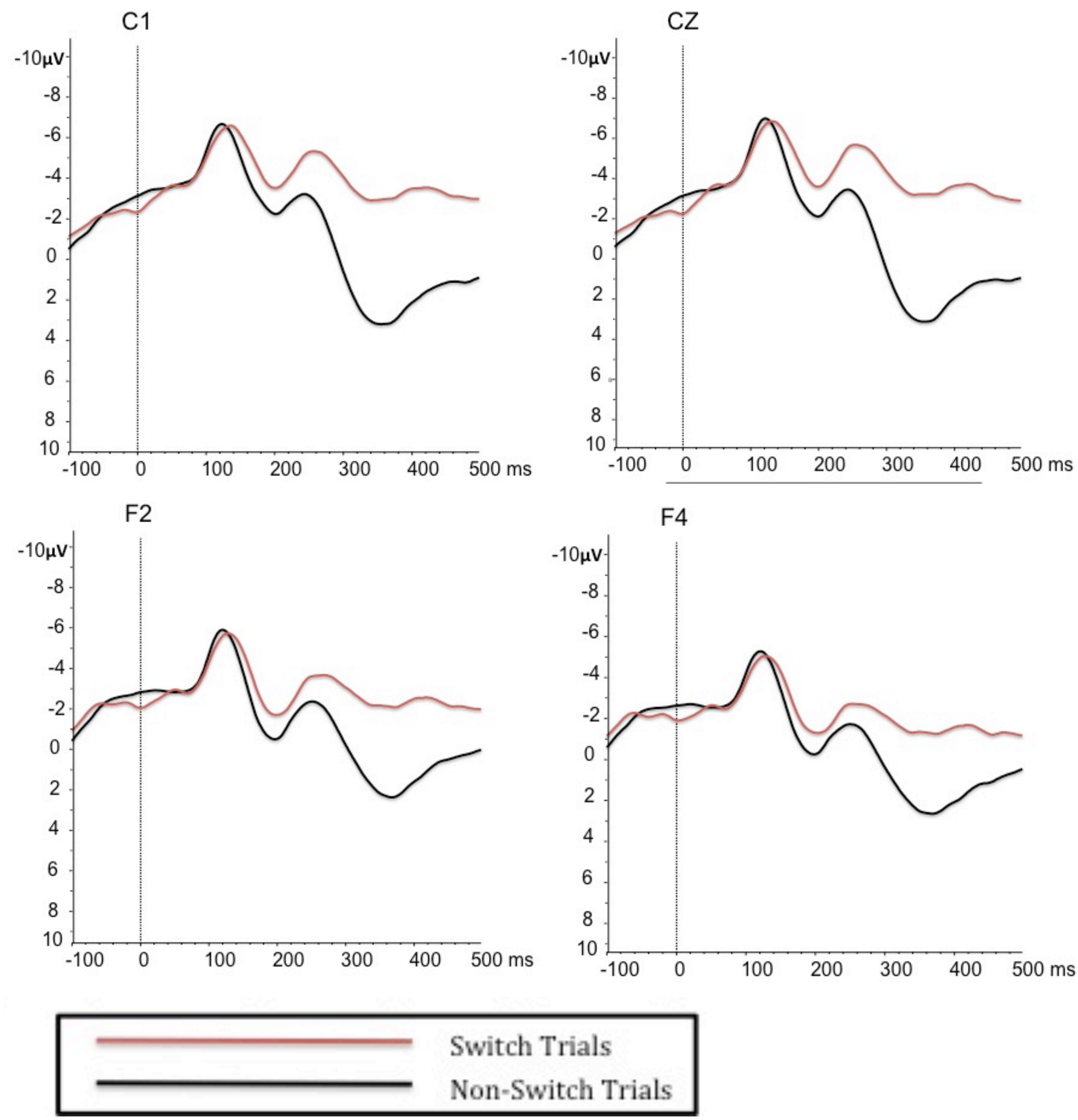


Image IV.IV: Stimulus-locked waveform for TS in electrodes C1, CZ, F2 and F4.