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Doctoral dissertation by

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Para meus pais José e Ana Dias

To all deaf people

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Abstract

Learning to read implies not only knowledge of isolated words, but also the prior assimilation of the syntactic rules necessary to form a sentence. However, anterior studies have mainly looked at how deaf readers process reading at the word level, and only a few have investigated this question in respect to sentence processing. Moreover, these few studies that investigated semantic and morphosyntactic processing in deaf readers were conducted in languages other than Spanish (i.e. English and German), and presented different linguistic properties such as the case of grammatical agreement. Therefore, the main goal of the present study is to investigate the brain mechanisms that underlie reading comprehension in skilled deaf readers of Spanish.

To understand how deaf readers process semantic and syntactic information, we used EEG to record brain activity during a sentence judgment task from three different groups of readers of Spanish: deaf highly-skilled readers, hearing native speakers and English L2 learners of Spanish. Within a grammatical violation paradigm, participants read sentences in Spanish with and without semantic or morphosyntactic errors and decided if sentences were acceptable or not. The morphosyntactic manipulation consisted of agreement violations for number and gender, which could be transparent (i.e. the grammatical gender is apparent from the word form) or opaque. Results showed that deaf readers present similar brain activity compared with the hearing group to process sentences with semantic violations, reflected by a classic N400 effect, and syntactic violations, reflected by an early negativity and a canonic P600 effect. Importantly, however, some differences were found between deaf and hearing readers in the early time-window for sentences with gender violations: while violations of agreement for transparent gender showed a typical LAN-P600 effect for hearing readers, deaf readers elicited a N400-P600, indicating different processing mechanisms when computing agreement with transparent nouns; violations of opaque gender elicited the same type of response for both groups. This study provides evidence that deaf readers might use orthographical information to facilitate agreement computation; whenever such information is not available, deaf readers' processing is native-like.

To disentangle whether these differences could be due by the fact that deaf readers are behaving as second language readers we conducted another experiment comparing the same group of deaf readers with native English speakers who are L2 learners of Spanish. The results showed no difference for semantic processing as both groups of readers elicited a N400 effect for semantic violations but indicate differences between deaf readers and L2 learners in for morphosyntactic processing. Overall, the results revealed three broad differences. Firstly, in grammatical violation conditions L2 readers failed to show an ERP effect in the early time-window (350-500 ms), while deaf readers elicited a negativity, indicating the use of more automatized processes for the deaf group in comparison to the L2 readers. Secondly, differences in the P600 effect were also found, with L2 readers showing less robust or shorter-lived effects (that did not achieve significance in the P600b time-window), suggesting that L2 readers had problems monitoring, checking and reprocessing the linguistic input that is related to gender agreement. Thirdly, the L2 readers but not the deaf readers showed a correspondence between behavioral measures (reading comprehension, sentence acceptability task) and the P600 effect elicited in the grammatical conditions, demonstrating that both types of measure were tracking second language proficiency.

Finally, I discuss how high-skilled deaf readers should be treated as native readers rather than L2 learners and the role a different first language (e.g. Spanish Sign Language) can play in the acquisition of a written language, for instance, the importance orthographical features for deaf readers during morphosyntactic processing.

Keywords: deaf readers, sentence processing, ERPs, P600, N400, Individual differences, morphosyntactic agreement, gender, number, orthographic transparency

Resumen

En la mayoría de las sociedades, aprender a leer tiene un papel fundamental, permitiendo el acceso no solo a la información, pero también proporcionando una habilidad central en la educación. A diferencia de la adquisición del lenguaje oral, el proceso de alfabetización no ocurre de forma espontánea. Es decir, no podemos reconocer palabras escritas y extraer su correspondiente significado sin una previa instrucción formal: aprender a leer no es un proceso natural y requiere cierto esfuerzo. Muchos niños tienen dificultades significativas para alcanzar un nivel alto de alfabetización y uno de cada diez adultos[1] no domina totalmente la habilidad de comprensión lectora (Dehaene, 2008). En cambio, no es así la adquisición de la lengua hablada. Salvo en circunstancias excepcionales, todos los niños aprenden a hablar durante los primeros tres años de vida sin mucho esfuerzo, comenzando con un número limitado de vocalizaciones durante los primeros meses de vida hasta culminar con la producción de frases sintácticamente complejas, alrededor de los tres años (Kennison, 2014). Por lo tanto, la exposición temprana a un idioma es lo que desencadena el desarrollo normal del lenguaje, y más tarde servirá como la base para la alfabetización.

Si aprender a leer implica la capacidad de decodificar un sistema escrito arbitrario que representa su respectiva lengua hablada hay, consecuentemente, un vínculo fundamental entre el lenguaje oral y el escrito. Lógicamente, aprender a hablar antes de aprender a leer facilita el proceso de alfabetización, ya que gran parte del sistema lingüístico, como por ejemplo las reglas sintácticas, ya ha sido implícitamente asimilado a través del habla. Por el contrario, las personas que nacen con sordera severa o profunda no tienen acceso temprano

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[1] Estadística referente a países desarrollados.

al lenguaje oral. A falta de esta base previa ¿cómo es posible que las personas sordas aprendan a leer un idioma que nunca han escuchado?

Para una persona sorda, convertirse en un lector competente es una tarea difícil de lograr: sólo un pequeño número de personas sordas alcanzan un nivel de lectura comparable al de sus compañeros oyentes (Goldin-Meadow & Mayberry, 2001; Musselman, 2000; Traxler, 2000). La investigación sobre los problemas de lectura de las personas sordas no ha proporcionado todavía una respuesta clara. Sabemos, por ejemplo, que lectores sordos no utilizan necesariamente la información fonológica durante la lectura de palabras (Bélanger, Baum, & Mayberry, 2011), aunque esa información esté disponible para ellos (Gutierrez-Sigut, Vergara-Martínez, & Perea, 2017). En el caso de la lectura de frases, hay evidencias indicando que lectores sordos competentes tienen una percepción visual más amplia, pudiendo acceder antes a la información verbal presente en la parafóvea (i.e. ortográfica y fonológica) durante la lectura de textos (Bélanger, Slattery, Mayberry, & Rayner, 2012). La ventaja de una mayor amplitud perceptual durante la lectura es que permite a los lectores sordos el procesamiento de una mayor cantidad de información verbal. Eso hace con que sean lectores más eficientes en comparación con lectores oyentes (Bélanger, Mayberry, & Rayner, 2013).

Sin embargo, además del procesamiento de palabras, la lectura también implica la asimilación de reglas sintácticas presente en cada idioma y fundamentales para la correcta comprensión de frases y textos. Gran parte de los estudios realizados con personas sordas se han limitado a analizar solamente el procesamiento de la lectura a nivel de palabras (e.g. Bélanger, Lee & Schotter, 2018; Corina, Lawyer, Hauser, & Hirshorn, 2013; Emmorey, Weisberg, McCullough, & Petrich, 2013; Fariña, Duñabeitia, & Carreiras, 2017), siendo que apenas unos pocos se han centrado en el procesamiento de frases en esta población (e.g. Domínguez & Alegria, 2010; Mehravari, Emmorey, Prat, Klarmand, & Osterhout, 2017; Skotara, Salden, Kügow, Hänel-Faulhaber & Röder, 2011, 2012). Asimismo, los pocos estudios que investigaron el procesamiento de frases en lectores sordos fueron mayoritariamente realizados en idiomas distintos del español (e.g. inglés y alemán). Debido a que estos idiomas presentan propiedades lingüísticas que son propias de cada lengua, como es el caso de los tipos de concordancias gramaticales, la extensión de sus resultados al español no es posible. Al contrario de lenguas consideradas opacas (e.g. inglés), el español (castellano) es una lengua que presenta una ortografía transparente y rasgos morfosintácticos específicos, como la concordancia nominal, de género gramatical y numérico. Esas concordancias son obligatorias y su conocimiento necesario para una correcta comprensión lectora (Anton-Mendez, Nicol, & Garrett, 2002). Además, la concordancia de género en castellano puede darse de dos formas: cuando un ítem lexical está marcado con el sufijo '-a' indica que la palabra es femenina (e.g. mesa o casa); y cuando marcado con el sufijo '-o' indicando que la palabra es masculina (e.g. carro o plato). Al contrario, palabras opacas no llevan marcadores ortográficos que indiquen si dicho ítem es masculino o femenino, y el lector debe saber de antemano el género para poder realizar correctamente las concordancias gramaticales durante la lectura. En efecto, estudios realizados con personas oyentes demuestran que lectores nativos del castellano procesan los dos tipos de concordancia de género de forma similar (Caffarra & Barber, 2015), mientras que para lectores oyentes aprendices tardíos del castellano, la dificultad de procesar concordancias de género opaco dependerá de la frecuencia y del uso diario de la L2 (Caffarra, Barber, Molinaro, & Carreiras, 2017). Vemos, por lo tanto, que conocer las especificidades de la gramática de cada idioma es esencial para una buena performance lectora, y que la experiencia lingüística de cada grupo lector (e.g. nativos vs. aprendices de L2) ejercerá una importante influencia en la forma que el cerebro procesará esa información. Así, entender cómo los lectores sordos procesan esas características lingüísticas nos permitirá comprender cómo procesan la lectura en general.

El objetivo de esta tesis es, por lo tanto, investigar cómo se da el procesamiento de la información sintáctica y semántica en lectores sordos competentes. En primer lugar, investigaremos qué similitudes y/o diferencias comparten los lectores sordos con los lectores oyentes nativos. Para tanto, evaluamos estas propuestas a través de la técnica de electroencefalograma (EEG) y de los Potenciales Evocados Relacionados a Eventos (ERP): grabamos la actividad cerebral de un grupo de 19 sordos buenos lectores y de un grupo de 19 oyentes nativos de español (experimento 1) mientras leen frases con y sin errores semánticos o morfosintácticos. Para entender las diferencias y similitudes entre estos grupos de lectores sólo contamos con buenos lectores sordos, porque pueden arrojar luz sobre los procesos cognitivos necesarios para sustentar la lectura en lectores sordos. En segundo lugar, puesto que sabemos que la experiencia lingüística impacta el procesamiento del lenguaje en el cerebro (Costa & Sebastián-Gallés, 2014), y considerando que algunos autores sugieren que las personas sordas procesan la información escrita como los lectores no-nativos (e.g. Hoffmeister y Caldwell-Harris, 2014), comparamos el mismo grupo de lectores sordos con un grupo de 19 bilingües tardíos del español (experimento 2).

En resumen, mi objetivo es investigar:

a) cómo los lectores sordos de español procesan la información semántica y sintáctica, y cómo este procesamiento puede diferir (o no) del de los lectores oyentes nativos del español;
b) en qué medida los lectores sordos procesan el lenguaje escrito como una segunda lengua, es decir, si se parecen más a bilingües tardíos del español que a los lectores nativos;
c) si los lectores sordos utilizan la información semántica para procesar frases con errores morfosintácticos según propone la hipótesis de la estrategia de la palabra clave.

Las respuestas a estas preguntas aportarán conocimiento sobre los mecanismos cognitivos de los buenos lectores sordos, y conllevan implicaciones prácticas respecto a la creación de nuevos métodos de enseñanza.

En el experimento 1, los resultados demostraron que los lectores sordos presentan una actividad cerebral muy similar al del grupo de oyentes respecto al procesamiento de frases con errores semánticos, reflejada por la N400, y con violaciones sintácticas (género y número), reflejadas por una negatividad temprana y una positividad posterior. Sin embargo, observamos algunas diferencias significativas entre los grupos: mientras que las respuestas a las violaciones de número y género opaco obtuvieran resultados equivalentes en los dos grupos, las respuestas a la condición de género transparente no lo eran. Los lectores sordos se valen de diferentes mecanismos cuando la relación de concordancia depende de un sustantivo de género transparente (e.g. casa o barco), posiblemente utilizando la información ortográfica para facilitar el procesamiento. Por un lado, las respuestas electrofisiológicas de los lectores sordos eran equiparables a las de sus compañeros oyentes, contradiciendo otros trabajos recientes que proponen que lectores sordos no tienen las mismas respuestas electrofisiológicas que los oyentes respecto al procesamiento gramatical (e.g. Mehravari et al., 2017). Por otro lado, las diferencias observadas entre los dos grupos indican que, en ciertas circunstancias, el grupo de buenos lectores sordos utilizaron distintos recursos cognitivos para procesar la información gramatical.

En el experimento 2, para investigar si las diferencias observadas en experimento 1 se debían a un procesamiento propio de una segunda lengua, comparamos el mismo grupo de lectores sordos con un grupo de hablantes nativos de inglés y aprendices tardíos del español (L2). Los resultados revelan importantes diferencias entre los lectores sordos y los oyentes L2. No hubo diferencia entre los grupos en la condición semántica: ambos grupos mostraron el efecto N400 típico. En cambio, sí hubo diferencias en el caso del procesamiento morfosintáctico. En concreto, el grupo de L2 no presentó una respuesta electrofisiológica temprana para las tres condiciones gramaticales y solamente se observó un efecto más tardío, el P600. Además, este efecto P600 era meno robusto para los lectores L2 comparados con el grupo de lectores sordos.

Estos resultados sugieren que el procesamiento de los buenos lectores sordos se parece más al de los lectores nativos que al de los lectores L2. Sin embargo, como hemos resaltado, en algunos casos el procesamiento de los lectores divergió del procesamiento nativo. Esas diferencias demuestran que lectores sordos expertos tienen su propia forma de procesar la información gramatical. Concretamente, los resultados indican que aprovechan información visual, como la ortográfica, para procesar la concordancia. Debido a que el español tiene una morfosintaxis regular y explícitamente marcada en el caso del número o el género transparente, en este contexto, facilita el uso de estas regularidades, ofreciendo un soporte adicional durante los procesos de recuperación léxica (e.g. la recuperación de la información de género), así como la resolución de dependencias sintácticas (e.g. concordancia de estos rasgos).

La solución de los problemas de lectura observados en la población sorda no puede ser reduccionista: seguramente son el resultado de una serie de factores presentes en el desarrollo de cada una de esas personas, tales como la falta de exposición a un lenguaje natural en la primera infancia y/o la dificultad de aprender a leer únicamente a través de la modalidad escrita, sin una suficiente exposición previa a las características de la lengua hablada (Hoffmeister y Caldwell-Harris, 2014). Además, la gran variabilidad en la forma en que los lectores sordos aprender a leer dificulta identificar el impacto de cada una de sus experiencias anteriores en el resultado final. Sin embargo, caracterizar los buenos lectores sordos como más cercanos a los nativos que a los bilingües tardíos a la hora de procesar la información sintáctica contribuye a una mejor delineación del perfil lector de esta población. Asimismo, tiene importantes implicaciones prácticas de cara a la creación de nuevas intervenciones educativas y metodologías de enseñanza. El uso de la información ortográfica como apoyo y guía para el procesamiento sintáctico podría ser un ejemplo de cómo los lectores sordos superan el hecho de que no pueden acceder al lenguaje hablado.

Por último, entender cómo los lectores sordos son capaces de alcanzar niveles nativos de alfabetización desafía lo que sabemos acerca de la lectura. Casi todo lo que sabemos sobre cómo el cerebro procesa el lenguaje escrito proviene de estudios realizados con la población oyente. Ciertamente, es muy útil tener una población de referencia típica que sirva como referencia ya que podemos utilizar estos hallazgos como punto de partida para entender cómo leen las personas sordas. Sin embargo, como muestran los resultados de

este estudio, los lectores sordos no son lectores oyentes. Para comprender cómo las personas sordas se convierten en lectores competentes, debemos prestar atención a los mecanismos alternativos que utilizan estos lectores, y a cómo esos procesos les ayudan u obstaculizan su proceso de alfabetización. Por ejemplo, comprender cómo el uso de la lengua de signos o las experiencias educativas previas moldan el procesamiento lingüístico de personas sordas alfabetizadas; estas diferencias individuales pueden arrojar luz sobre cómo lectores sordos logran tornarse lectores competentes. Espero que este trabajo contribuya e informe nuestra comprensión de la lectura en personas sordas.

Palabras clave: lectores sordos, procesamiento de frases, ERP, P600, N400, diferencias individuales

Table of contents

1. Introduction

In most societies, learning to read has a central role, allowing access to information and providing a crucial skill in education. In contrast to spoken language, literacy is not naturally acquired. We cannot recognize written words and extract meaning from them without formal instruction. Difficulties with word reading can lead to literacy problems: many children struggle to achieve a high level of literacy and one in ten adults fails to master text comprehension (Dehaene, 2009). This is not the case for spoken language, which, save for exceptional circumstances, can be acquired effortlessly during the first three years of life. The milestones of language development follow the same steps for most typical children, usually starting with a limited number of vocalizations during the first months of life and culminating with the production of syntactically complex sentences by the age of three (Kennison, 2013). Therefore, exposure to a language during the first years of infancy is the necessary input that will trigger language development, serving later as the base for the attainment of literacy.

This link between spoken and written language is due to the fact that learning to read implies the ability to decode a written system that represents the spoken forms. Thus, acquiring a spoken language prior to learning to read facilitates the task as much of the linguistic system, such as the syntactic rules, has already been implicitly assimilated by the learner. In the case of people who are born deaf, there is no access to any spoken language input. Even if the deaf individual naturally acquires a sign language from birth, they still lack direct access to the spoken language. So, is it possible for deaf people to learn to read a language that they have never heard?

The answer to this question is yes, there are deaf individuals who become high-skilled readers. Nevertheless, becoming a proficient reader for deaf people is a very hard task to accomplish: only a small number of deaf individuals achieve a reading level comparable to that of their hearing peers (Goldin-Meadow & Mayberry, 2001; Musselman, 2000; Traxler, 2000). Many studies have been devoted to enquiring why deaf individuals fail to become skilled readers or even learning to read (Mayberry, del Giudice, & Lieberman, 2011). In this thesis we formulate a related but different question asking *how it is possible* for some deaf individuals to learn to read a language they have never heard. Thus, understanding how some deaf individuals become skilled readers while others do not is the central question of this doctoral thesis. How do deaf readers process a written code? Are their reading processes similar to those of hearing readers? Alternatively, do they read more like second-language learners? My main goal is to address these questions to shed light on the brain mechanisms that underlie the cognition of (written) language in deaf individuals. Specifically, my aim is to develop a cognitive and linguistic profile of deaf readers of Spanish using behavioral and electrophysiological measures to investigate how their brains process the written code.

In this introductory chapter, I will start by briefly discussing the history of deaf education to provide the context that explains why deaf people were excluded from the educational system for so many years and the consequences of this delay for their education outcomes and, specifically, for their reading and language skills. For the sake of clarity, I provide definitions of important terms and concepts that will be used throughout this thesis. Finally, a description of the main objectives of this work and the structure of this thesis are set out in the final sections of this chapter.

1.1 Education and literacy in deaf people: an overview

The history of deaf education in an organized manner started three centuries ago, two centuries later than the advent of formal education for hearing people (Moores, 2010). The first steps of this history occurred much earlier, during the sixteenth century in Spain, where deaf children from aristocratic families were sent to live in monasteries and convents to receive education from the monks (Plann, 1997). At the time, acquiring a spoken language was necessary for both legal and religious reasons: legally, it was required for deaf individuals from royal families to be eligible to inherit family wealth; and from a religious point of view, having a language would allow them to achieve salvation (Plaza-Pust & Main, 2012). This illustrates the importance given to the acquisition of a language and how negative it was considered to be incapable of speaking. The Spanish monk Pedro Ponce de Leon was the first to succeed in educating deaf children and is considered the first teacher of the deaf (Plann, 1997). Although his teaching methods were never documented, another Spanish cleric Juan de Pablo Bonet created the first manual alphabet based on Ponce de Leon’s teaching methods. The publication of Bonet’s manual greatly inspired deaf educators within Europe and impacted deaf education years later in France and UK. Despite these isolated cases, deaf people who were not wealthy were generally barred from education, and the received wisdom was that they were incapable of acquiring a language and, consequently, unable to learn and reason. The situation of the people who were born deaf in the seventeenth century was a calamity: they were completely excluded from society, isolated from their families and forced to work in deplorable conditions (Sacks, 2009).

This situation started to change in the 1760s with the work of Abbé de l’Eppé, a French abbot who opened the first recognized official school for the deaf supported by the

French government. De l'Eppé developed a system of "methodical signs" that was influenced by the work of the Spanish educators Ponce de León and Bonet. The system was based on both the native signs used by the French deaf community and manual gestures derived from the spoken French (Marschark, Schick, & Spencer, 2006). The inclusion of deaf people in a formal educational system was a historical landmark because for the first time they were recognized as being capable of learning. De l'Epée's work served as a model for educators of deaf individuals from around the world. One significant example was the American Thomas Hopkins Gallaudet, who learnt about de l'Epée's method, and based on his teaching approach opened the first American school for the deaf, which became what is today Gallaudet University, the only university for deaf individuals.

The importance of this from a point of view of the history of the deaf education was that they were finally recognized as able to learn and develop a language, and therefore, to read. However, teaching deaf people to read was very challenge, and it still is. Different methods were developed since then, which generated different point of views about the best method to educate deaf people. Therefore, the next years was marked by the development of different educational methods to teach deaf children to read. School programs for deaf individuals tended to focus exclusively on the acquisition of the spoken language, since sign languages were not yet considered a language. The use of signs in educational settings was either avoided or served only as a means to communicate with the deaf until they were able to learn a spoken language. The debate surrounding the role of sign language and the perceived primacy of the spoken language came to head at an international conference held in Milan in 1880. The attendees, who were educators of the deaf from across Europe and the US, voted to reject the use of signs in the education of the deaf and established the prevalence of an oral approach in deaf education (Gertz & Boudreault, 2016). Although the deaf community continued to use sign languages outside schools (and covertly at the schools), the adopted policy in educational settings of most countries was strict. Consequently, until the mid to late twentieth century *oralism* was the predominant method in deaf education across Europe (Plaza-Pust & Main, 2012).

However, these methodologies faced an important paradox: even though they focused exclusively on the spoken language, the results were not satisfactory and deaf children were finishing school with poor language skills and poor levels of reading. Evaluations of the academic achievements of deaf children found that, when compared with their hearing peers, deaf children presented very low reading comprehension skills, poor speech intelligibility and lip-reading skills (Conrad, 1979). A nationwide academic achievement testing program in the United States that used the Stanford Achievement Test to assess academic skills in deaf children also showed relatively low reading comprehension skills (Allen, 1986). These evidences raised many questions concerning the correct approach to teach deaf children. The fact that acquiring a spoken language was a very hard task to deaf, the possibility that schools could use a signed language to teach the deaf was appealing. Consequently, a "war of methods" emerged, with defenders of the *oral approach* on one side and adepts of the *sign-based approach* on the other (Marschark et al., 2006).

I am not entering the details of this 'war of methods' and the advantages and disadvantage of each of these teaching approaches. Rather, my intention here is to point out some of the relevant aspects of the history of the deaf education that contributed to the current scenario presented in most of the educational systems around the world, which is a great variety of language profile among deaf children. Although there are still a lot of discussion about the importance of learning a spoken language to promote literacy attainment in the deaf population, the consensus in the more recent scientific literature emphasizes the importance of the acquisition of a solid (first) language prior to the acquisition of reading, that could be either a spoken or a signed language. While sign languages have been identified as the most coherent linguistic input available for deaf children as they can be acquired effortlessly through normal exposure and without formal instruction (Lillo-Martin & Sandler, 2008; Petitto, 2000), when it comes to reading acquisition, it is still not clear how learning to read is mediated by knowledge of sign language, although some attempts to explain this link have been brought up (Hoffmeister & Caldwell-Harris, 2014; Petitto et al., 2016). I will discuss more about the findings that support this view with details in section 1.3.

This overview about the history of deaf education reveals how the heterogeneity of the deaf population, in terms of both language profiles, educational methodologies and other relevant factors, is a result of these different views about the best method to educate the deaf. That is, all the differences in educational outcomes observed among deaf children is a consequence of both language backgrounds and the exposure to different teaching methods. This makes difficult to find only one solution to this problem that could be applied to all deaf children, especially in the current context of the growing number of hearing-aids and cochlear implants users. Irrespective of educational histories and philosophies adopted, some authors have emphasized that effective teaching and learning require *shared* communication between instructors and students, and it is fundamental that the language used in class is well understood by the student, considering that many deaf children arrive at school with an impoverished language background (Marschark & Wauters, 2008).

1.2 Deaf and deafness: defining concepts

According to the World Health Organization (WHO), 466 million people in the world are affected by some level of hearing loss (WHO, 2019). A person is considered to have hearing loss if hearing thresholds are 25 dB or greater in both ears. A continuum of different grades of hearing loss is illustrated in Figure 1. As shown by the continuum, being born with severe or profound deafness means that only very loud sounds from the environment (e.g. a fire alarm) can be heard, and the discrimination of complex sounds, such as speech, is not possible.

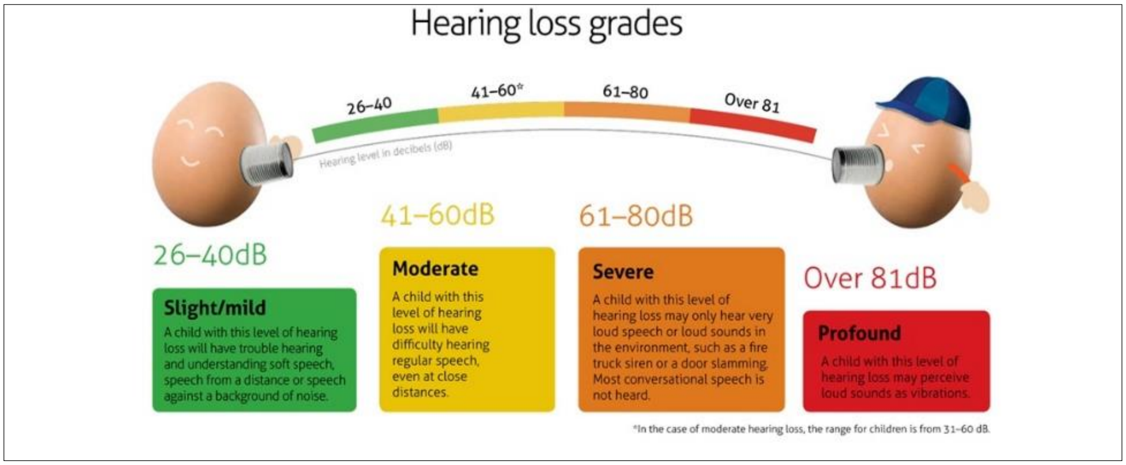

Figure 1. Different degrees of hearing loss according to the World Health Organization (2019).

Different terms can be used to characterize someone with hearing loss and, usually, these labels refer to two factors: the onset and the degree of the hearing loss. Onset is important because becoming deaf at the age of 65 is not the same as for a three-year old, whose language development is still in progress. The degree of loss also plays an important role: the higher the hearing loss the less access there is to an auditory input such as spoken language. The combination of these two aspects are defining factors to the term *deaf person.* Being a deaf person typically means that someone has *been born* or has become deaf *before* the age of *three years old* (onset) and has *severe* or *profound* (degree) hearing loss. This implies very little or no hearing, and, typically, the use of sign language as the main mode of communication (WHO, 2019).

In this thesis, I adopt this distinction: anytime I refer to a deaf person I will only be referring to those people who are *severely* or *profoundly deaf* that have either *been born deaf* or have become *deaf before the acquisition of spoken language* (i.e. prelingually deaf)[2]. Finally, I use the term sign-print bilinguals to refer to those people who use sign language as the main mode of communication and the written form of the spoken language as their second language (Hoffmeister & Caldwell-Harris, 2014).

1.3 Reading in deaf individuals: behavioral and neuroscientific evidence

As mentioned in introduction of this chapter, the proper acquisition of a spoken language is an important prior step for the development of reading skills for typical children. This is especially so when the writing system is a representation of the phonological form of the spoken language, as is the case for most of the world’s writing systems. For deaf people, who are unable to access auditory information directly, learning to read is a difficult task as they do not have access to the underlying phonological information. Most of the studies looking at reading abilities in deaf people suggest that the lack of phonological awareness is the main reason that deaf learners fail to read proficiently (Musselman, 2000). However, more recent investigations have proposed that other factors such as working memory and

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[2] It is important to point out that being deaf is not limited to a biological condition: it can involve belonging to a community that shares not only a language but also cultural aspects such as beliefs and practices (Padden & Humphries, 2005). An important distinction is made between the use of lowercase deaf when referring to the audiological condition of not hearing, and the uppercase Deaf when referring to a sociolinguistic group of people who share a (sign) language and a culture (Padden & Humphries, 1988). However, I am not adopting this distinction here.

language background might play a crucial role in explaining reading problems among deaf individuals (Hirshorn, Dye, Hauser, Supalla, & Bavelier, 2015; Mayberry et al., 2011). Naturally, learning to read isolated words is the first step of the reading process, and any problem at this stage will lead to subsequent errors when putting words together to comprehend a sentence or text. Therefore, in the following subsections, I will start describing the scientific evidence that explains how deaf people process isolated words, and how deficits at this stage could affect the process of reading at the sentence level. Then, I will present studies that looked specifically at how deaf people process sentences and the syntactic structures required for sentence comprehension.

1.3.1 Reading at the word level: lexical access and phonological awareness

The absence of early language exposure is related to later reading problems in deaf (Chamberlain & Mayberry, 2000; Clark et al., 2016; Mayberry & Lock, 2003). As mentioned above, much of the work on reading in deaf individuals has focused on how phonological representations, or the lack thereof, affect word encoding. Whether or not deaf readers make use of phonological information remains unclear as findings are inconclusive. A meta-analysis of studies that investigated reading in deaf people revealed that phonological skills only explained 11% of the variance in reading ability, and that the best predictor to account for this heterogeneity was language ability (either spoken or signed), which explained 35% of reading variance (Mayberry et al., 2011). Thus, other factors, such as the degree of hearing loss, proficiency in the language being read, age of exposure to a first language, and degree of knowledge of sign language, might also play an important role in explaining this variation. Deaf readers of French used orthographic information during word processing, but not phonological information, suggesting an independent contribution of orthographic and phonological processing to visual word recognition (Bélanger, Baum, & Mayberry, 2012). These results are consistent with other studies that suggest that adult deaf readers do not activate phonological codes during lexical processing in American English (Chamberlain, 2002; Cripps, McBride, & Forster, 2005; Waters & Doehring, 1990), French (Bélanger, Baum, et al., 2012) or Spanish (Fariña, Duñabeitia, & Carreiras, 2017), but there is evidence indicating that phonological information is available for deaf readers in the early stages of visual word recognition (Gutierrez-Sigut, Vergara-Martínez, & Perea, 2017). Considering that deaf readers cannot rely on a speech-based phonology, the development of phonological representations might happen by other means. Visual information from the lips and mouth (or manual information from systems such as cued speech), articulatory feedback, and fingerspelling might serve as alternative routes to create phonological-like representations of the spoken language (Perfetti & Sandak, 2000). Alternatively, it could also be the case that linguistic experience is the necessary foundation for learning to read: the crucial link for early reading achievement may not be between segmental sounds and print, but instead lies in a more general capacity of the human brain to segment, categorize, and discern linguistic patterning. This provides the intrinsic ability to segment any linguistic code, including written language. As such, exposure to a sign language in early life makes possible the discovery of the silent segmental units of the (visual) sign phonology but may also facilitate the segmental decoding of print (Petitto et al., 2016). The link between sign language knowledge and reading ability is supported by a study of Swedish deaf children: phonological skills in Swedish Sign Language predicted reading skills better than phonological ability in Swedish did (Holmer, Heimann, & Rudner, 2016). Nevertheless, sign language phonology might not be the only path to phonological awareness, and, in the case deaf non-signers, the brain could rely on other sources of phonological representations such as lip reading or fingerspelling (Musselman, 2000).

The use of phonological information depends on the type of writing system that is used to read. Alphabetic orthographies differ in the consistency of letter-to-sound mapping, which means that the pronunciation of the words can be more or less consistent, depending on how transparent or opaque the orthography is (Ziegler et al., 2010). For example, some languages like English present an opaque letter-to-sound mapping and the pronunciation of a given letter varies depending on the word. This is important because the orthographic consistency of a writing system influences fundamental aspects of skilled reading, including the role of phonological information (Frost, Katz, & Bentin, 1987; Ziegler, Perry, Jacobs, & Braun, 2001). Brain networks involved in reading also work differently as a function of language transparency (Oliver, Carreiras, & Paz-Alonso, 2016). Most of the studies conducted so far with deaf readers have been carried out on languages with opaque orthographies such as English or French (Bélanger & Rayner, 2015; Goldin-Meadow & Mayberry, 2001; Mayberry et al., 2011). Reading a language with irregular letter-to-sound mapping may be different from reading one with a consistent mapping, as is the case of Spanish (Fariña et al., 2017; Rodríguez-Ortiz, Saldaña, & Moreno-Perez, 2017).

Language experience and reading skills influence and modify the brain (Carreiras et al., 2009; Corina, Lawyer, & Cates, 2013; Costa & Sebastián-Gallés, 2014; Emmorey & McCullough, 2009). Neuroimaging studies have shown that the brain network underlying reading in deaf individuals presents important differences when compared with that of hearing individuals. For instance, the systems supporting rhyme processing are largely similar in hearing and deaf readers of English (MacSweeney, Goswami, & Neville, 2013). However, during a rhyme task, deaf readers of English showed greater activation of brain areas related with phonological processes compared with hearing readers (Emmorey, Weisberg, McCullough, & Petrich, 2013). This activation pattern was also observed in deaf readers of French (Aparicio, Gounot, Demont, & Metz-Lutz, 2007). This activation may reflect increased demand on brain areas related with phonological processing as a result of the extra cognitive effort by deaf readers as an alternative strategy to overcome poorly specified phonological representations of words. Moreover, similar brain responses to tasks that require phonological processing were also found for people with language disabilities such as developmental dyslexia, indicating that this might reflect a compensatory process that is used to support phonological processing when auditory representations are either absent, in the case of deaf readers, or impaired, as observed in dyslexic individuals (Macsweeney, Brammer, Waters, & Goswami, 2009; MacSweeney, Waters, Brammer, Woll, & Goswami, 2008).

An ERP study of deaf and hearing readers of English revealed that phonological awareness had a much larger impact on the EEG signal in hearing than in deaf readers, and that the neural distribution of the effect was different for both groups: left-lateralized in the hearing group but right-lateralized in the deaf group (Emmorey, Midgley, Kohen, Sehyr, & Holcomb, 2017). The pattern of electrophysiological responses was very similar in high-skilled deaf readers and low-skilled hearing readers, suggesting that neural adaptations that are maladaptive for hearing readers may actually be beneficial for deaf readers.

The use of explicit phonological tasks to test deaf readers' abilities to decode words raises the question whether these results might reflect the effort of deaf readers to correctly perform the tasks rather than their natural reading pattern. In contrast to evidence that focus on phonological processing during reading, for (word-level) semantic processing, neuroimaging studies reveal no difference in brain activation between deaf and hearing readers, with both groups engaging very similar semantic neural networks (Emmorey et al., 2013). Furthermore, a study that used an implicit phonological reading task to assess the neural systems that support word-reading for two groups of skilled ASL signers, who were either proficient or less proficient readers, showed that brain activation of proficient deaf readers was highly consistent with those found for hearing readers, In contrast, the authors found that the less-proficient deaf readers group activated different brain networks, which were similar to those observed in Chinese readers when they read logographic-like forms as they were processing the words using a whole-word approach rather than a lexical decomposition method (Corina, Lawyer, Hauser, & Hirshorn, 2013).

In summary, the process of decoding words is different for deaf and hearing readers. Behavioral studies show that although phonological awareness is an important skill for the acquisition of reading in hearing children, this might not be the case for deaf readers. Neuroimaging studies suggest that deaf readers show greater activity (relative to hearing readers) when phonological decoding is required by the task. These processing differences may reflect adaptations to the context of deafness (and impoverished phonological representations). However, for implicit word-reading tasks brain activation of high-skilled deaf readers does not differ from that of hearing readers. Overall, the evidence available suggests that lacking access to phonological input is just one factor that contributes to the variability of reading levels observed in deaf individuals, and that there is an important link between general language skills (including sign language skills) and reading ability.

Finally, if phonological access alone does not account for low reading levels in deaf people, as has been shown in studies with different languages, the problem might not be limited to how deaf readers make use of phonological information to decode words, but also how they connect words together to form and process sentences. The next section presents important findings that shed light on how deaf readers process language at the sentence level and discusses possible reading strategies used by deaf individuals to comprehend written language.

1.3.2 Reading at the sentence level: semantic and syntax processes

Studies looking at the word level show that phonological awareness might not necessarily be the main problem behind reading difficulty in deaf readers, and that phonological realization might be developed through alternative means (Hoffmeister & Caldwell-Harris, 2014; Petitto et al., 2016). In the face of insufficient spoken language to develop a comprehensive vocabulary and good morphosyntactic abilities, skilled deaf readers might develop different reading strategies to extract information from texts, overcoming their lack of access to phonological information and their impoverished contact with the spoken language (Domínguez, Carrillo, González, & Alegria, 2016). Therefore, an alternative cause of reading difficulties in deaf individuals could be related to reading at the sentence level at which the final meaning of single words is elaborated through a process of integration supported by morphosyntactic (structural) knowledge (Miller, 2010). As most of the research so far has focused on the ability of deaf readers to access phonology, few studies have directly addressed these issues. Nevertheless, in recent years, more attention has been given to understanding how deaf people process sentences and texts. This section provides an overview of these studies and their contribution to the field.

Deaf readers struggle to learn syntactic information and might use reading strategies such as a *keyword strategy*, which consists of focusing on *content words* such as verbs, adjectives and nouns to extract meaning from texts, disregarding *functional words*, such as prepositions, articles or pronouns (Domínguez & Alegria, 2010). This reading approach is observed in Spanish deaf adults and Spanish deaf children with or without cochlear implants (Domínguez et al., 2016; Domínguez, Carrillo, Pérez, & Alegría, 2014). Some models of language comprehension suggest that (hearing) readers make use of certain strategies that favor reading efficiency in detriment of a detailed language analysis. For instance, the *good enough strategy* assumes that individuals do not always engage in full detailed processing of linguistic input, either spoken or written, and that a shallow and superficial semantic interpretation of the language might be computed when difficulties are confronted during comprehension (Ferreira & Patson, 2007). Therefore, it is possible that hearing and deaf readers make use of different reading strategies that share a similar goal: prioritizing effectiveness in reading rather than a deep examination of the text in those cases when language processing does not require a more elaborate analysis and comprehension can be achieved using less cognitive effort (Karimi & Ferreira, 2016). This view is different from most classical views of language comprehension that assume that language processing is precise and detailed, but recent studies have been demonstrated that under certain circumstances language processing is superficial and inaccurate (Christianson, 2016; Christianson, Williams, Zacks, & Ferreira, 2002; Ferreira, 2003; Karimi & Ferreira, 2016). Nevertheless, it is still not clear if the use of the *keyword strategy* by deaf readers is an instance of this “good enough” approach or a final consequence of a “not good enough” teaching methods that do not emphasize the correct use of the spoken language and its more complex syntax structures.

Other factors may also have an impact on reading development in deaf individuals, including aptitude in visual information, language experience, and nonverbal cognitive skills. Deaf individuals make extensive use of visual representations of language as they need to process linguistic input mainly in its visual form. For example, previous research on eye-movements indicates that adult skilled deaf readers present an enhanced visual attentional span, making them faster and more efficient at reading compared with hearing readers (Bélanger, Baum, et al., 2012; Bélanger & Rayner, 2015; Bélanger, Slattery, et al., 2012). Specifically, adult skilled deaf readers spend less time looking at each word in a text, regress less to re-check words, and make longer saccades forward in the text compared with hearing readers with the same level of reading comprehension. Enhanced visual attentional span and faster reading patterns are also observed in young skilled deaf readers of English (Bélanger, Slattery, Mayberry, & Rayner, 2018).

Language comprehension might also be affected by language background, and in the case of deaf readers, the abilities necessary to become a skilled reader might differ depending on whether the individual’s linguistic experience is based on signed or spoken language. A neuroimage study to investigate how language experience shapes the brain network that supports reading in deaf individuals compared three groups during a passive reading comprehension task: deaf signers, oral deaf and hearing individuals (Hirshorn, Dye, Hauser, Supalla, & Bavelier, 2014). Although all groups engaged a similar reading circuit, some significant differences were observed: deaf signers and oral deaf showed greater activation of the auditory cortex compared to hearing individuals; more activation in areas related with semantic processing was observed for both deaf groups; and, importantly, deaf signers presented less activation of the Visual Word Form Area[3] than oral deaf and the hearing group. Additionally, a behavioral study looking at how language experience could affect predictors of reading comprehension tested two groups of deaf readers who differed only in their main mode of communication (either English or ASL) during verbal (phonological awareness and verbal memory) and nonverbal (semantic memory) tasks (Hirshorn et al., 2015). Predictors of reading comprehension in deaf readers differed as a function of language experience: for deaf native signers, semantic memory predicted better levels of reading comprehension; for orally trained deaf readers, phonological skills were the best predictor.

Studies using the EEG technique to investigate reading comprehension in deaf readers give divergent results, depending of the language used and the language profile of participants. For instance, a German study found that deaf readers who are native signers of German Sign Language elicited very similar electrophysiological responses to semantic and syntactic errors comparing to German native hearing readers. In contrast, deaf non-signers were less sensitive to morphosyntactic errors, and showed a neural pattern very similar to those observed in (hearing) L2 learners of German (Skotara, Kügow, Salden, Hänel-Faulhaber, & Röder, 2011; Skotara, Salden, Kügow, Hänel-Faulhaber, & Röder, 2012). A more recent EEG study looking at English showed that deaf (signers and non-signers) and hearing readers rely on similar electrophysiological mechanisms to process semantically incongruent sentences, but use distinct neural processes to read sentences with syntactic

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[3] The Visual Word Form Area (VWFA) is a brain area located in the visual cortex that is especially sensitive to visual words (McCandliss, Cohen, & Dehaene, 2003).

errors (Mehravari, Emmorey, Prat, Klarman, & Osterhout, 2017). More details about EEG studies and reading comprehension in hearing and deaf readers will be provided in chapter 2.

Finally, nonverbal cognitive abilities such as visual-spatial working memory have also been shown to play a special role in reading comprehension for deaf readers. For example, Daza and colleagues showed that in tests of verbal (vocabulary and phonological awareness) and nonverbal skills (attention, visual-spatial working memory and executive functions) two groups of orally trained deaf children with different reading levels but similar levels of phonological awareness, good deaf readers performed significantly better than poor deaf readers on nonverbal measures (Daza, Phillips-Silver, Ruiz-Cuadra, & López-López, 2014), such as selective visual attention mechanism and visual-spatial working memory. This demonstrates that certain nonverbal cognitive processes may be especially relevant for the development of reading comprehension in orally trained deaf children.

In conclusion, most studies on reading comprehension in deaf readers show that deaf individuals do not read sentences in the same way that hearing readers do. Previous behavioral studies suggest that deaf children and adults use a *keyword strategy* when they are reading, paying more attention to content words in order to extract the information conveyed by the text, thus, relying more on the semantic import of sentences rather than on syntactic information. In line with this, neuroimaging studies indicate that deaf readers show greater semantic processing during sentence-reading tasks compared to hearing readers. Additionally, sensitivity to grammatical errors differs between signing and orally trained deaf readers. Finally, nonverbal abilities such as visual-spatial working memory appear to play an important role in the acquisition of reading, at least for oral deaf readers.

1.4 Research question

The main goal of this thesis is to understand how deaf readers process (written) language at the sentence level. As shown above, learning to read implies not only knowledge of isolated words, but also the prior assimilation of the syntactic rules necessary to form a sentence. However, anterior studies have mainly looked at how deaf readers process reading at the word level (Bélanger, Slattery, et al., 2012; Corina, Lawyer, Hauser, et al., 2013; Emmorey et al., 2013; Fariña et al., 2017), and only a few have investigated this question in respect to sentence processing (Mehravari et al., 2017; Skotara et al., 2011, 2012). Moreover, these few studies that investigated semantic and morphosyntactic processing in deaf readers were conducted in languages other than Spanish (i.e. English and German), and presented different linguistic properties such as the case of grammatical agreement. Therefore, the aim of the present thesis is to understand how deaf readers process morphosyntactic information in Spanish, a transparent orthography, that present specific types of language agreement such as the case of grammatical gender and number agreement. Also, since previous studies proposed that deaf readers make use of semantic information to process grammatical information, I will also investigate semantic processing. For this, only high-skilled deaf readers of Spanish will take part in this study as they can shed light on the cognitive processes that are necessary to support native-like reading capacity in deaf readers.

In sum, in order to better understand how skilled deaf readers of Spanish are able to achieve reading levels that are comparable to their hearing peers, I will investigate: (a) how semantic and syntactic information is processed by deaf readers of Spanish, and how this process might differ (or not) from hearing native readers; (b) to what extent deaf readers are more likely L2 learners of Spanish; and finally, (c) do deaf readers rely more on semantics when reading sentences with morphosyntactic errors as has been proposed by some authors (e.g. keyword strategy)? Answers for these questions might shed light on previously researched topic in this field and hope to have practical implications for deaf education, such as the creation and development of more effective teaching methodologies.

1.5 Structure of the thesis

In chapter 2 of the thesis, I will cover the specialized literature on reading comprehension, focusing on previous studies that used the Event Related Potential (ERP) technique and the *Grammatical Violation Paradigm* to investigate the process of semantic and syntactic information in monolingual and bilingual readers. On this chapter, I will also describe the specific predictions of the present study.

In chapter 3, I will present the methodology used in the two experiments, describing general aspects of the participants who took part of this study, the behavioral assessment and the materials used with the participants, and the procedure adopted for the recording of the electrophysiological data (EEG).

In Chapter 4, I will explain *Experiment 1* that was conducted with deaf and native readers of Spanish, describing specific aspects of the groups of participants, the behavioral and EEG analysis and results, as well as the discussion of these results.

Similarly, in Chapter 5, I will describe *Experiment 2* that compared deaf readers (same group used in Experiment 1) with English speakers who were late L2 learners of Spanish, describing specific aspects of the group of participants, the behavioral and EEG results, and discussion of these results.

The general discussion combining the findings of Experiments 1 and 2 will be presented in chapter 6, where I will contrast the evidence discussed in chapters 4 and 5. In this chapter, I will also include a limitation of this study and future directions of research lines. Finally, in chapter 7, I will present the conclusion of this doctoral dissertation.

2. EEG studies of reading comprehension

Neuroimaging techniques have been used as a tool to investigate human behavior and brain function for almost a century (Luck, 2005). Scientists have developed different non-invasive techniques to understand the neural basis of human cognition, such as how we think and how we use language to communicate. The study presented in this thesis makes use of electroencephalography (EEG) and in this chapter, I explain the principles behind this technique, how it is used to study language, and why it is considered a good measure to make inferences about language processing. To do this I will explain what Event Related Potential (ERPs) components are, and their relationship with syntax and semantic linguistic processing. Secondly, I will review the main ERP findings on reading comprehension focusing on the processing of grammatical relations and meaning for hearing readers (both monolingual and bilingual), and for deaf readers. Finally, I will provide an overview of the study carried out and outline the predictions of the two experiments, which will be presented in chapters 4 and 5.

2.1 Electroencephalography and Event Related Potentials

Electroencephalography, or simply EEG, is a technique that measures the electrical activity of the human brain by placing electrodes on the scalp, amplifying the signal that is captured, and plotting the changes in voltage over time (Berger, 1929; Stone & Hughes, 2013). The raw data provided by the EEG signal, however, does not directly provide information on the subtle cognitive processes underlying human behavior as it contains a mix of innumerable different neural sources of activity (as well as noise in the signal), making it difficult to isolate specific neuro-cognitive responses (Luck, 2005). One way to extract meaningful information from the electrophysiological signal is by isolating the response evoked by a given (type of) stimuli using different averaging techniques (Handy, 2005; Kutas & Dale, 1997; Luck, 2005). These evoked responses are called Event-Related Potentials (ERPs) and are defined as the voltage fluctuations observed in the ongoing EEG signal that is time-locked to a specific event such as the onset of a stimulus, or the execution of a manual response (Luck & Kappenman, 2012). ERPs are the result of the combined action of postsynaptic potentials produced when a group of similarly-oriented cortical pyramidal neurons fire in synchrony while processing information related to a specific even (Kutas & Federmeier, 2007). These ERP components can be characterized and distinguished by various features such as latency, amplitude, polarity, and scalp distribution (Osterhout & Holcomb, 1992). Specific differences between relevant language-related ERP components will be further discussed in the following sections (2.1.1-2.1.3).

The use of neuroimaging methods to investigate cognitive processes has been extremely useful in identifying the brain networks related to the production and comprehension of language. For example, a technique like magnetic resonance imaging (MRI) works using the brain hemodynamic response[4] to a given stimuli. However, this response takes seconds to be captured and, consequently, does not offer a fine-grained temporal resolution. In contrast, EEG uses the brain's electrical activity to detect unfolding changes in neural responses at the scale of milliseconds, offering a better temporal resolution. Therefore, the possibility to access language processing in real time, on a millisecond by millisecond basis, is one of the greatest advantages of the ERP technique (Luck, 2005). (The fine temporal resolution of EEG is offset by a much poorer spatial

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[4] The hemodynamic response refers to the changes in cerebral blood flow that are related with the neural activity in the brain and that can be detected by functional magnetic resonance imaging (fMRI) techniques.

resolution, especially when compared with other techniques like MRI. The more appropriate technique will, of course, depend on the research question and the goal of each investigation.) In the language research field, and specially for the investigation of reading processes, temporal resolution is crucial because it makes it possible to detect neural activity associated with subprocesses that are inherent to the linguistic domain, such as grammatical and semantic processing. These processes are subtle and short-lived and could not be precisely recorded by hemodynamic-based methods (Friederici, 2004; Swinney, 1981).

The discovery of ERP components associated with language function provides a means of characterizing language-related cognitive function not only for the typical population but also for special populations, such as bilinguals, people with language disorders, or deaf people, which is the population of interest in the present study. The following sections describe the main language-related ERP components that will be pertinent for the present work and the role they might play in understanding language processing in the deaf population.

2.1.1 Semantic-related ERP components: N400

The first language-related ERP component discovered was the N400 component[5]. In their seminal work, Kutas and Hillyard (1980) observed that electrophysiological responses to semantic violations elicited a negative wave that peaked around 400ms after the presentation of the anomalous word. This negativity was greater in response to incorrect sentences relative to correct sentences, and this difference in the amplitude of the ERP

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[5] The names of most ERP components are based on their polarity (P for positive; N for negative) followed by the approximate time in milliseconds at which they appear.

responses was called the N400 effect[6] (Kutas & Hillyard, 1980). Since then, the N400 effect has been widely studied and is usually described as a neural marker of semantic-related language processing. The function of the N400 goes beyond the linguistic domain since it is sensitive to other experimental manipulations such as nonwords, pictures and face recognition (Kutas & Federmeier, 2011). Nevertheless, in the present work, we will only focus on the linguistic aspects of the N400.

As mentioned in the previous section, an ERP component can be described in terms of its time course, anatomical distribution and variation in the amplitude. The time course of the N400 component starts relatively early, around 200 ms after the presentation of the critical word (written, spoken, or signed), reaching its maximum peak before 400 ms (Hosemann, Herrmann, Steinbach, Bornkessel-Schlesewsky, & Schlesewsky, 2013; Kutas & Federmeier, 2011; Swaab, Ledoux, Camblin, & Boudewyn, 2012). Anatomically, the distribution of the N400 on the scalp of typical individuals is usually located in central-posterior areas and slightly right lateralized, although its topography may differ depending on the stimuli used (e.g. more anterior for concrete than abstract words) and the input modality (Hagoort & Brown, 2000). The amplitude of the N400 can also vary as a function of different aspects of the stimuli such as the position of the target word in a sentence, word frequency, and repetition. For example, target words in the middle of a sentence are less affected by frequency effects than words located at the beginning (Kutas & Federmeier, 2007).

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[6] Additionally, it is important to distinguish between an ERP component and an ERP effect: the former is a portion of an ERP waveform that presents specific characteristics and sensitivity to some experimental manipulations; the latter is the difference observed between the ERP components elicited in two conditions (Kutas & Federmeier, 2011).

Generally, the N400 effect is widely associated with semantic processing due to its sensitivity to semantic violations (Kutas & Federmeier, 2000). This component can be observed in the context of single words (Barber & Kutas, 2007; Osterhout & Holcomb, 1996), isolated sentences (Friederici, 2004), and at the discourse level (Nieuwland & Van Berkum, 2006; Van Berkum, Brown, Zwitserlood, Kooijman, & Hagoort, 2005). However, other authors claim that the N400 reflects other cognitive processes such as orthographic and phonological analysis (Deacon, Dynowska, Ritter, & Grose-Fifer, 2004), or conceptual unification (Hagoort, Baggio, & Willems, 2009). Additionally, more recent evidence has linked the N400 effect to predictive processing in language comprehension (Freunberger & Roehm, 2017; Rabagliati, Gambi, & Pickering, 2016).

For reading comprehension (i.e. sentence and discourse level), contextual information such as world knowledge, pragmatics and discourse-level information might influence the N400 effect (Van Berkum, 2008). For instance, in the case of hearing bilinguals, the N400 component might index the use of contextual information to process grammatical features by late L2 learners when they are in the initial stages of reading acquisition as recent studies observed a negative correlation between the N400 and P600 amplitude and levels of reading comprehension in their second language (Tanner, Inoue, & Osterhout, 2014; Tanner, Mclaughlin, Herschensohn, & Osterhout, 2013). More details about different language-related ERP components in the bilingual population (i.e. hearing and deaf readers) will be further debated in the section 2.2 of this chapter.

Overall, the N400 reflects brain processes underlying the detection of semantic anomalies, although this component is also implicated with other cognitive processes such as prediction and may be modulated by language proficiency in bilinguals. In the present work, I adopt the view that the N400 indexes semantic processing, and that an N400 effect would be expected in the presence of a semantic violation.

2.1.2 Syntactic-related ERP components: P600 and LAN

Semantic and syntactic information are processed by different cognitive mechanisms as each of them elicits distinct patterns of brain responses to violations (Hagoort, Wassenaar, & Brown, 2003; Osterhout & Holcomb, 1996). Generally, while semantic anomalies generate a N400 effect (described in the previous section), (morpho)syntactic violations typically generate two other types of ERP effect, namely, Left Anterior Negativity (LAN) and P600. The LAN effect is a negative-going modulation that reaches its maximum peak around 400 ms post-target word. Although it occurs in a time window similar to that of the N400, the LAN can be distinguished by its left-frontal topography (in contrast to the central-posterior distribution of the N400). The P600 effect is a positive modulation with maximum peak around 600 ms post-target word, and distributed across posterior areas (Hagoort, Brown, & Osterhout, 1999). Although these components are both related with morphosyntactic processing they appear to reflect different parsing stages in reading comprehension (Friederici, Hahne, & Saddy, 2002).

The LAN component has been associated with early detection of morphosyntactic agreement processes (Friederici et al., 2002) and phrase structure violations (Hagoort et al., 2003). However, this component is not always observed in the presence of grammatical violations and recent work has questioned whether the LAN effect is actually a reliable ERP effect, or the result of EEG artifacts (Molinaro, Barber, Caffarra, & Carreiras, 2015;

Steinhauer & Drury, 2012; Tanner, 2015). I discuss this further in section 2.2.1 as well as in the general discussion of chapter 6.

The P600 effect has been associated with different types of syntactic violations. It was first observed in contexts in which phrase structure was violated (Osterhout & Holcomb, 1992, 1993) and has since been shown to index a variety of grammatical features, including, but not limited to: number and grammatical gender agreement violations (Barber & Carreiras, 2005; Caffarra, Siyanova-Chanturia, Pesciarelli, Vespignani, & Cacciari, 2015), case marking (Coulson, King, & Kutas, 1998), and violations of verb tense (Osterhout & Nicol, 1999) and of verbal agreement (Mancini, Molinaro, & Carreiras, 2013; Mancini, Molinaro, Rizzi, & Carreiras, 2011). Importantly, different from the LAN effect, the P600 component has been replicated in a wide range of languages and in studies that used different methodological approaches, in particular, input modality (auditory vs. visual), rate of word presentation, isolated sentences and natural prose (Osterhout, Kim, & Kuperberg, 2012). This makes the P600 a well-established electrophysiological effect in the psycholinguistic field.

Concerning the functional significance of the P600, the effect might reflect cognitive costs due to sentence reprocessing (Osterhout & Holcomb, 1992, 1993; Osterhout, Holcomb, & Swinney, 1994) or, conversely, it may be an index of sentence reanalysis (in the case of ambiguous structure) and repair (in the case of violated structure), indicating that this component supports late syntactic processes (Friederici & Mecklinger, 1996; Friederici, Pfeifer, & Hahne, 1993; Hahne & Friederici, 1999). There is also disagreement over whether the P600 reflects pure syntactic processes (Hagoort, Brown, & Groothusen, 1993) or difficulties in syntactic integration in general (Kaan, Harris, Gibson, & Holcomb, 2000).

For the purpose of the present work, I will adopt the view assumed by Molinaro and colleagues according to which the P600 reflects a first phase of integration of the morphosyntactic information and a second phase of reanalysis and repair processes of these parsing mechanisms (Molinaro, Barber, & Carreiras, 2011). That is, that the P600 component indexes a two-phase syntactic parsing process: the first phase, the *early P600*, occurs around 500-750 ms after the critical word, with a broadly central-posterior distribution, and indexes difficulties in integrating morphosyntactic features; the second phase happens around the 750-1000 ms time-window, has a more posterior distribution on the scalp, and reflects reanalysis/repair processes (Barber & Carreiras, 2005; Carreiras, Salillas, & Barber, 2004; Molinaro, Vespignani, & Job, 2008).

Even though many studies have demonstrated a relation between the P600 component and syntactic processing, this component might not be exclusive to the language domain: other studies have also demonstrated that violation of non-verbal sequences can also elicit a P600 effect (Lelekov, Dominey, & Garcia-Larrea, 2000; Núñez-Peña & Honrubia-Serrano, 2004; Patel, Gibson, Ratner, Besson, & Holcomb, 1998). This could indicate that this component indexes difficulty in integrating structures that are governed by some kind of abstract rules, regardless of whether this structure is linguistic in nature (Kaan, 2007). Nevertheless, the P600 is a robust and reliable index of morphosyntactic processing and it is this property that will be exploited in this dissertation.

2.1.3 Summary of language-related ERP components

Language-related ERP components offer a unique perspective to investigate how language is processed in the brain because they reveal how comprehension unfolds over time. These different ERP components reflect distinct brain mechanisms underlying language comprehension and are sensitive to semantic and syntactic manipulations: The N400 is a component that primarily indexes semantic processes (Kutas & Federmeier, 2011), while the LAN and the P600 are syntactic-related ERP components. Specifically, the LAN component indexes the automatic detection of grammatical information (within a 200 and 400 ms time-window), and the P600 reflects a two-phase process, including the integration of the syntactic features, between 500 and 750 ms, and a reanalysis/repair of syntactic parsing (within a 750 and 1000 ms time-window; Molinaro et al., 2011).

Even though these components were initially identified in studies conducted with monolinguals, in recent years, more attention has been given to the role of these effects in the bilingual population. Studies have compared reading performance from different experimental groups, with distinct reading levels and different ages of reading acquisition (Caffarra, Molinaro, Davidson, & Carreiras, 2015). More details of studies that investigated ERP components related to language processing in bilinguals (both hearing and deaf) are presented in section 2.2 of this chapter. The following section describes the experimental paradigm adopted in this study to elicit the ERP effects of interest.

2.1.4 Agreement in Spanish: an overview

Agreement as a linguistic phenomenon can be defined as when the value of a feature of one element is expressed on some other element that is syntactically dependent on the first (Corbett, 2006). In this study, we are interested in agreement in the nominal domain (agreement also takes place in Spanish in the verbal domain, with concordance between a verb and its subject). To make the definition above more concrete, the agreement relation may take place between a noun and a dependent element such as an adjective, determiner, or quantifier. In Spanish, these agreement processes are obligatory, and, therefore, essential to correctly understand and process this language (Anton-Mendez, Nicol, & Garrett, 2002). Within the nominal domain, the features that take part in agreement in Spanish are number and gender. For example, in the phrase “las casas blancas” (the$_{\text{FEM-PL}}$ house$_{\text{FEM-PL}}$ white$_{\text{FEM-PL}}$ [‘the white houses’]), the head noun is feminine in gender and plural in number. We can see that the determiner *las* and the adjective *blancas* are also marked for feminine plural since they are in an agreement relationship with the head noun *casas*.

Gender agreement is a common grammatical feature that is usually present in Romance languages; in Spanish, all nouns are either masculine or feminine, the two possible values of the feature in this language. There are three different aspects of gender (Barber, Salillas, & Carreiras, 2004; Corbett, 1991). Firstly, semantic gender refers to the biological sex (i.e. masculine and feminine) and is only associated with animate nouns, reflecting something about the semantics of the referent. In Spanish, *padre* (father) is masculine and *madre* (mother) is feminine. Secondly, grammatical gender is considered a formal and arbitrary syntactic property that is inherent to a noun. In Spanish, *casa* (house) is feminine whereas *hogar* (home) is masculine, but this is just an arbitrary feature of the language’s lexicon and has nothing to with the meaning of each word. Thirdly, morphological gender refers to the orthographic and phonological representation of grammatical gender. Thus, in Spanish, the use of the -a suffix indicates feminine words and the use of the -o suffix designates masculine words[7]. Of the nouns in Spanish, 68.15% are considered to be morphologically regular because their gender is marked either with the -a suffix for

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[7] According to (Harris, 1991), in Spanish, 99.9% of nouns ending in -o are masculine and 96.4% of those ending in -a are feminine.

feminine or the -o suffix for masculine (Anton-Mendez et al., 2002). In contrast to these transparent nouns, whose morphological form indicates their grammatical gender, nouns that do not end with the -a or -o also have a gender feature that is not orthographically explicit and are known as opaque nouns (Andonova, D'Amico, Devescovi, & Bates, 2004).

In this thesis, I focus on grammatical gender to concentrate on the arbitrary language property free of semantic considerations (driven by biological gender). Additionally, I consider morphological gender and exploit the consistent relationship between morphological and grammatical gender in Spanish to look at form versus feature-based processing during reading (see chapter 3 for more information about the experimental design and manipulations).

Differently, number conveys information about the numerosity of the referent, and, therefore, it can be considered more semantic and meaningful than grammatical gender. Number in Spanish has two values: singular and plural. The singular is unmarked, and the plural is marked with an *-s* at the end of the word. In contrast to English, which has extremely limited number agreement in the nominal domain ('this cat' versus 'these cats'), Spanish has number agreement on many elements that depend upon a nominal head, including adjectives and determiners.

Although both gender and number are features that are associated with nominal elements, there may be differences in the way gender and number are computed during parsing. For instance, according to Faussart and colleagues' model of lexical retrieval (Faussart, Jakubowicz, & Costes, 1999), gender is considered a lexical feature (Ritter, 1993), while number is considered a syntactic head (Ritter, 1988). When a disagreement is detected for gender, the reader would have to check both syntactic integration processes and lexical access, while for number violations, the reader would only have to check the syntactic integration processes (Faussart et al., 1999). This suggests that gender might be costlier to process than number. I will discuss this further in section 2.2.1 when I present previous research that investigated gender and number in typical readers.

More than understanding whether gender and number are process differently or not, my goal here is to clarify what are the main differences as well as similarities on the computation of these features between hearing and deaf readers. To investigate this, I will cover the main findings that was previously reported for typical readers, so we can extent this understanding to more specific populations such as deaf individuals (see section 2.2.2 for further details). Before that, I will first explain the *sentence violation paradigm* which has been vastly used to investigate sentence comprehension as well as language agreement and will be also adopted in the present study.

2.1.5 Sentence violation paradigm

Language-related ERP components such as the N400 or LAN/P600 are neurophysiological responses that can be elicited after, for example, the detection of semantic and syntactic mismatch, respectively. Specifically, in the presence of language violations, the relevant effects are observed as a result of the difference between the ERP components elicited in two conditions: a correct or control trial and an incorrect or experimental trial. For example, a semantically incorrect sentence such as '*My house is happy today',* would elicit a more negative response 400ms after the target word 'happy' in comparison to a correct sentence such as '*My boss is happy today'.* The target word in the first sentence is incongruent to the meaning of the sentence, while in the second sentence it is not. The difference in amplitude of these two electrophysiological responses is the N400 effect described in section 2.1.1. A similar effect is observed when comparing two sentences, one of which shows a grammatical error and the other does not. For instance, a grammatically incorrect sentence such as *‘My plate are full of food’* would elicit a greater positivity 600ms after the target word ‘are’ relative to a grammatically correct sentence like *‘My scooter is black and white’*. The target word in the former sentence fails to agree with the subject, while there is no such incongruence between constituents in the latter. Morphosyntactic violations target specific agreement features; in the case of the previous example, the incongruent sentence violated the number feature on the verb. Other features that may be manipulated include person (e.g. *‘The cat chase the dog.’*), or gender (e.g. ‘la mesa pequeño’ [the table$_{\text{FEM}}$ small$_{\text{MASC}}$]). Figure 2.2 illustrates an example of these two effects.

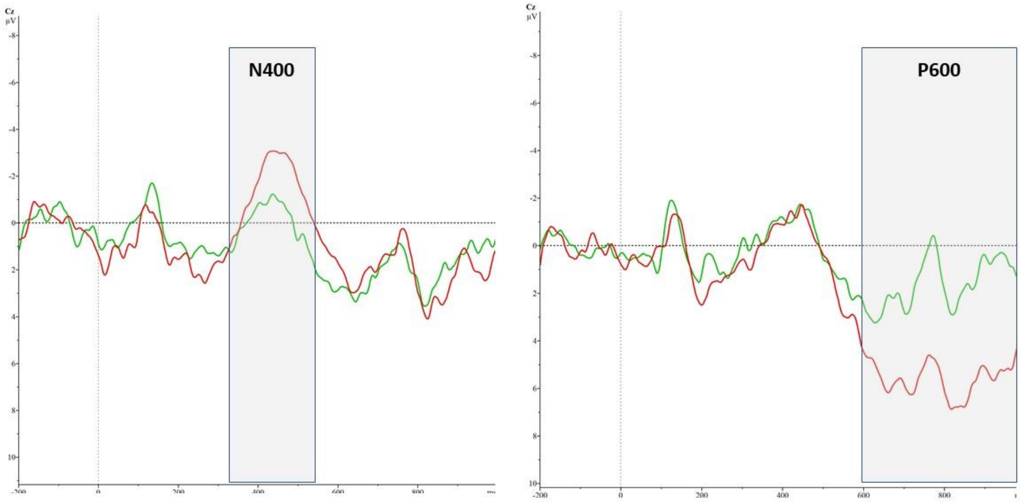

Figure 2.1. An example of a N400 (left) and P600 effect (right). The plots show the average potential for the Cz electrode in two conditions: the green line represents correct trials and the red line incorrect trials. The difference in amplitude between the two lines is the ERP effect. Note that on the x-axis negative is plotted upward, a convention that is adopted throughout this dissertation.

Following the seminal work by (Kutas & Hillyard, 1980) various studies have used violations in sentences to create different linguistic manipulations that allow language processing to be probed and investigated. An important characteristic of the violation paradigm is the implementation of the Rapid Serial Visual Presentation (RSVP), the process normally used to display words sequentially at the same spatial location (e.g. the middle of the screen) at a given presentation rate (e.g. 500ms/word). The RSVP makes it possible to record the participant's electrophysiological response at the specific moment they encounter the incorrect (target) word. Furthermore, this paradigm is also useful to avoid lateral eye movements that normally occur during reading, minimizing the presence of artifacts in the electrophysiological responses (Berg & Scherg, 1991).

Being able to access the temporal information associated with the violated word embedded within the sentence is the great advantage of the sentence violation paradigm and the RSVP. Essentially, it permits the observation of the cognitive processes that is happening in a given epoch of interest, and the comparison of different epochs across stimuli. One shortcoming of RSVP is that it represents a fairly unnatural way of reading sentences: very rarely in the real world do we read words flashing on a screen. Another possible disadvantage of the RSVP manipulation is that it does not allow participants to read the stimuli at their own pace, since words are presented one by one with a specific presentation time. Nevertheless, even though reading is not tested in a completely natural way, both sentence violations and the RSVP provide a robust means to investigate ERP effects and have given rise to a productive line of research into language processing over the last 4 decades (for a review see Kutas & Federmeier, 2011).

In the case of Spanish, the grammatical violation paradigm has been used to investigate specific agreement structures such as number and gender agreement, in typical populations (Barber & Carreiras, 2005; Barber et al., 2004; Caffarra & Barber, 2015; Carreiras et al., 2004; Mancini et al., 2011; Mancini et al., 2013). As discussed in chapter 1, the main goal of the present work is to explore how semantic and syntactic information (i.e. number and gender agreement) is processed by readers with distinct language backgrounds (for more details of the research question see section 1.3). Since the sentence violation paradigm has been adopted as the classical paradigm for eliciting ERP components to investigate language comprehension (Kutas, Kiang, & Sweeney, 2012; Van Berkum, 2008), the next section provides an overview of different work that has looked at agreement as well as semantic processing in native speakers, deaf readers, and L2 learners.

2.2 Previous ERP studies on reading comprehension

Since the discovery of language-related ERP components in the 1980s many studies have used EEG to investigate language processing and, more specifically, reading. Generally, what these studies showed is that when people read sentences the semantic and the syntactic information are handled by different cognitive mechanisms as each of these linguistic features elicits dissimilar patterns of brain responses to violations (Hagoort et al., 2003; Osterhout & Holcomb, 1996). As we saw in section 2.1, the N400 component typically reflects lexico-semantic processes, while the LAN and P600 components are sensitive to (morpho)syntactic violations and syntactic structure (see sections 2.1.1 and 2.1.2). Moreover, experiments exploit the sentence violation paradigm, in which an incorrect word within a sentence produces a modulation of the ERP responses in comparison with correct sentences (see section 2.1.4 for more details of this paradigm). The critical word can either violate a sentence in terms of its meaning (semantic violation) or its syntax structure (syntactic violations such as agreement mismatches; see the examples in section 2.1.4).

Importantly, the ERP effects associated with language processing are based mainly on research with adult native-language speakers. However, a growing body of research on groups with more diverse language profiles and experience, including L2 learners, children and, more recently, deaf readers, reveals that these ERP effects may have different properties in ‘atypical’ groups (Van Hell & Tokowicz, 2010). Differences in ERP components can be explained both qualitatively, when differences are indicated by the presence or absence of some ERP component (e.g. an N400 response rather than a P600), and quantitatively, when differences are measured in terms of the absolute size of a particular effect (e.g. the magnitude of the effect) or in terms of the timing of a component (e.g. delayed onset or peak latency). Thus, for example, longer ERP latencies might indicate longer time for processing an incongruency (Bernall et al., 2005; Kutas & Federmeier, 2011). Therefore, understanding differences in the ERP responses provided by typical (i.e. native) and atypical (e.g. non-native) groups may help to disentangle different brain mechanisms that support reading attainment in distinct groups.

This consideration of typicality is relevant because if we wish to characterize reading processing in deaf individuals, we need to think carefully about what we take to be the standard against which they are compared. Should the standard be typical monolingual readers, or some other group? The bilingual-bicultural model of literacy education for deaf students (Cummins, 1989) maintains that deaf individuals who use a signed language as their dominant language and a written code based on a spoken language to read are a special group of bilinguals. Just like other bilinguals, deaf individuals present different levels of proficiency or/and different ages of acquisition (henceforth Age of acquisition). In general, bilinguals transfer their L1 knowledge to their L2 during the process of second language acquisition. By analogy, deaf students should also transfer their knowledge in a signed language (L1) to the learning of a spoken language through literacy (L2). On the one hand, it may be the case that these transfer effects do not occur. Firstly, the sign and spoken languages operate in different modalities (visual-gestural versus oral-aural) so transfer across modalities might be impeded by the very different forms of the language units. Secondly, sign languages do not have any written form[8] and, therefore, the process of transfer between L1 and L2 might be weaker or not even be possible (Mayer & Akamatsu, 1999; Mayer & Wells, 1996). On the other hand, the acquisition of a signed language early in life may provide deaf readers with abstract capacities, such as the ability to categorize phonemes or to apply morphosyntactic rules, and these general skills could be transferred to the acquisition of the written form of a spoken language, along the lines of the theory of visual sign phonology (Petitto et al., 2016). This idea is reinforced by evidence showing that the acquisition of a first language (independent of its modality) correlates with higher levels of reading comprehension in deaf readers, which indicates that somehow deaf readers avail of their L1 knowledge (either spoken or signed) to achieve literacy (Chamberlain & Mayberry, 2008; Mayberry et al., 2011).

Considering all the above, I will discuss in the following sections the main findings of ERP studies with different groups of readers, namely, native speakers, deaf readers and

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[8] There are some writing systems for signed languages, such as HamNoSys (Prillwitz, & Schulmeister, 1987) or Signwriting (Sutton, 1974), but none of these has been widely adopted by the signing community.

L2 learners, to ascertain to what extent deaf readers behave more like native readers or L2 learners.

2.2.1 Typical readers

Reading a sentence is much more than just putting words together. The reader must be able to encode and retrieve each lexical item while processing morphosyntactic information conveyed by the sentence structure (Dehaene, 2009). The neural processes that support literacy have been widely investigated in native speakers of different languages since this population can shed light on the canonical mechanisms underlying normal reading. In this subsection, I will first discuss the most relevant findings of language-related ERP components in typical readers in the context of sentence comprehension to understand what factors usually modulate these components. Subsequently, I will present more specific evidence related to different types of grammatical violations in Spanish such as number and gender agreement, since these are the grammatical manipulations that are going to be used in this study.

Semantic and Syntactic ERP effects in typical readers

The N400 effect has been replicated in typical readers of different languages (Alemán Bañón, Fiorentino, & Gabriele, 2012; Caffarra, Siyanova-Chanturia, et al., 2015; Friederici & Mecklinger, 1996; Hagoort, 2003; Hagoort et al., 2003). Variation in this effect in native speakers is usually observed in relation to its amplitude: modulations of the N400 amplitude are related to word properties such as semantic relatedness, word frequency, repetition, and the size of orthographical neighborhood. Context also affects the size of the

N400 and can trump the effect of lexical properties: although the N400 effect is sensitive to word frequency, if the sentential context indicates that a low-frequency word is more likely in a given sentence than a high-frequency word, a bigger N400 effect would be elicited by the less probable option, that is, by the high-frequency lexical item (Van Petten, 1993; Kutas, 1993). In contrast to these modulations of the amplitude, the latency of the N400 is more stable in typical readers (Kutas & Federmeier, 2009, 2011).

Similarly, the P600 effect has also been observed in response to a variety of morphosyntactic violations and across different linguistic systems in spite of the fact that different languages present different grammatical combinations and syntactic rules (Molinaro et al., 2011). However, as I showed in section 2.1.3, the factors that modulate this syntactic-related ERP component are different from those that influence semantic-related ERP components (N400). For example, word properties do not influence the magnitude of the P600 effect, while violations of sentence agreement and/or violations of structural preferences do modulate the size of this effect (Friederici, 2004).

The LAN component is also observed among typical readers in response to syntactic violations and indexes automatic processing of morphosyntactic information (see section 2.1.2). However, it does not show the same level of reproducibility as the P600 (Osterhout & Mobley, 1995; Wicha, Moreno, & Kutas, 2004). Some authors argue that this instability could be due to different considerations such as the nature of the agreement used in the violation (e.g. within-phrase violations elicit a LAN effect more than across-phrase violations do; (Alemán Bañón et al., 2012) or others methodological factors, like the referencing site of the EEG recording (Molinaro et al., 2011). The very existence of the LAN as an independent effect has been called into question, with the suggestion that it merely reflects artifacts in the EEG signal (Tanner, 2015). I go back to this debate in chapter 6, where I will discuss the overview of my experimental findings.

Overall, the N400 and the LAN/P600 components are sensitive to different sets of factors because semantic and syntactic processes show a certain degree of independence from each other: they rely on different brain areas and do not overlap in their time course (Vigliocco, 2000). Importantly, the types of language agreement vary depending of the language under study and this, in turn, gives rise to quantitative differences in the ERPs components they elicit (Alemán Bañón et al., 2012; Barber & Carreiras, 2005; O'Rourke & Van Petten, 2011). Since this study looks at hearing and deaf readers of Spanish, I will now concentrate on previous research that has looked at the processing of agreement in Spanish, specifically, number and gender agreement[9].

Gender and number agreement in typical readers: ERP studies

In the previous sections, I discussed the different types of agreement that are observed in Spanish, and the relevance of nominal agreement for the present work, such as the case of gender and number concordance between a noun and an adjective (see section 2.1.4). Therefore, it is clear the relevance of this type of agreement computation for the acquisition of high levels of literacy in Spanish. Due to this relevance, previous works using ERPs have raised many questions on how these syntactic features are computed during reading comprehension in typical readers. For example, questions regarding the underlying processing of gender and number agreement in the presence of structural distance (i.e.,

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[9] As mentioned in section 2.1.4, even though is not my intention to focus on the differences between number and gender specifically, it is relevant for the present work to understand what the main characteristics of these two features are and how typical readers process thus type of information.

within and across-phrase agreement), or the existence of a dual-route for gender retrieval during parsing processes. I will address these points now as they are relevant for the present work. I am also going to address the issue regarding the role that individual differences might play in the computation of agreement for typical readers, although this latter point will not be exclusively related to gender and number concordance, but agreement in general.

a) Structural distance

One question that has been raised in previous work is how typical readers deal with more complex sentence structures such as the case of sentences in which the agreement dependencies involve two non-adjacent elements, such as noun-adjective agreement[10] (e.g., Alemán Bañón et al., 2012). During language comprehension, readers must perform within-phrase sentence agreement (e.g. concordance between a determiner and a noun), as well as across-phrase agreement (e.g., concordance between a noun and a predicative adjective). In the first scenario, the reader does not need to hold in the working memory the information necessary to perform parsing computation as the information is located just next to each other. In the latter case, agreement information is not localized in the adjacent element and reader must retrieve this information later to successfully perform parsing computations. As explained in section 2.1.4, gender and number agreement in Romance languages such as Spanish can be very complex as different elements within a sentence must agree in gender and number. Since the present study looks at gender and number agreement between a noun and a predicative adjective (details about the materials used and examples are provided in section 3.2), understanding how native readers process these grammatical features in the

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[10] SVO sentence structure.

presence of a structural distance (i.e., rather than local agreement) will help to better delineate the predictions of this study regarding deaf readers and L2 learners (see section 2.3).

Previous ERP studies have shown that the distance between the agreement constituents, that is, within and across-phrase agreement, play an important role modulating elicited electrophysiological response (Molinaro et al., 2011). For example, (Barber & Carreiras, 2005) conducted an experiment with typical readers of Spanish to investigate possible differences in the processing of gender and number violations between determiners and nouns (i.e., within phrase) and between nouns and adjectives (i.e., across phrase). Generally, they found that both gender and number agreement elicited the classic biphasic LAN/P600 effect regardless of the position of the agreement. However, differences in the late time window of the P600 (700 - 900 ms; henceforth P600b) were observed for across-phrase violations which elicited a larger P600b effect when compared to within-phrase violation, and the authors suggest that across-phrase violations are more difficult to process because of the greater complexity of the agreement structure (Barber & Carreiras, 2005). The authors also found a larger P600b for gender in comparison to number agreement and suggest that this difference might be due to reanalysis processes that are *costlier* after the detection of gender violations than after the realization of number violation because of the lexical nature of grammatical gender (Barber & Carreiras, 2005). This justification is based on the previous mentioned Faussart's lexical retrieval model (for further information see section 2.1.4) which states that gender is costlier to process than number (Faussart et al., 1999).

In a similar study, (Alemán Bañón et al., 2012) also examined the brain mechanism underlying gender and number agreement in Spanish and the effects of structural distance on the online processing of agreement in typical readers, but found different results from those reported by (Barber & Carreiras, 2005). First, they found no LAN effect for either gender or number violations, and no difference in the P600 effect elicited in these two conditions. Second, regarding the effects of structural distance, they found that within-phrase agreement yielded more positive waveforms than across-phrase agreement, that is, the bigger the distance, the smaller the P600 effect for both gender and number. The authors suggest that these differences in waveforms indicate that structural distance reduces sensitivity to the establishment of agreement overall irrespective of the type of agreement (i.e., number or gender). They also acknowledge other explanations such as the possibility that participants were using some kind of syntactic predictability, since in their experimental design it was easier for the parser to predict the syntactic structure of within-phrase agreements in comparison to across-phrase agreement (Alemán Bañón, Fiorentino, & Gabriele, 2012). In line with these results, (O'Rourke & Van Petten, 2011) also found that the distance in gender agreement between the elements in a sentence modulated the size of the P600 effect: the bigger the distance, the smaller the effect. Specifically, the authors found that this negative correlation between the amplitude in the P600 amplitude and the structural distance of the agreement was due to the cost of processing and suggest that participants became progressively reluctant to reanalyze their initial parse of a sentence as the number of words between the agreement elements increased (O'Rourke & Van Petten, 2011).

Overall, studies that looked at gender and number agreement violations between noun and adjectives found both qualitative differences in the LAN effect (i.e. absence of a LAN response) and quantitative differences in the P600 effect (smaller or bigger P600 effect). These differences observed showed that structural distance affects language processing as this type of structure is more complex for readers. Although there is a consensus in the literature regarding this point, the interpretation that structural distance makes agreement effortful comparing with local agreement are based on different ERP results. On the one hand, in the Barber and Carreiras (2005) paper, a bigger ERP effect was found for long-distance agreement in Spanish compared to local agreement, and the authors suggest that this reflects the cost of reanalysis which is bigger for across-phrase agreement (Barber & Carreiras, 2005). On the other hand, Alemán Bañón and colleagues as well as O'Rourke and Van Petten (2011) found a smaller ERP effect for long distance agreement in Spanish and interpret this result as an evidence that long-distance agreement is costlier to compute than local agreement, and readers might want to avoid this cost of reanalysis, and perform a "lazy" parsing computation which is reflected in the ERP responses, but not in the behavioral data as participants accurately performed the task (O'Rourke & Van Petten, 2011). This effortless approach during reading has been discussed in other studies of language comprehension. It has been demonstrated that typical readers do not always comprehend syntactic information in full detail and, consequently, engage comprehension in a shallow and superficial manner, particularly when facing difficulties in parsing (Ferreira, Bailey, & Ferraro, 2002; Ferreira, Engelhardt, & Jones, 2009; Ferreira & Lowder, 2016; Ferreira & Patson, 2007; Karimi & Ferreira, 2016). Therefore, depending of the type of syntactic difficulty experienced during reading, different parsing strategies might be adopted in order to achieve full comprehension, which would result in a “lazier” approach as suggested by O’Rourke and Van Petten (2011).

Although I am not comparing within and across-phrase agreement, it is important to understand the possible effects in using long distance agreement as part of my experimental design. For typical readers, this type of agreement seems to be costlier than within-phrase concordance, modulating the P600 effect. Therefore, it is possible that for deaf readers as well as L2 readers these cognitive costs are even higher, which might result in smaller effects for these two groups in comparison to native readers. I will return to this in section 2.3 when I present the predictions of this study, as well as in chapters 4 and 5 when I discuss my main results

b) Differences between number and gender: A dual-route for gender agreement

Regarding possible differences between gender and number agreement, as showed in section 2.1.4, gender is considered a lexical feature (Ritter, 1993), while number is considered a syntactic head (Ritter, 1993). Previous ERP findings showed that gender might be costlier to process than number due to its lexical nature, as gender disagreement elicited larger P600 effects in comparison to number disagreement (Barber & Carreiras, 2005, but see Alemán Bañón et al, 2012). If gender is costlier to process than number for typical readers, to what extent this might also be true to deaf and L2 readers? To address this, I will now show how gender information is retrieved by typical readers and the existence of a dual-route to process gender agreement.

How gender information is represented and retrieved from the lexicon to perform agreement computations during parsing, is an important question that has been investigated in the previous agreement literature. This is because, different from number which is considered a syntactic head, grammatical gender has a lexical nature. According to Faussart's model (Faussart et al., 1999) when a disagreement is detected for gender, the reader would have to check both syntactic integration processes and lexical access since gender information is part of the lexical properties of the word. A model of gender processing was proposed by (Gollan & Frost, 2001) describing two routes to access and retrieve grammatical gender: a *lexical route* that involves an abstract gender node, and a *form-based route* that take into account gender information on the basis of its orthographic features, and is assumed to play a greater role in recovery from agreement errors.

To verify the existence of the brain mechanisms that support this two routes model of gender retrieval, (Caffarra, Janssen, & Barber, 2014) conducted and ERP study using article–noun pairs that could agree or not in gender, and asked native speakers of Spanish to perform a gender agreement judgment. The results showed no difference in the electrophysiological pattern (N400-like) elicited by both transparent and opaque pairs. However, behaviorally, the results showed a significant effect of noun transparency, that is, higher accuracies for the transparent nouns than opaque nouns. ERP data were also in line with this: more robust effects for transparent article–noun pairs in comparison to the opaque pairs. Despite these observed behavioral and quantitative differences in ERPs there was no significant interaction between agreement and transparency which indicates that native speakers were processing both type of pairs in similar way and that the presence of orthographical cues does not seem to have a strong influence on the computation of agreement mismatches for isolated word-pairs (Caffarra et al., 2014).

To see to what extent this would also be true in the computation of agreement in a sentence context, (Caffarra & Barber, 2015) used ERPs to examine how native speakers of Spanish would engage this dual route of grammatical gender in a sentence context. For this, sentences with local violations (i.e., determiner and noun) were presented to participants who were asked to perform a grammatical judgment task. The nouns used in the sentences could be either opaque or transparent. The results showed that agreement violation of both types of nouns elicited the canonical biphasic pattern LAN/P600. They also observed that the detection of the orthographic regularities (i.e., transparent nouns) was observed in an earlier time window compared with the detection of the agreement violations, meaning that native readers detected these visual cues even before the detection of the violations. The authors suggest that native users of Spanish are sensitive to the distributional properties of the gender system and can detect regular correspondences between word-form level and morphosyntactic features very early during reading, even before performing the agreement. These findings support evidence in favor of the existence of the dual route for grammatical gender (Gollan & Frost, 2001), showing that although transparent and opaque nouns computed in similar fashion by native speakers, readers are sensitive to the presence of these orthographical cues (Caffarra et al., 2014).

Typical readers access gender information to perform agreement in a very automatic way, possibly using the fastest route to achieve comprehension, in this case, the lexical route to retrieve gender information. This does not mean, however, that native speakers never use the form-based route and take advantage of available orthographical cues to perform agreement computation under certain situations, such as the case of early native bilinguals (Molinaro, Giannelli, Caffarra, & Martin, 2017). In the case of Spanish, since both routes can be taken depending of the characteristics and regularities of the noun be retrieved (e.g., transparent nouns), different factors, such as language proficiency, might lead the reader to process via one route or another, possibly depending of what is more efficient during parsing computation. Moreover, to what extent high-skilled deaf readers also retrieve gender information through a lexical route or, instead, take advantage of visual cues when they are available to compute agreement relations, remains an open question. Previous studies have demonstrated, for instance, that deaf readers have an enhanced perceptual span in reading (Bélanger et al., 2012). This could suggest they might also use orthographical cues to facilitate agreement computations. I will properly address this issue in chapter 4, when I show the main results of experiment 1. I will also refer back to this in the description of this study (see section 2.3), when I delineate the predictions of the two experiments showed here.

c) Individual differences

Individual differences also play an important role in agreement. For instance, (Tanner & Van Hell, 2014) investigated the role of individual differences among monolingual native English speakers in response to morphosyntactic violations such as subject–verb agreement and verb tense constraints. Results based on grand mean analyses yielded a LAN followed by a large P600 effect for both subject–verb agreement violations and verb tense violations. However, an analysis based on individual differences showed that the biphasic LAN-P600 effect observed in the grand mean analysis did not correspond to most individuals' ERP responses. Instead, the ERP components elicited by the violations varied along a continuum between negativity-dominant, biphasic, and positivity-dominant.

Moreover, the authors also observed that the negativity seen in the negativity-dominant groups did not have the left hemisphere distribution present in the grand mean waveforms, but a central scalp distribution, very similar to N400 effects that are typically reported for semantic violations. Furthermore, this effect was negatively correlated to the classical P600 typically observed in grammatical violations. The conclusion given by the authors is that individual differences in the N400–P600 continuum are not restricted to L2 learners or low proficient monolinguals. Instead, this negative correlation can be also observed in native and high-skilled monolinguals performing parsing computations (Tanner et al., 2014, 2013; Tanner & Van Hell, 2014). Thus, it is important to take into account that native speakers, who are usually considered the standard against which other populations are compared, are also a source of individual variation.

Summary

ERP work on typical readers has shown that language-related ERP components (i.e. N400 and LAN/P600) are modulated by different factors. We have seen that properties of agreement relationship itself, such as structural distance (local vs. long distance agreement) and the features involved (number vs. gender agreement), affect how the processing takes place. Furthermore, different individuals rely on distinct processing mechanisms even among typical L1 readers. In the next section, I will present studies that have investigated language processing in deaf readers. Table 1 shows a summary of ERP evidence on noun-adjective number and gender agreement in typical readers of Spanish.

Table 2.1. ERP evidence on noun-adjective number and gender agreement in typical readers of Spanish.

Previous studies	ERP effects							
	LAN		**N400**		**P600 (early)**		**P600 (late)**	
	Number	Gender	Number	Gender	Number	Gender	Number	Gender
Barber & Carreiras (2005)	YES	YES	NO	NO	YES	YES	YES*	YES**
O'Rourke & Van Petten (2011)	YES*	YES**	NO	NO	YES*	YES**	-	-
Alemán Bañón et al. (2012)	NO	NO	NO	NO	YES	YES	YES	YES
Guajardo & Wicha (2014)	-	NO	-	YES	-	YES	-	-
Aleman Bañón & Rothman (2016)	NO	NO	NO	NO	YES	YES	YES	YES

*less robust effect
**more robust effect

2.2.2 Deaf readers

Following the debate started in chapter one, learning to read a language without having proper access to its auditory information has a major impact on the way this language will be processed in the brain (Corina, Lawyer, Hauser, et al., 2013; Emmorey et al., 2017; Hirshorn et al., 2014; MacSweeney et al., 2008; Waters et al., 2007). Many authors advocate that deaf readers process written language as bilinguals, but up to the present time, there is no consensus in the literature on whether deaf readers are more similar to native readers or L2 learners. In recent years, most research has focused on how deaf readers could acquire literacy despite their lack of phonological awareness and the consequences this would provoke in the acquisition of a phonological-based written code. So far, the available results reported from behavioral and neuroimaging studies suggest that acquisition of a solid first language is more important to literacy attainment than phonological representation (Mayberry et al., 2011). Furthermore, it was demonstrated that deaf readers do not necessarily use phonological information to read (Bélanger, Baum, et al., 2012; Fariña et al., 2017; Mayberry et al., 2011), although this information might be available for them in the initial stages of word recognition (Gutierrez-Sigut et al., 2017). There is also evidence demonstrating that deaf readers activate more brain areas related to semantic processing during reading comprehension tasks when compared to typical readers (Hirshorn et al., 2014), and that they make use of contextual information to extract meaning from texts, without deeply engaging in syntactic processing (Domínguez & Alegria, 2010; Domínguez et al., 2014; Domínguez et al., 2016). Only a small number of ERP studies have looked at the neurophysiological processes underlying reading comprehension in deaf individuals, and up to the present date no study has yet used the EEG technique to investigate language agreement in a Romance language such as Spanish. Therefore, it is not clear yet whether deaf readers elicit similar ERP components for grammatical violations in comparison to those observed for typical readers.

A recent ERP study exploring subject-verb agreement in deaf readers of English showed that deaf readers do not show the same ERP pattern for grammatical violations as those observed for hearing readers, and similarities in ERP responses are only observed for semantic violations (Mehravari et al., 2017). American hearing and deaf participants performed a sentence acceptability judgment task where they read sentences in English that were grammatically acceptable, had grammatical violations (i.e. subject-verb agreement), had semantic errors (meaningless sentences), or had both grammatical and semantic errors (double violations). The results showed that both groups (hearing and deaf) elicited a comparable N400 for both semantic violations and for the semantic error embedded in the double violation sentences. In contrast, *only* the hearing group elicited a P600 for sentences that contained only grammatical violations as well as the grammatical error embedded in the double violations. A further analysis restricted to a sample of highly skilled deaf readers revealed that this group showed a small P600-like response to semantic and double violations, but not to grammatical violations. Additionally, a positive correlation between reading comprehension scores and the magnitude of the N400 effect emerged for deaf readers. The authors interpreted these results as evidence that deaf readers use semantic processes when reading sentences with grammatical violations (Mehravari et al., 2017). However, this interpretation should be taken with caution as the authors have included all trials (with both correct and incorrect acceptability judgments) in the ERP analysis, even though deaf readers had a very low accuracy rate (only 33%) for the grammatical violation condition, making it difficult to draw solid conclusions from these results. Nevertheless, this evidence goes in line with previous behavioral studies that showed that deaf readers struggle to process syntactic information (Domínguez & Alegria, 2010; Domínguez et al., 2014; Domínguez et al., 2016), which could explain the absence of the P600 effect for syntactic violations.

Reading difficulties related to the process of grammatical processing among deaf readers might come from the lack of exposure to a natural language in early childhood, and, consequently, the inherent difficulty of learning English only through the written modality (Hoffmeister & Caldwell-Harris, 2014). The low frequency of exposure to written texts during school life could also be another source of this struggle (Tomasuolo, Roccaforte, & Di Fabio, 2018). Because there is a great variability in the way deaf readers learn to read it is difficult to disentangle the impact that language experience, educational background, and other confound variables might have on language processing. In order to address this, Skotara and colleagues tested German deaf readers who were also native signers in a grammatical judgment task and found that they elicited the same ERP pattern as hearing native readers of German and high-proficient L2 learners of German (Skotara et al., 2011). Specifically, all the three groups elicited an N400 effect for semantic violations as well as a biphasic LAN/P600 effect for subject-verb violations and the authors concluded that deaf readers who have acquired language and reading skills at an early age use similar neural systems to read as hearing readers who are native speakers of a language and high proficient L2 learners (Skotara et al., 2011).

In a follow up study, Skotara and colleagues investigated whether deaf non-signers would show a similar ERP pattern when compared with hearing readers as well as deaf signers (Skotara et al., 2012). The results revealed that deaf non-signers elicited a N400 effect for semantic violations, just like deaf signers, native hearing and high proficient L2 learners of German. However, after subject-verb syntactic violations, deaf non-signers failed to elicit a LAN effect, showing, instead, a negativity over the right hemisphere. Additionally, the P600 for this group had a smaller amplitude and a different scalp distribution. The authors concluded that language delay in early childhood alters the cerebral organization of syntactic processing mechanisms, but semantic processing remains unaffected. It is important to note, however, that both studies (Skotara et al., 2011, 2012) used a very small sample size (n =8) for the EEG analysis and the low statistical power might produce unreliable findings as it has a reduced chance of detecting a real effect (Button et al., 2013).

Summary

Overall, the available evidence provided by ERP studies on literacy attainment in deaf readers does not offer a clear picture of the neurophysiological signature underlying reading comprehension processes in this population. However, it indicates that reading problems among deaf readers may lie in their difficulty in processing syntactic information and, as a consequence, the use of semantic cues to boost comprehension (Breadmore, Krott, & Olson, 2014; Domínguez & Alegria, 2010; Domínguez et al., 2014; Hirshorn et al., 2014). The present work addresses this issue by examining agreement processing in a morphologically rich language. In the next section, I will present findings on the brain response to semantic and grammatical information in the context of second language learning. Table 2 shows the available ERP evidence on agreement violation in Deaf readers.

Table 2.2. ERP evidence on morphosyntactic processing (subject-verb agreement) in Deaf readers.

Previous studies	**Language**	**ERP effects**			
		LAN	**N400**	**P600 (early)**	**P600 (late)**
Skotara et al (2011)	GERM	YES	NO	YES	-
Skotara et al. (2012)	GERM	NO	NO	YES	-
Mehravari et al (2017)	ENG	NO	NO	NO	NO

2.2.3 L2 learners

Second language learners are a valuable source of information that can shed light on how language processing evolves along the spectrum of language proficiency (i.e. from beginners to advanced language users). Since the written language is not the first language of most deaf readers understanding how L2 learners process language might shed light on the mechanisms that support the acquisition of a written language by deaf people.

Electrophysiological studies provide relevant data to better understand the brain mechanisms underlying language function during the acquisition of a second language (Kotz, 2009). The findings show qualitative and quantitative differences in the on-line processing of L2 speakers (Caffarra, Molinaro, et al., 2015; Kotz, 2009; Mueller, 2005). Specifically, longitudinal studies that investigated electrophysiological changes in the brain of L2 learners from the moment they start acquiring a L2 until they achieve high levels of proficiency suggest that semantic and syntactic processing do not develop at the same pace (McLaughlin, Osterhout, & Kim, 2004; McLaughlin et al., 2010; Osterhout, McLaughlin, Pitkänen, Frenck-Mestre, & Molinaro, 2006). For example, L2 learners need little instruction to acquire basic semantic knowledge of a language as revealed by the presence of an N400 effect for semantic tasks among novice learners; in contrast, syntactic processing is more difficult to assimilate during these initial stages of language acquisition (Osterhout et al., 2006). The acquisition of grammatical features is positively correlated with language proficiency as indexed by different ERP patterns: new learners of an L2 show an absence of the P600 effect for grammatical violations, indicating no sensitivity to grammatical errors; low proficient readers present an N400 effect instead of a P600 effect for morphosyntactic violations; and only highly proficient readers display a more native-like ERP pattern, showing the biphasic LAN/P600 response for grammatical violations (Osterhout et al., 2006; Tanner et al., 2014, 2013).

Regarding quantitative differences, ERP responses elicited during semantic and syntactic processing of L2 reading is different to those for the L1: some evidence show that bilinguals present a less robust ERP effect such as a reduction of the N400 amplitude in their L2 compared to their L1 (Braunstein et al., 2012). Mueller (2005) proposes that even if an L2 speaker acquires native-like linguistic knowledge by behavioral measures, it is possible that L2 parsing is regulated by different neural mechanisms than in L1 syntactic processing. The factors that influence qualitative and quantitative differences in ERP responses in L2 learners will be treated specifically in section 2.2.4.

The main differences in ERP correlates for reading between typical readers and L2 learners are more striking for morphosyntactic processing than for semantic processing (i.e. Hahne, 2001; Hahne & Friederici, 2001). Neuroimaging studies show that the brain mechanisms that support semantic processing in L2 learners are generally very similar to those observed in typical readers; however, this is not the case for morphosyntactic processing (Domínguez et al., 2014; Emmorey et al., 2013; Hirshorn et al., 2014; Mehravari et al., 2017; Skotara et al., 2011, 2012). Differences in semantic and morphosyntactic processing might be due to the way these features are stored and retrieved in memory. Specifically, grammatical rules may be stored in procedural memory, while lexical knowledge is maintained in declarative memory (Lewis & Vasishth, 2005). Ullman (2001, 2004) proposes a declarative/procedural (DP) model in which the mental lexicon of memorized word-specific knowledge depends on declarative memory, associated with the knowledge of facts and events. In contrast, the mental grammar, which subserves the rule-governed combination of lexical items into complex representations, depends on procedural memory, associated with the learning and execution of motor and cognitive skills, especially those involving sequences. According to this model, L2 learners and other special populations such as people with specific language impairment rely more in semantic memory to process grammatical features (Ullman, 2016).

An alternative focus maintains that more critical than the way semantic and grammatical information is treated by different memory mechanisms is how the reader makes use of specific linguistic cues to guide memory retrieval during parsing, and the different use of these cues by L1 and L2 readers (Cunnings, 2017). Cunnings posits that L2 learners rely more heavily on certain types of cues than others, such as cues derived from explicit (morphosyntactic) agreement features. Highly proficient L2 learners can easily identify and apply this information during parsing, because it is overtly marked on lexical items (e.g., gender information on transparent nouns). This ties in with the distinction between lexical and form-based routes (see section 2.2.1), and essentially Cunnings's claim that L2 readers rely more on explicit cues is a parallel of the form-based route.

Additionally, Cunnings (2017) also hypothesizes that possible differences between L1 and L2 processing can be due to cognitive control mechanisms regulating the two languages: L2 speakers can suffer more intrusion from the unintended language during memory retrieval operations, and to resolve such interferences, L2 learners might need to adopt certain reading strategies. For example, they might rely more on discourse-based cues and give less weight to syntactic information, in comparison to their L1 peers. L2 reading strategies of this type may be similar to approaches adopted by L1 readers, who do not always engage in full detailed processing of the linguistic information, but employ a shallow and superficial semantic interpretation of the text when facing difficulties in parsing (Ferreira & Patson, 2007; Ferreira et al., 2015, 2009; Ferreira & Lowder, 2016; Karimi & Ferreira, 2016).

Summary

We have seen that L2 learners' morphosyntactic processing is modulated by proficiency and these changes are evident in their ERP components. Specifically, novice learners are more likely to elicit an N400 effect for grammatical violations, a signal that they tend to rely more on the available semantic cues. Differently, intermediate and advanced learners show more typical syntactic-related ERP components (P600 and biphasic LAN/P600, respectively) in response to morphosyntactic violations, indicating that high levels of proficiency allow them to be more sensitive to these types of linguistic features. Figure 2.2 illustrates this continuum of L2 language processing.

I also presented different theories that were developed to account for these observed differences such as the declarative/procedural model proposed by Ullman (2001, 2004) which states that L2 learners might rely more in the semantic memory to retrieve morphosyntactic information, rather than in the procedural memory which is characterized by more automatic and unconscious processes of memory retrieval, and more similar to a native-like type of language processing. A different view proposed by Cunnings (2017) is that L2 readers make more use of linguistic cues (e.g., transparency of nouns) or semantic information to guide morphosyntactic computation, as they also need to control for linguistic intrusions from their L1 (Cunnings, 2017). Although both views are not necessarily cancelling each other out what they have in common is the idea that some linguistic features are more difficult to acquire than others (i.e., grammatical features), and learning them requires more effort and time to reach an automatic native-like stage of processing.

In the next session, I will show that different factors that influence language acquisition such as the similarity between a first and a second language, the age of acquisition of the L2, and immersion experience, are key factors that will affect proficiency level, and consequently, modulate ERP effects.

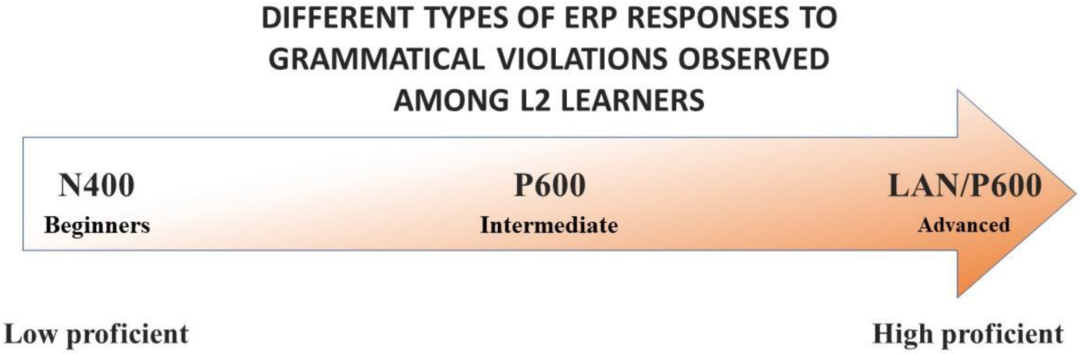

Figure 2.2. Different types of ERP responses elicited by L2 learners to grammatical violations as a function of language proficiency (Osterhout et al., 2006).

2.2.4 Factors that modulate ERP responses in deaf and L2 learners

The differences observed in the processing of grammatical information for L2 readers can be a result of different factors influencing the acquisition of a second language. Some authors believe that late L2 learners cannot process all morphosyntactic information presented in the second language in a native-like manner (Clahsen & Felser, 2006; MacWhinney, 2005), and native-like levels of proficiency will depend of different factors such as immersion and practice (Caffarra et al., 2015). Learning a second language can be very simple but also very complex. For example, a child can learn a second language much more naturally than an adult, and people who are immerse in another culture can achieve proficiency faster than people who only study language in classroom settings (Kotz, 2009; Osterhout et al., 2006). Therefore, different factors will affect the way a second language is acquired and, consequently, the level of proficiency the learner will achieve. In a review comparing different ERP studies that investigated syntactic performance in L2 learners, Caffarra and colleagues (Caffarra, Molinaro, et al., 2015) identified the most relevant factors that were shown to modulate language-related ERP components (i.e. N400, P600 and LAN). These factors are: a) L1-L2 similarity, that is, how similar or dissimilar is the second language in comparison to the first language; b) the age of acquisition of the second language; c) the type of L2 exposure (i.e. immersion vs. classroom settings) and the achieved proficiency level (Caffarra, Molinaro, et al., 2015). In the following paragraphs I will address each of these factors in the context of L2 learners and previous ERP studies to show how they can influence the processing of agreement computation (especially related to number and gender agreement), and how this evidence can also be extended to what is known about language processing in deaf readers.

L1-L2 Similarity: the transfer effect

The use of L1 information in the processing of the L2 is known as the *transfer effect*. The transfer effect may be positive, when grammatical aspects of the L1 can be transferred to the L2 depending on the level of similarity of the grammatical structure and information between the two languages (Weber & Lavric, 2008), or negative, in the case when the two languages are very different (MacWhinney, 2005, 1997). Different models were developed to explain the interactions between L1 and L2 during the process of second language acquisition. These models assume that the grammar of the L1 is the foundation in which grammatical rules from the L2 will be assimilated. Consequently, the morphosyntactic features in the L1 could influence how we acquire the syntactic rules presented in the L2. This influence occurs taking into account three aspects: a) the grammatical features that are similar and present in both languages; b) the grammatical features present in the L1 that are different in the L2; c) grammatical features that are only present in the L2. I will now explain these models and the L1-L2 interaction in more details.

The first model called f*unctional feature hypothesis* posits that only features that are present in the L1 can be acquired during L2 acquisition (Franceschina, 2001; Hawkins & Franceschina, 2004). Therefore, late L2 learners can only process grammatical features in the L2 in a native-like manner when those traits are identical in both languages. In other words, L2 learners cannot achieve native-like processing in the L2 when morphosyntactic traits are different to those of the L1 or unique to the L2 (Díaz et al., 2016; Erdocia, Zawiszewski, & Laka, 2014; Foucart & Frenck-Mestre, 2011; Zawiszewski, Gutiérrez, Fernandéz, & Laka, 2011).

In contrast, the *competition model* claims that features that are shared between L1 and L2 or are exclusive to the L2 can be processed by L2 learners in a native like fashion, but syntactic features that *compete* between L1 and L2 are more difficult to be acquired by L2 learners and more unlikely to be processed in native-fashion way (MacWhinney, 1997). Specifically, when there is competition in the syntactic features between the two language (e.g., different types of number agreement), language interference prevent learners to achieve native-like processing. For example, Tokowicz and MacWhinney (2005) examined transfer effects of syntactic features in English speakers who were late L2 learners of Spanish. They studied three different types of syntactic constructions: one that the L1 form matched the L2 form (tense marking[11]); a second construction for which the L2 form directly conflicted with the L1 form (number agreement); and a third construction that did not competed between the languages and only existed in the L2 (gender agreement). The results showed that L2 learners elicited a P600 effects for similar sentence structures in L1/L2 (tense marking) as well as L2-specific syntax (gender agreement), but not for number agreement where information was competitive between the L1 and L2. The competition between the L1 and the L2 can lead to a *positive transfer*, when morphosyntactic features present in the L1 support L2 processing due to their similarity (Kotz, 2009), or a *negative transfer*, when grammatical features are different and interfere in the correct processing of syntactic features in the L2 (e.g. Erdocia & Laka, 2018).

Alternatively, the *full transfer and full access model* (White, 2003) states that during the initial stages of L2 acquisition the representation of grammatical features is based on the features available in the L1, but learners have ‘full access’ to underlying universal grammar throughout their life-span and new features required by the L2 can be acquired, regardless of the age of acquisition (Foucart & Frenck-Mestre, 2012). Likewise, MacWhinney (2007) posits that although initially L1 structural cues such as word order dominate the learning of L2 syntax (negative transfer effect), over time, these L1 cues become less important and L2-specific structures start being more crucial for parsing. For example, (Alemán Bañón, Fiorentino, & Gabriele, 2014) investigated how native speakers of Spanish and English speakers who were L2 learners of Spanish process number and gender agreement in

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[11] Both English and Spanish form the progressive tenses by placing the auxiliary before the participle (Tokowicz & MacWhinney, 2005)

Spanish, considering that English does not have gender agreement and although it has number agreement, this agreement never occurs between noun and adjective, as is the case for Spanish. Their results showed that for both contexts number and gender violations elicited a P600 effect for both L2 learners and native speakers (no LAN effect for any of the groups), suggesting that highly proficient L2 learners can effectively process morphosyntactic dependencies without being limited to structurally local domains, and that the properties of the L1 are not deterministic with respect to ultimate L2 attainment, as learners can show native-like processing for properties that are unique to the L2, as was the case for gender agreement in this study (Alemán Bañón et al., 2014).

Although there is no consensus on which model better explain L1 transfer effects in L2 language processing, one thing all three hypothesis have in common is the premise that grammatical information is difficult to acquire by late learners and, therefore, L1 grammar serve as the main support to learn L2 grammar (Caffarra, Molinaro, et al., 2015). If there is only one model that can account for all types of L1 and L2 interaction is still not clear. For example, one study that could illustrate the complexity of L1 and L2 interactions and could be used as a reference to support two out of the three models abovementioned is the study presented by Gillon Dowens and colleagues (Gillon Dowens, Vergara, Barber, & Carreiras, 2010). The authors reported very similar ERP response between natives of Spanish and English speakers L2 learners of Spanish for both number and gender violation when the agreement happens between the determiner and the noun (LAN and P600), but observed a different pattern of response for the L2 group when the violations were across phrase: L2 learners only elicited a P600 response, with no negativity preceding it, while native readers still elicited the biphasic LAN/P600 ERP pattern (Gillon Dowens et al., 2010). In the discussion of the results, Gillon Dowens and colleagues address the fact that if we consider only the results for the local violations, we could say that L2 learners can process grammatical features not present in their L1 just like native readers (gender agreement), as well as similar features like number agreement, bringing evidence to support the full access and full transfer model. However, if we only take into account ERP responses for the across-phrase violations, we could say that, in fact, neither of the two types of agreement can be processed by L2 learners in a native fashion way, providing evidence in favor of the functional feature hypothesis. This clearly shows how complex it is to fully disentangle all the factors that influence syntactic processing in L2 learners. That is, the role each of these factors play during parsing computation and under what circumstances they can be observed.

In the case of deaf readers, the bilingual-bicultural models of literacy education proposed by Cummins in the 1980s (see the beginning section 2.2 for details) stipulate that deaf readers, like other types of bilinguals, transfer their L1 knowledge into the L2 during the process of second language acquisition. In this case, the transfer effect would occur across language modalities, that is, between sign language and the written code of a spoken language. The two language modalities are evidently different, especially with respect to grammatical and phonological features. Implicit cross-language co-activation between sign and spoken language in both hearing and deaf bimodal bilinguals has been demonstrated (Meade, Midgley, Sehyr, Holcomb, & Emmorey, 2017; Villameriel, Dias, Costello, & Carreiras, 2016), so an interaction between the two languages is clearly possible.

Previous studies have shown a positive correlation between sign language levels and reading abilities as learning a sign language during the first years of life was shown to benefit literacy attainment (Andrew, Hoshooley, & Joanisse, 2014; Hermans, Knoors, Ormel, & Verhoeven, 2008; Hoffmeister & Caldwell-Harris, 2014; Petitto et al., 2016). This might suggest that, despite the linguistic differences, the sign language could be exerting somehow a positive transfer effects on learning to read, although is not clear how transfer effects would occur across modalities. It is important to note, however, that deaf signing children may be benefit from the sign language during reading acquisition because it represents a solid first language. Therefore, having such a linguistic base is what facilitates the acquisition of written language, and not transfer effects from the sign language; the linguistic distance between the two languages would increase the possibility of interference through negative transfer effects. Indeed, a combination of negative transfer between the sign language and the written form of the spoken language and low reading proficiency could partly explain why many deaf signers face problems in parsing.

Up to the present time, and to my knowledge, no study has looked specifically into negative transfer effects across modalities using online neuroimaging techniques such as EEG. This is relevant to the present work because morphosyntactic differences between Spanish Sign Language (LSE) and written Spanish will be taken into account: gender agreement is present in Spanish but absent in LSE, and this might lead to negative transfer effects modulating the ERP responses, particularly in the case of less proficient readers[12]. The predictions based on possible negative transfer effects between LSE and Spanish will be set out in section 2.3.

Overall, the available evidence shows that there is a clear influence of the first language on the second language regarding morphosyntactic processing. Some studies have

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[12] Although the sample will be formed by high-skilled deaf readers, it is expected to see variations in the ERP responses of these readers that could be explained by differences in proficiency.

shown that L1-L2 similarity seems to facilitate the acquisition of morphosyntactic information (positive transfer), while L1-L2 differences would create interference or make it more difficult the acquisition of new features (negative transfer). Different models of language transfer were developed to try to explain how this influence occur between L1 and L2 (Caffarra et al., 2014) and although they offer different explanation for that they all agree that the L1 grammar serve as the main support to learn the L2 grammar. In the case of deaf readers, it is still not clear how different language modalities would interact and what type of language transfer would be observed. I hope to bridge this gap with the results of the present study (see chapter 6 for further discussion of this topic).

Age of acquisition

The impact the age of acquisition of a given language for language proficiency and attainment has been a matter of long and intense debate, mainly due to the observation that adults have more difficulty in learning a new language than children (Birdsong, 2009, 2018). Before discussing the effects of age of acquisition on language processing, a terminological issue needs to be addressed. Age of acquisition is defined as the age at which learners are immersed in the L2 context (immigrants), in contrast to *age of first exposure*, which can occur in a formal schooling environment, visits to the L2 country, extended contact with relatives who are L2 speakers, etc. (Birdsong, 2006). This is relevant if we think about language acquisition in deaf people. Deaf individuals are born in a country where one (spoken) language is the official national language, but they do not have direct access to it. They might have access to more or less linguistic information depending on familiar factors and environment in which they inserted. This is important because deaf children born to deaf signing families receive language input from birth through sign language and, therefore, experience typical language development; this is not the case for deaf children born to hearing families, as the age of first language input, and thus the language outcome later in life, is much more variable (Friedmann & Rusou, 2015). Even though deaf children might have access to the spoken language very early in life this exposure is usually poor and limited to the visual modality (e.g. lipreading). In the present work, I will adopt the term age of acquisition rather age of first exposure to refer to the onset of literacy attainment among deaf people, even though they are immersed in the L2 context from birth.

The explanation for the significance of age of acquisition lies in the *critical period hypothesis*, which states that the human brain has periods of sensitive time-windows during development that are prone to language learning (Lenneberg, 1967). Based on evidence from the development of a first language by deaf children, feral children, or children with serious cognitive impairments, the critical period hypothesis does not exclude the possibility of learning a foreign language after puberty, but does hold that this would happen with much conscious effort and typically less success (Vanhove, 2013). As I discussed in the last point of this section (see transfer effects L1-L2), there is still an ongoing debate on whether late acquisition of a second language (i.e., during adulthood) prevents learners from achieving native-like competence, especially in those skills related to the assimilation morphosyntactic features (Clahsen & Felser, 2006; Hartshorne, Tenenbaum, & Pinker, 2018; Morgan-Short, Steinhauer, Sanz, & Ullman, 2012; Pakulak & Neville, 2011; Steinhauer, White, & Drury, 2009), or whether no such critical period for L2 language attainment exists (Birdsong, 2006, 2009, 2014, 2018; Birdsong & Molis, 2001; Friederici, Steinhauer, & Pfeifer, 2002; Singleton, 2005; Vanhove, 2013). On the one hand, data from electrophysiological studies supporting a critical period in L2 learning claim that delayed L2 exposure is usually associated with qualitative and quantitative changes of ERP components specially those related to syntactic-related ERP components such as LAN and P600 (Ullman, 2001). In a seminal study, (Johnson & Newport, 1989) proposed a maturational model of L2 attainment according to which a critical period for language acquisition extends its effects to second language acquisition. The authors tested a group of 46 Chinese and Korean who acquired English in different ages (range: 3 to 39 years old) in a grammaticality judgment task. The results showed a clear linguistic advantage for earlier learners compared to late leaners in all the grammatical structures tested. Similarly, (Weber-Fox & Neville, 1996) observed that Korean and Chinese learners of English who also had acquired their L2 in different periods of life (from the age of one to after 16 years of age) elicited different N400 and P600 responses to semantic and syntactic violations, respectively, as a function of their age of acquisition. Specifically, although all groups displayed a significant N400 effect in response to semantic violations, the peak latencies of the N400 elicited in bilinguals who were exposed to the L2 and later than 11 years old showed a later onset, suggesting a slight slowing in processing semantic information, while ERP responses to syntactic processing yielded differences in both the morphology and distribution of the LAN and P600 which were associated with delays in exposure to L2.

In a very recent article (Hartshorne et al., 2018) reported an large-scale online behavioral study with a dataset of 669,498 native and non-native English speakers that used a computational model to estimate the trajectory of underlying learning ability by disentangling current age, age at first exposure, and years of language experience. Their results showed strong evidence in favor of the existence of a critical period for second language acquisition in which grammar-learning ability is preserved throughout childhood and declines rapidly in late adolescence (18 years old), supporting the critical period hypothesis, although defending that the age of offset of the critical period happens much later than previously speculated. In this new and revisited view of the critical period theory, the authors explain that changes in late adolescence rather than childhood (biological, social, or environmental changes) are responsible for difficulties in L2 processing, in a way that the critical period cannot be attributed to neuronal development in the first few years of life, nor to hormonal changes or puberty (Hartshorne et al., 2018). Importantly, Hartshorne and colleagues showed that ultimate L2 attainment is equally consistent among learners who begin to learn the L2 prior to 10–12 years of age and that both native and non-native learners require about 30 years to reach asymptotic performance[13] (in immersion).

On the other hand, there is also evidence against the critical period account of L2 acquisition. For example, (Birdsong & Molis, 2001) replicated the seminal work by (Johnson & Newport, 1989), using the exact methods and materials of the original experiment, but with a different sample (Spanish native speakers who were learners of English) and found that relationship between L2 attainment and age of acquisition help up even when learning commenced after the critical period (Seol, 2005). Other studies not only fail to find an advantage for early learners but do not even obtain a significant correlation between the age of exposure and any measure of language proficiency (Muñoz, 2008, 2010),

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[13] The terms asymptote or asymptotic performance refer to the idea that there may be a practical end, but no absolute finality, in the development of linguistic knowledge and language processing ability (Birdsong, 2009).

going against the notion of maturation as a constraint on achieving high levels of L2 attainment.

Friedmann and Rusou (2015) argued in favor of a critical period for the acquisition of L1 rather than L2, highlighting the importance of language input during first years of life, especially for the development of syntax skills. Poor language input during this period can have severe implications for the syntax ability later in life, affecting syntax processing in the L2, if there is any. For example, children with hearing impairment who are born to hearing parents and are raised in a spoken language environment will receive very little language input in the first years of life. As a result, the acquisition of syntax in the first language is affected, and that is the reason why many of these children show syntactic impairments (Friedmann & Rusou, 2015). Other studies with deaf people also observed significant effects from the delay of L1 acquisition on L2 performance (Cormier, Schembri, Vinson, & Orfanidou, 2012; Mayberry & Lock, 2003). From a biological perspective, Arshavsky (2009) also suggest that the critical period only relates to the acquisition of the L1 and the role of early language experience is not limited to the assimilation of words and grammatical rules, but also allows the initiation of genetic programs underlying language production and comprehension. As occurs with any other genetic programs underlying developmental processes, linguistic programs can only be initiated during a critical period, and once this process is initiated, first language attainment can be completed as well as the proper acquisition of additional languages (Arshavsky, 2009).

A review of previous ERP studies that supported the critical period hypothesis found that the available evidence is less convincing than previously assumed due to methodological issues such as confounds of age of acquisition with proficiency levels and ambiguous ERP results (Steinhauer, 2014). The author argues that more recent and better controlled ERP studies are in line with the *convergence hypothesis*, according to which L2 learners initially differ from native speakers but then converge on native-like neurocognitive processing mechanisms (Steinhauer, 2014). Furthermore, in a recent MEG study showed that L1 Spanish speakers with little knowledge of Basque were able to learn syntactic rules of Basque that are not present in Spanish and to produce electrophysiological responses like native speakers of Basque after some hours of training (Bastarrika & Davidson, 2017). Similarly, adults who learned a miniature artificial language displayed a similar ERP pattern when processing this language as native speakers do when processing natural languages (Friederici, Steinhauer, et al., 2002). These findings challenge the critical period hypothesis as they show evidence that native-like processing can be achieved in certain circumstances.

Although the existence of a critical period for second language acquisition is still open to debate, the most recent evidence is showing that learning a second language later in life is complex and aspects such as morphosyntactic features are more difficult to acquire in a native-like manner. Nevertheless, one important aspect that most studies agree on is the importance of *first language acquisition* and a rich linguistic input during the first years of life (Arshavsky, 2009; Birdsong, 2018; Cormier et al., 2012; Kuhl, 2010; Mayberry & Lock, 2003). This is crucial for deaf people as many of them show a delay in the acquisition of the L1, especially those who do not have early access to signed language (Friedmann & Rusou, 2015).

In the present study, I am interested here in understanding how deaf individuals who are native or early learners[14] of Spanish as well as hearing late learners of Spanish process morphosyntactic and semantic information. If deaf readers process language like late L2 learners such as previous authors have proposed it would make more sense to compare them with late learners rather than with early learners. This is because the amount of spoken language input deaf readers receive (e.g. via written code or lipreading) during life is much less when compared with the input received by their hearing peers when learning a second language. Therefore, for deaf people, age of acquisition is directly affected by their language experience as some deaf individuals might share the same age of acquisition, but one individual might be exposed to substantial less linguistic input in comparison to other deaf peers (e.g. due to family and school environments). In the next session I will discuss how language experience and language proficiency are relevant for language comprehension in L2 learners and deaf readers, and how these factors might modulate ERP components.

Proficiency and language experience (immersion)

Levels of language proficiency and the age of acquisition of a language are two concepts that are intertwined as it is usually assumed that the sooner a language is acquired the higher the level of proficiency in this language in adulthood (Moreno & Kutas, 2005; Ullman, 2001, 2004). However, this relationship is not completely straightforward as language experience may vary and leads to different outcomes. Specifically, language experience includes the degree of language exposure, the types of social context(s) of use, and the methods in which the language was learnt (Cohen, 2016; Nicoladis & Montanari,

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[14] What I mean with early learners, I am referring to those people who learn a second language early in life, still during childhood, but have another language as the native language (in this case LSE).

2016). This has led to a debate about whether age of acquisition or proficiency is a better index to evaluate L2 processing and which one contributes more to a more native-like processing (Steinhauer et al., 2009).

As discussed before in this session, qualitative and quantitative differences in ERP components elicited by L2 learners in comparison to native readers are more commonly reported for morphosyntactic processing than for semantic processing. However, even though modulations of the N400 effect as a function of L2 proficiency has not been consistently observed (Braunstein et al., 2012), previous studies have reported subtle differences in the semantic processing between L2 and L1. For example, diffferences in the distribution of the N400 effect on the scalp were previously resported for low-proficient speakers who showed a broader distribution of the N400 component (Bowden, Steinhauer, Sanz, & Ullman, 2013). Moreno and Kutas (2005) also showed that differences in proficiency might lead to modulation of the N400 effect. The authors presented evidence where two groups of Spanish-English bilinguals, one group with Spanish as the dominant language and the other with English as the dominant language, elicited a delayed N400 effect when processing semantic violations in their L2. Ojima, Nakata, and Kakigi (2005) found similar N400 results (i.e. a delayed in the N400 effect) when native speakers of Japanese who learnt English after childhood read sentences with semantic violations.

Nevertheless, more robust differences in ERP components have been reported for L2 learners during L2 morphosyntactic processing. Some authors argue that L2 syntactic computation initially differs from L1 processing, but can shift to native-like processes with sufficient proficiency or exposure, particularly in cases of immersion experience (Bowden et al., 2013). For example, Rossi and others (Rossi, Gugler, Friederici, & Hahne, 2006) compared different levels of proficiency in late L2 learners of German and Italian to native speakers and reported a comparable syntactic processing pattern for agreement violations (LAN/P600) in the native and late high proficient L2 learner groups, but, in contrast, low proficient learners only showed a small and delayed P600 effect (Rossi et al., 2006).

Ojima and colleagues (2005) also found that the development of syntactic processing is more dependent on proficiency levels than age of acquisition. Two groups of native Japanese speakers, who presented the same age of acquisition for their L2 (English), but varied in L2 levels of proficiency[15], were compared to a group of native English speakers. Agreement violations (subject-verb) elicited a LAN effect for the native and high-proficient group, but not for the low-proficient group. Furthermore, no P600 effect was found for non-natives in contrast to the native control group, which, according to the authors, might indicate effects of age of acquisition in acquiring syntactic features that are absent in the L1 (i.e. absence of agreement-inducing features in Japanese). Moreover, although not common, Ojima and colleagues explain that an absence of P600 effect for syntactic violations has been also reported to healthy subjects (Osterhout, 1995). Nevertheless, these results differ from most common replicated ERP studies, which show that high-proficient L2 learners usually elicit a P600 effect for agreement violations, and that the LAN effect reflects a more automatized mechanism of morphosyntactic processing that is more likely to be observed in native speakers and, sometimes, in high proficient L2 learners (Caffarra, Molinaro, et al., 2015; Friederici, 1995; Friederici, 2012; Friederici, Hahne, et al., 2002).

Tanner and colleagues (Tanner et al., 2013) investigated subject-verb agreement violations in native German speakers and native English speakers studying German and

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[15] The groups varied on the levels of proficiency due to differences in the length of stay abroad.

found that grammatical violations elicited large P600 effects in the native Germans and advanced learners. Interestingly, grand mean analysis for learners enrolled in first-year courses showed a biphasic N400–P600 response, but a correlation analyses revealed that most individuals showed either an N400 or a P600, but not both. Furthermore, the type of brain response correlated with behavioral measures of grammatical sensitivity: low proficient readers were more likely to elicit a N400 effect for grammatical violations, whereas high proficient readers were more likely to elicit the classical P600 effect for these violations. Furthermore, an analogous study observed the same results in proficient L1 Spanish – L2 English bilinguals during L2 morphosyntactic processing (Tanner et al., 2014). Even though grand mean ERP analyses revealed a biphasic N400–P600 response to English subject–verb agreement violations, subsequent analyses showed that participants' responses varied along a continuum between N400 and P600 dominance in which low proficient learners elicited more N400-like responses and high proficient learners a P600-like responses. The authors conclude that these results indicate that the learner's proficiency can impact sensitivity to L2 morphosyntax and use of linguistic cues during reading processing (Osterhout et al., 2008; Tanner et al., 2014, 2013).

According to Muñoz (Muñoz, 2008, 2010) naturalistic L2 learning settings usually offer an extensive amount of language input, in contrast to foreign language settings, which offer a limited amount of linguistic input usually distributed in very small doses. Thus, when L2 speakers are regularly exposed to a substantial amount of native-speaker input, the duration of immersion has a facilitatory effect on L2 comprehension skills and grammatical sensitivity (Flege, 2018; Flege & Liu, 2001). Therefore, long term immersion experience seems to lead to native-like language processing. For example, L1 English and late L2

Spanish bilinguals who were immersed in the country of the L2 more than 20 years elicited a native-like ERP response, that is, a biphasic LAN-P600 for both grammatical gender and number disagreement but only between an article and an adjacent noun. In contrast, noun-adjective disagreement failed to elicit an early negativity (Gillon Dowens et al., 2010).

The effect of explicit (classroom settings) and implicit training (immersion settings) on neurophysiological and behavioral measures of syntactic processing was examined using an artificial language paradigm (Morgan-Short, Sanz, Steinhauer, & Ullman, 2010). Participants from both settings were tested on noun-article and noun-adjective gender agreement at the beginning of the training, when they were considered low-proficient and at the end of the training, when they were considered high-proficient in the artificial language. Results showed that during the low-proficiency phase learners from neither the explicit nor the implicit training group elicited the P600 component in response to any of the gender agreement violations. Instead, at this early phase, the implicit group showed an N400 effect for both types of agreement violations, whereas the explicit group showed an N400 effect only for the noun-adjective gender agreement violations. At the end of the training, when they were considered more high-proficient in the artificial language, participants of both groups elicited a P600, but only for noun-article gender violations, as the noun-adjective gender violations elicited a N400 (Morgan-Short et al., 2010). This can be linked to the previous discussion raised in section 2.2.1 where I showed studies reporting that structural distance reduces sensitivity to the establishment of agreement overall also for native readers, that is, local violations elicit a more robust effect in comparison to across phrase violations (Alemán Bañón et al., 2012; Barber & Carreiras, 2005).

A study with a similar experimental design investigated whether different methods of language training, namely, implicit and explicit trainings, would impact the acquisition of gender agreement and word order in an artificial language (Morgan-Short et al., 2012). Although behavioral results showed that explicitly and implicitly trained participants showed statistically the same performance in both phases of the training (beginning and end), the ERP measures yielded striking differences. Specifically, only the implicit training learners showed ERP components typically found for L1 syntactic processing at the end of the training: grammatical violations elicited an Anterior Negativity (AN)[16] and a P600 biphasic effect.

For deaf readers, variation of proficiency levels is usually due to differences in the linguistic experience they were exposed to during the process of language acquisition. For those who acquire sign language as the first language, experience with the official spoken language is usually make through reading and lipreading. Differently, for those who do not use sign language is their L1, they are taught to speak and make an intensive use of lipreading, having a partial access to the spoken language, which is usually complemented with the acquisition of reading at a school age. Although these two examples are very common scenarios for many deaf people, linguistic experience can widely vary. Therefore, for them, it is possible that both immersion and classroom settings will play a crucial role to achieve high levels of proficiency.

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[16] Morgan-Short and colleagues hypothesized that the bilateral distribution found for the AN effect in the implicit training group could change with time and become more left-lateralized as the level of proficiency increases (Morgan-Short et al., 2012).

Summary

Proficiency level has an important impact on the ERP responses elicited by L2 learners for both semantic and grammatical violations, although these modulations are much more robust in the latter case. Low proficient L2 learners usually fail to elicit syntactic-related ERP components (LAN and P600), while usually showing a N400 effect for semantic violations. Differently, high proficient learners are more likely to elicit native-like ERP effects for syntactic violations (biphasic LAN-P600), although some studies failed to report these effects (e.g. Ojima et al., 2005). Furthermore, levels of proficiency also depend of the linguistic context in which the L2 is acquired and learning environment affects levels of proficiency: learners who acquired the L2 in immersion settings show higher levels of proficiency as illustrated by elicited native-like ERP responses for syntactic violations in comparison to learners who acquired the L2 in classroom settings. Table 2 shows a summary of the main ERP components elicited by L2 learners when processing noun-adjective violations of number and gender agreement.

For deaf people, the situation can be very different as they are already immersed in the country of the L2 and have some access to the spoken language. However, because deaf people do not have the same amount of linguistic input as a hearing person living abroad, which slow down their learning pace, both classroom settings and immersion play an important role for them to achieve higher levels of literacy.

Table 2.3. ERP evidence on noun-adjective number and gender agreement in L2 readers of Spanish.

Previous studies	L1	Learning environment	ERP effects							
			LAN		**N400**		**P600 (early)**		**P600 (late)**	
			Num	Gen	Num	Gen	Num	Gen	Num	Gen
Dowens et al. (2010)	ENG	Immersion	YES	YES	NO	NO	YES	YES	-	-
Dowens et al. (2011)	CHIN	Classroom	YES	YES	-	-	YES	YES	-	-
Alemán Bañón et al. (2014)	ENG	Mixed*	NO	NO	NO	NO	YES**	YES*	-	-

*Mixed: classroom and immersion settings.

2.3 Description of this study and predictions

The aim of this study is to investigate reading comprehension in deaf readers of Spanish using ERP measures to explore to what extent high skilled deaf readers process sentences like native readers of Spanish or if their reading processing is more similar to L2 learners of Spanish. In order to identify possible differences in processing between these three groups, semantic and syntactic information of Spanish sentences will be manipulated. Specifically, violations between a noun and the post-nominal adjective will be presented for semantic and syntactic manipulations. The latter will involve violations in number and gender agreement and gender agreement will be divided in two conditions: transparent gender, in which the orthographic form of the noun indicates the gender of the lexical item (e.g. feminine: casa [house]; masculine: barco [boat]) and opaque gender (e.g. feminine: muerte [death]; masculine: puente [bridge]).

Predictions: semantic condition

My hypothesis for the Semantic condition is that all the three groups will elicit a comparable N400 effect for semantic incongruencies since they are high-skilled L2 readers of Spanish, according to the available findings discussed in chapter 2. However, even though I expect that high-skilled deaf readers will present a similar N400 effect found for native hearing readers, it is possible that high-skilled L2 readers show a delay on the onset of the N400 effect (Braunstein et al., 2012; Moreno & Kutas, 2005).

Predictions: number condition

For the Number conditions, my predictions are that native speakers of Spanish will elicit the classical biphasic LAN P600 effect, while deaf readers will elicit only a P600 and might fail to show a more automatic processing of this feature, not eliciting a LAN effect. Another possibility is that deaf readers might rely more on the semantics of the text than on the syntactic features of the sentences, and that this dependence on semantics might make them to elicit a N400 instead. Specifically, skilled deaf readers will show the P600 component (associated with syntactic processing), but will fail to elicit a LAN effect and, instead, might show, but larger effects in the N400 due to a reliance on semantics rather than grammar. For L2 learners, I expect to see a P600 effect for this type of violation. However, since agreement between noun and post-nominal adjective is not observed in English, participants might not process this feature automatically, and as a consequence, show an absence of the LAN effect (e.g. Alemán Bañón et al., 2014).

Predictions: gender transparent condition

For the prediction of transparent gender agreement, I expect native speakers to elicit the classical biphasic ERP response, that is, a LAN and a P600 effect. For deaf readers and L2 learners, since both groups do not process gender features in their dominant and L1 language, respectively, it is possible that grammatical processing might differ from native participants. Specifically, if features that are not present in the L1 are more difficult to be acquired during L2 acquisition, both deaf and L2 readers will not elicit the classical biphasic syntactic-relate ERP responses. However, since gender transparent convey gender information through orthographical cues, this might facilitate gender retrieval, and therefore, gender agreement processes.

For deaf readers, since they only use Spanish to read as the sign language has no written version, it is also possible that they have developed some sensitivity to the regularities in Spanish and might be more sensitive to certain grammatical features in this language such as transparency. Consequently, deaf readers might elicit an ERP pattern that is somehow closer to the native group (e.g. a comparable P600 effect in both native and deaf groups). Nevertheless, in order to overcome possible difficulties in syntactic processing they might also elicit an N400 effect in an earlier time window due to the use of semantic information as support to parsing computation. In other words, deaf readers might rely more on the semantics than on the syntactic aspect, and that this dependence on semantics is modulated by reading skill.

In the case of L2 learners, due to their high level of proficiency, they will possibly elicit a P600 effect for this type of violation, but might fail to elicit a LAN effect, as they might not process gender in an automatized manner due to the absence of the grammatical feature in the L1, and the syntactic distance in the agreement relationship manipulated in this study.

Predictions: gender opaque condition

For the prediction of opaque gender agreement, I expect native speakers to elicit a similar ERP pattern to the transparent gender condition: a LAN and a P600 effect. Accordingly, for deaf readers and L2 learners, due to both the absence of gender features in their dominant and L1 language and the opacity of the nouns used in the agreement, I expect that grammatical processing in this condition will be different from native participants.

For deaf readers, they might fail to show sensitive to grammatical information in the case of opaque nouns and will not elicit a LAN or a P600. However, it is also possible that deaf readers have developed some sensitivity to the grammatical features in Spanish as they only read in this language and, consequently, elicit a similar P600 effect ERP that is somehow comparable to the native group. Similar to the gender transparent condition, deaf readers might rely more on the semantics than on the syntactic aspect, and that this dependence on semantics is modulated by reading skill. Consequently, they might also elicit an N400 effect in an earlier time window.

In the case of L2 learners, due to their high level of proficiency, they might elicit a P600 effect for this type of violation, but might fail to elicit a LAN effect, as they do not process gender in an automatized manner due to the absence of the grammatical feature in the L1.

3. Methodology

In this chapter I will explain in detail the methodological aspects of the studies carried out for the present dissertation. The first section offers a general description of the participant profile for each of the three groups that took part in this study and the procedures adopted to select and form the three groups. Specific details of these groups will be further described in chapter 3 (deaf and hearing) and chapter 4 (deaf and L2 learners) of this thesis. In section 3.2, I describe and explain the materials used in the behavioral assessments and in the experimental task designed for the EEG experiment. Finally, in section 3.3, I will explain the data acquisition procedure, including behavioral and ERP data collection.

3.1 Participants

Three groups of participants participated in the present study: one group consisting of deaf adult readers of Spanish, a second group make up of hearing native readers of Spanish, and a third group of hearing L2 readers of Spanish whose native language was English.

Deaf participants

Skilled deaf readers are part of a special population that are relatively rare given that reading is not an ability that all deaf people acquire well (see section 1.3). Therefore, considering the difficulty in finding deaf participants who could perform reading tasks at the same level as their hearing peers, a questionnaire was developed to serve as a pre-selection of the deaf participants. This survey was available online and provided a detailed explanation of the present study given in both LSE (video format) and written Spanish. Since the final goal of the questionnaire was to find skilled deaf readers, the questions in the survey were presented only in written Spanish. This online questionnaire made it possible to contact deaf individuals living all over Spain, and to collect profile information to select participants that fulfilled the requirements of the study and could take part in data collection held in different cities in Spain. The questionnaire included questions regarding their personal information, audiological profile (i.e. degree of hearing loss in decibels in both ears, age of onset of hearing loss, cause of deafness, etc.). Other relevant information, such as demographic information, educational background, handedness, and reading habits and preferences were also included. A sample of this survey is provided in appendix A of this thesis.

Hearing participants

All hearing participants (native speakers and L2 learners) who volunteered to take part in this experiment responded to a linguistic questionnaire that was similar to the deaf readers survey (see appendix A) in order to allow us to collect information about their language profile. L2 learners were intermediate to high-proficiency Spanish readers. More details of the profiles of native Spanish speakers and L2 learners of Spanish will be given in chapters 4 and 5, respectively. The behavioral assessment used to evaluate language level and non-verbal IQ was the same for all the three groups and is described in the next section.

3.2 Materials

Behavioral assessment

A battery of behavioral tests was administered to participants to evaluate cognitive capacities that are important to reading, such as language, vocabulary and IQ. The battery included:

- *Language questionnaire:* An online language questionnaire provided information about participants' language history. The questionnaire for native and L2 speakers included self-assessed ratings of proficiency in Spanish, knowledge and use of Spanish, knowledge of other languages, and reading frequency and habits (in Spanish). For deaf readers the survey also included self-assessed ratings of proficiency in LSE, knowledge and use of LSE, knowledge of other languages, the main mode of communication and instruction in school (Spanish and/or LSE), and reading frequency and habits (in Spanish).
- *Reading comprehension*: measures of reading comprehension capacities were investigated in both experimental and control group using the Spanish test *Evaluación de la comprensión lectora, nivel 2* (De la Cruz, 1999), a Spanish standardized assessment to evaluate language comprehension.
- *Vocabulary:* measures of vocabulary level were assessed using the Spanish version of the receptive vocabulary test *Peabody* (Dunn & Dunn, 1997).
- *Grammatical assessment:* measures of grammatical knowledge were evaluated using the Spanish grammatical test CEG: *Test de Comprensión de Estructuras*

Gramaticales (Mendoza, Carballo, Muñoz, & Fresneda, 2005), which evaluate the level of grammatical comprehension in sentences using different syntactic structures.

- *Intelligence (IQ):* the subtest *Odd Item Out* (OIO) from the *RIAS Scale* (Reynolds Intelligence Assessment Scales) was used in our study to evaluate nonverbal reasoning skills (Reynolds & Kamphaus 2003).

EEG task

The experiment used the grammatical violation paradigm (see section 2.1.4 for background details and examples of studies that have used this paradigm). The stimuli consisted of 320 Spanish sentences that were divided in four conditions: 160 correct sentences (baseline), 40 sentences with semantic incongruence, 40 sentences with number incongruence, and 80 sentences with gender incongruence. The gender violations were divided in two separate conditions based on whether gender was explicitly marked on the noun: transparent gender violations and opaque gender violations. Table 3.1 shows examples of these four different conditions.

Table 3.1. Examples of sentence stimuli. The critical word for ERP averaging is underlined.

Conditions	**Sentences**
Correct sentences (baseline)	Mi llave está <u>rota</u> y no abre la puerta. *[My key is broken and does not open the door]*.
Semantic violation	Mi casa es <u>celosa</u> y grande. *[My house is jealous and big]*.
Number violation	Mis platos son <u>amarillo</u> y azules. *[My plates are yellow and blue]*.
Gender transparent violation	Su villa fue <u>renovado</u> el mes pasado. *[Your house was refurbished last month]*.
Gender opaque violation	Mi pie estaba <u>herida</u> después del partido. *[My foot was hurt after the match]*.

The experimental manipulation of the incorrect sentences was always *noun-predicative adjective agreement* and the violation always occurred on the adjective (see underlined words on table 3.1), which was the target/critical word. The nouns and adjectives used were never repeated within a list, this way participants never saw the manipulated agreement twice. In all conditions half of the nouns used were feminine and the other half masculine. For the number condition half of the nouns were singular and the other half were plural. We also balanced singular and plural nouns in the semantic condition, so participants would not anticipate that a given sentence was part of the number condition by seeing plural nouns within a sentence. We also balanced the use of opaque and transparent nouns in the number condition, so participants could not make predictions in the gender condition (e.g. see an opaque noun and predict a gender violation). Furthermore, all the sentences always started with a possessive article (e.g. Mi [my]; Tu [your]) instead of starting with a definite or indefinite article, to avoid the use orthographical cues for gender at the beginning of the sentence, since in Spanish possessive articles do not mark for gender whereas other articles (un/una; el/la) agree in gender with the noun and, therefore, convey gender information. Noun and adjectives used in the two lists were selected using the Spanish database *ESPAL* (Duchon, Perea, Sebastián-Gallés, Martí, & Carreiras, 2013). Moreover, adjectives used in both correct and violated sentences were controlled for frequency, number of letters, and number of syllables. See Tables 3.2 and 3.3 for more detailed information.

Two lists with different set of sentences (e.g. list 1 and list 2) were created for all the conditions and counterbalanced across participants (see appendix B to E). That is, 80 correct sentences and 80 incongruent sentences based on the other 80 correct sentences. The incongruent sentences presented on list 1 were based on the correct sentences on list 2, and vice-versa.

Table 3.2. Lexical features of the target words and statistical comparisons on List 1.

		Control		Violation		Comparisons	
		Mean (SD)	Range	Mean (SD)	Range	*t*	*p*
Semantic	No. of letters	8.42 (1.75)	5.0 - 11.0	8.20 (1.34)	5.0 - 11.0	-0.64	0.52
	No. of syllables	3.50 (0.78)	2.0 - 5.0	3.47 (0.81)	2.0 - 5.0	-0.13	0.88
	Log frequency	2.90 (0.76)	1.32 - 4.45	2.92 (0.58)	2.01 - 4.47	0.11	0.90
Number	No. of letters	8.12 (1.82)	4.0 - 12.0	8.45 (1,90)	5.0 - 12.0	0.77	0.43
	No. of syllables	3.47 (0.78)	2.0 - 5.0	3.47 (1.03)	2.0 - 6.0	0.38	0.70
	Log frequency	3.15 (0.68)	1.69 - 4.62	3.10 (0.78)	1.54 - 5.10	0.26	0.78
Gender Transparent	No. of letters	7.35 (1.52)	5.0 - 10.0	6.70 (1.66)	4.0 - 11.0	-1.81	0.07
	No. of syllables	3.30 (0.88)	2.0 - 5.0	3.15 (0.86)	2.0 - 5.0	-0.76	0.44
	Log frequency	3.55 (0.56)	2.61 - 4.70	3.70 (0.57)	2.65 - 5.21	1.18	0.23
Gender Opaque	No. of letters	7.60 (1.35)	4.0 - 10.0	7.10 (1.94)	3.0 - 11.0	-1.33	0.18
	No. of syllables	3.47 (0.67)	2.0 - 4.0	3.25 (0.83)	2.0 - 5.0	-1.31	0.19
	Log frequency	3.24 (0.55)	2.04 - 4.65	3.25 (0.60)	2.18 - 4.89	0.06	0.94

3.3 Data acquisition

3.3.1 Procedure

Participants took part in three experimental sessions: a one-hour session was dedicated to the collection of the behavioral measures, a two-hour session that included 90 minutes for the EEG task, and half an hour of a post-EEG behavioral session consisting of a lexical decision task and a gender task. The EEG recording session included experimental preparation (fitting participants with the electrode cap, etc.) and task execution. Experimental sessions were completed either on two days (i.e. one day for the behavioral session, and another day for the ERP recording plus post-EEG tasks) or on the same day (in this case, with a break between the behavioral and EEG session).

After providing written informed consent, participants were fitted with an electrode cap. Stimuli were presented using Psychopy software (Peirce, 2009) on a 14” Lenovo laptop (1600 x 900 pixels). For the deaf participants, an interpreter was available for all sessions, and all experiment procedures were explained in LSE and/or written Spanish. Participants sat approximately 40 cm from the computer monitor and were instructed to relax and minimize movements while silently reading the sentences and at the end of each sentence to judge if the sentence was correct or not by pressing the letters S or L from the keyboard. The two lists containing the sentences (see section 3.2) had two versions to counterbalance manual responses (e.g. list 1A and 1B or list 2A and 2B). For example, in version A participants had to respond to the acceptability judgment task using the right hand for *yes* responses if the sentence was correct, and the left hand for *no* if the sentence was incorrect; the version B of the two lists was the other way around.

Each sentence included a critical word (shown underlined in Table 3.1) used as a reference for analyzing and averaging the ERP components. Each sentence was randomly presented word-by-word using Rapid Serial Visual Presentation (RSVP; see chapter 2 for more details of this presentation paradigm). At the beginning of each trial, a fixation cross was displayed in the center of the screen for 700 ms and this was followed by a blank screen for 300 ms. Each word was in white letters on a dark-gray background and appeared for 400 ms, followed by a blank screen for 200 ms. The final word was displayed with a full stop and after the sentence offset a question appeared on the screen asking whether the sentence was correct or not. Participants had 5000 ms to give their response by pressing one of the two response buttons, although they were instructed to respond as soon as they saw the question. Once the response was given, the fixation cross appeared again, indicating the start of a new trial. At the beginning of the recording session, subjects were advised to blink during the presentation of the fixation cross in order to reduce the probability of eye movements during the critical epochs. A practice session with 16 different set of sentences preceded the real experiment, to familiarize participants with the task. Sentences in the practice session included one example of each of the 4 incongruent conditions and control sentences and were presented in random order. In this practice session the characteristics of the nouns (masculine-feminine; transparent-opaque gender marking; singular-plural) were balanced, so participants could not make predictions about the experimental manipulation. Feedback on performance was given during the practice but not during the main task. After finishing the practice session, participants could ask questions or clarify any doubts and were given the opportunity to redo the practice. The ERP recording session lasted approximately 60 minutes (including instructions and the practice session). The main task was divided in 4 blocks of 80 trials each, with breaks of up to 3 minutes between blocks. During the breaks, participants were given the choice of continuing with the task before the end of the 3 minutes.

3.3.2 EEG recording and analysis

The EEG was recorded from 27 electrodes placed in an elastic cap: Fp1, Fp2, F7, F8, F3, F4, FC5, FC6, FC1, FC2, T7, T8, C3, C4, CP5, CP6, CP1, CP2, P3, P4, P7, P8, O1, O2, Fz, Cz, Pz. Two external electrodes were placed on mastoids and four were placed around the eyes (two on the ocular canthi, one above and one below the right eye). All sites were referenced online to the left mastoid. Data were recorded and amplified at a sampling rate of 500 Hz. Impedance was kept below 5 KΩ for the electrodes on the scalp and below 10 KΩ for the external channels. EEG recordings were re-referenced offline to the average activity of the two mastoids. Then, the data were filtered offline with a bandpass of 0.01–30 Hz (24 dB/oct). Artifacts exceeding ±100 μV in amplitude were rejected. For each target word, an epoch of 1200 ms was obtained including a 200-ms pre-stimulus baseline. For each condition, average ERP waveforms, time locked to the onset of the target word (i.e. adjective), were computed only on the trials with a correct response. Horizontal and vertical eye movements were corrected using independent component analysis (ICA; Makeig, Bell, Jung, & Sejnowski, 1996). We decomposed the whole electroencephalogram into independent components for each subject and focused on the components that explained the highest percentage of the variance in the vertical and horizontal oculograms. The time course of these components was visually inspected (to ensure they represented real artifacts) and subtracted from the original data.

Statistical analyses were carried out on different time windows, which were selected in order to check for the presence of N400/LAN and P600 effects (N400/LAN: 350–500; P600: 600–800 and 800–1000, following Kutas & Federmeier, 2011; Barber & Carreiras, 2005; Caffarra & Barber, 2015; Caffarra, Barber, Molinaro & Carreiras, 2015). A between-group repeated measures analysis of variance (ANOVA) was performed for each time-window in all the 4 conditions to detect critical interactions. The factors included in the ANOVA was Group (levels: hearing x deaf), Congruence (levels: Congruent x Incongruent), Anteriority (levels: Anterior x Central x Posterior), and Laterality (levels: Left x Medial x Right). Table 3.3 shows the electrodes included in each level of the Anteriority and Laterality factors. The Greenhouse–Geisser procedure was applied where the sphericity assumption was violated (Abdi, 2010). Any p-values derived from multiple post-hoc tests were adjusted by using Hochberg’s procedure (1988). Effects of topographic factors (i.e.

Anteriority and Laterality) are reported when they interact with the experimental factors Congruence. This means that when topographical factors interact only with the factor Group results will not be reported. Importantly, only correct trials were included in the ERP analysis. On the next chapter I will present *experiment 1* that refers to the comparison between hearing and deaf readers.

Table 3.3. Description of the electrodes included in each level of the topographical factors.

Factor Anteriority	
Levels	**Electrodes**
Anterior	"Fp1","Fp2","F7","F3","Fz","F4","F8","FC5","FC6"
Central	"FC1","FC2","T7","C3","Cz","C4","T8","CP5","CP6"
Posterior	"CP1","CP2","P7","P3","Pz","P4","P8","O1","O2"
Factor Laterality	
Levels	**Electrodes**
Left	"F7","F3","FC5","T7","C3","CP5","P7","P3","O1"
Medial	"Fp1","Fp2","Fz","FC1","FC2","Cz","CP1","CP2","Pz"
Right	"F4","F8","FC6","C4","T8","CP6","P4","P8","O2"

4. Experiment 1

Previous ERP studies have suggested that the cognitive processes underlying deaf readers' ability to read is not the same as those observed in hearing readers: there is an absence of syntactic-related ERP components during reading comprehension, and this supports the idea that deaf readers make use of semantic strategies such as the *keyword strategy* or the *good enough strategy* to fully process complex sentences and texts (Domínguez & Alegria, 2010; Domínguez et al., 2014; Domínguez et al., 2016; Mehravari et al., 2017). In this chapter I will present electrophysiological data that will help to further understand how deaf individuals who are readers of a transparent language such as Spanish process written sentences by comparing them with a group of typical hearing native readers. This study uses the grammatical violation paradigm (see section 2.1.5 for a comprehensive explanation of this paradigm) to test how the brains of deaf and hearing participants identify and process semantic and grammatical errors while performing a semantic and grammatical judgement task, and to identify any differences between both groups. Our predictions are that deaf readers will perform this task very similarly to the hearing readers when faced with semantic and number incongruencies, but that they might perform relatively poorly when sentences with gender mismatches are presented. More information about specific predictions for each of the experimental conditions in both groups can be found in section 2.3.

4.1 Participants

Two groups of participants volunteered to take part in this study: a group of 36 Spanish deaf participants and a group of 36 hearing native Spanish readers. All participants were right-handed and did not present any vision or neurological problems. All participants gave consent to participate and received monetary compensation for their time. Deaf subjects were recruited by means of an online questionnaire and through deaf associations from different locations in Spain. Hearing subjects were selected using an existing participant database. Although data was collected from 36 participants, final analysis was conducted using a smaller sample due to the difficulty of finding deaf participants who matched hearing participants in the behavioral tasks and performed above chance (accuracy higher than 50%) in the acceptability judgment task. For the deaf group, some participants were excluded from the final EEG analysis either because of low performance in the EEG task (n = 12) or because they presented high rates of movement artifact in the EEG recording (n = 5). The difficulty in performing the task was expected as deaf people usually have difficulties in reading tasks (for an overview see section 2.1.2).

Therefore, a final sample of 19 deaf participants (13 females, *mean age* = 36.42, *SD* = 8.47) and 19 hearing participants (11 females, *mean age* = 26.36, *SD* = 2.56) was selected. Language profile of both hearing and deaf groups is shown in Table 4.1. Participants were matched on vocabulary, IQ, and years of education. (See Table 4.3 below for the behavioral measures and statistical comparison between the two groups.)

Table 4.1.
Participants' language profile and academic level. Standard deviation (*SD*) is in parenthesis.

Profile	**Group**		**Comparisons**	
	Hearing	**Deaf**	***t* value**	***p* value**
Spanish level (Self-report 1-5)	4,79 (0.40)	4,33 (0.74)	-2.11	.04
LSE level (Self-report 1-5)	0 (0)	4.52 (0.90)	21.80	<.001
Formal Education (years)	23.05 (2.75)	22.42 (4.25)	-0.50	.61

All participants responded to a language questionnaire that included questions related to their language profile. All deaf individuals presented pre-linguistic deafness with either severe (71-90 decibels) or profound (90-120 decibels) hearing loss. They reported knowledge and use of both Spanish and LSE (see Table 4.1). None of the participants had cochlear implants. Table 4.2 shows a more comprehensive profile of deaf participants. Hearing participants had Spanish as their dominant language and reported knowledge of other spoken languages. Deaf participants have also reported knowledge of other signed languages and the written form of some spoken languages (e.g. English).

Table 4.2. Linguistic and academic profile of deaf readers.

Deafness profile						
Deafness onset		Degree of hearing loss		Use of hearing aids		
Since birth (n=11)	Before 3yo (n=8)	Profound (n=15)	Severe (n=4)	Daily (n=11)	Sporadic (n=4)	None (n=4)
Language background						
Dominant language			Daily mode of communication			
LSE (n=8)	Spanish (n=10)	Sign supported speech (n=1)	LSE (n=5)	Spanish (n=8)	Sign supported speech (n=6)	
Environment						
Parents		Mode of communication at home				
Deaf (n=4)	Hearing (n=15)	LSE (n=4)	Spanish (n=15)			
Academic Background						
Highest level of Education			Main language of education			
High school (n=1)	University (n=12)	Graduate school (n=6)	LSE (n=6)	Spanish (n=11)	Sign supported speech (n=2)	

4.2 Methodology

The procedure and materials for this experiment are described in detail in chapter 3.

4.3 Results

4.3.1 Behavioral measures

A standardized behavioral battery was performed with both groups (see section 3.2). Table 4.3 shows the performance of both groups in these behavioral measures. Hearing participants performed better than the deaf group in the reading comprehension task and in the grammatical skills assessment. The distributions of scores in these two measures are presented in Figures 4.1 and 4.2.

Table 4.3.
Mean scores for the behavioral battery used to test participants in language comprehension, vocabulary, grammar knowledge, and IQ. Standard deviation (*SD*) is in parentheses.

Task	Group		Comparisons	
	Hearing	**Deaf**	***t* value**	***p* value**
Comprehension (Max score: 27)	24.57 (1.50)	20.26 (4.53)	-3.94	< .001
Vocabulary (Max score: 192)	166.15 (11.87)	163.00 (16.41)	-0.67	.50
Grammar (Max score: 80)	78.68 (1.49)	76.73 (3.07)	-2.48	.01
IQ (Max score: 94)	72.84 (7.38)	72.73 (5.05)	-0.05	.95

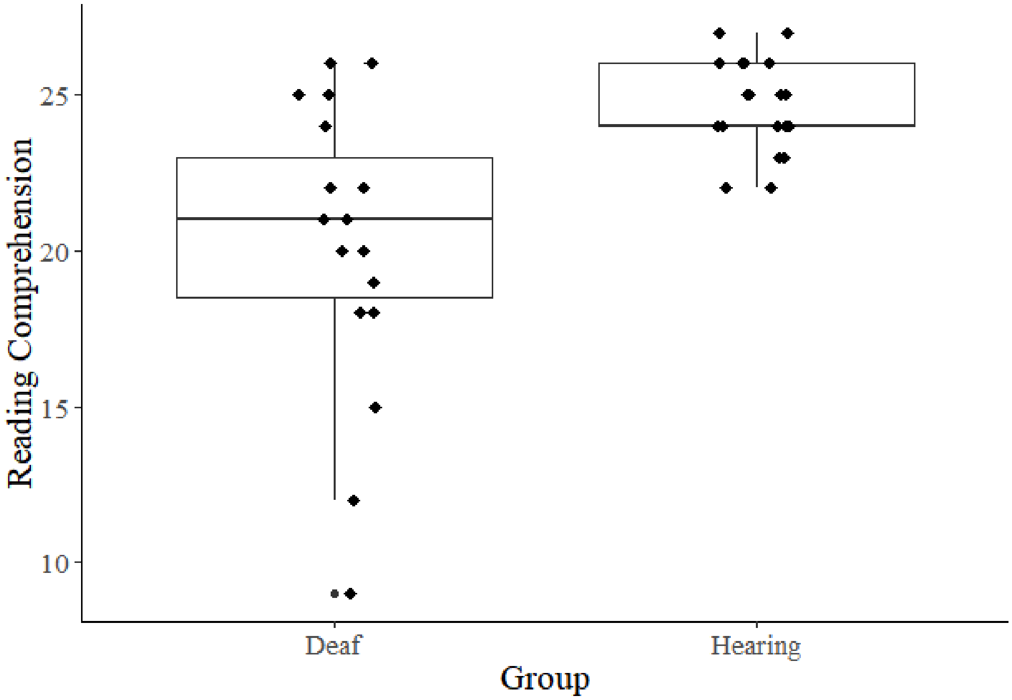

Figure 4.1. Distribution of reading comprehension scores for hearing and deaf participants. Hearing participants scored significantly higher in comparison to deaf participants.

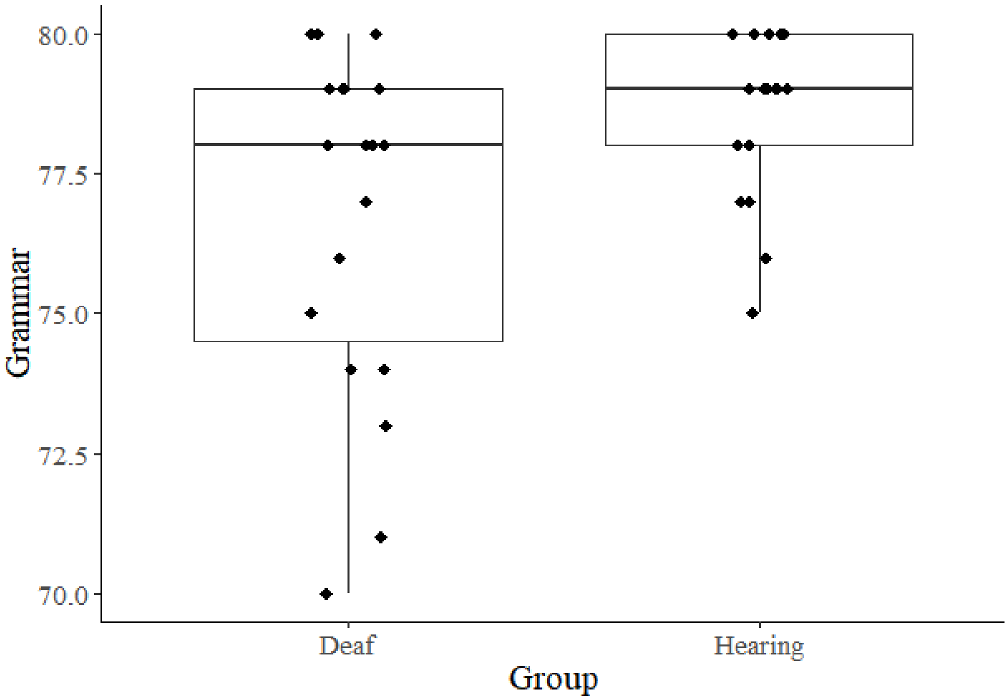

Figure 4.2. Distribution of grammatical ability scores for hearing and deaf participants. Hearing participants scored significantly better than the deaf participants did.

4.3.2 EEG: end-of-sentence acceptability judgement task

Responses from the end-of-sentence acceptability judgement task were analyzed calculating d-prime scores from the 4 experimental conditions: Semantic, Number, Gender Transparent, and Gender Opaque. Percentage of correct responses for each condition are shown in Table 4.4 as well as the corresponding d-prime scores and t-values for the comparison of the d-prime scores between groups.

Table 4.4. Average percent of participants’ performance (accuracy) in the end-of-sentence acceptability judgment task. Standard deviations (SD) are in parentheses.

Conditions	**Group accuracy**				**Comparisons of d-prime scores**	
	Hearing		**Deaf**			
	% Correct responses	d-prime	% Correct responses	d-prime	*t* value	*p* value
Semantic violation	91.8 (7.2)	3.46 (0.69)	88.9 (16.2)	3.02 (0.93)	-1.66	.10
Number violation	93.3 (6.1)	3.36 (0.78)	92.0 (12.3)	3.21 (0.99)	-0.53	.59
GT violation	93.9 (6.5)	3.35 (0.61)	92.5 (6.6)	3.17 (0.97)	-0.67	.50
GO violation	93.1 (8.5)	3.53 (0.73)	86.8 (11.8)	2.87 (1.18)	-2.05	.04
Overall performance	93.2 (5.7)	3.17 (.60)	90.45 (8.3)	2.96 (0.95)	-1.66	.10

Overall d-primes scores from the hearing group showed that they were better at discriminating sentences with violations compared with the deaf group. However, statistical comparisons of the d-prime scores of each condition as well as overall d-prime showed that this difference was only significant in the Gender Opaque condition (see Table 4.4). This indicated that the hearing group was better at discriminating grammatical errors within this condition in comparison to the deaf readers. Results are illustrated in figure 4.3.

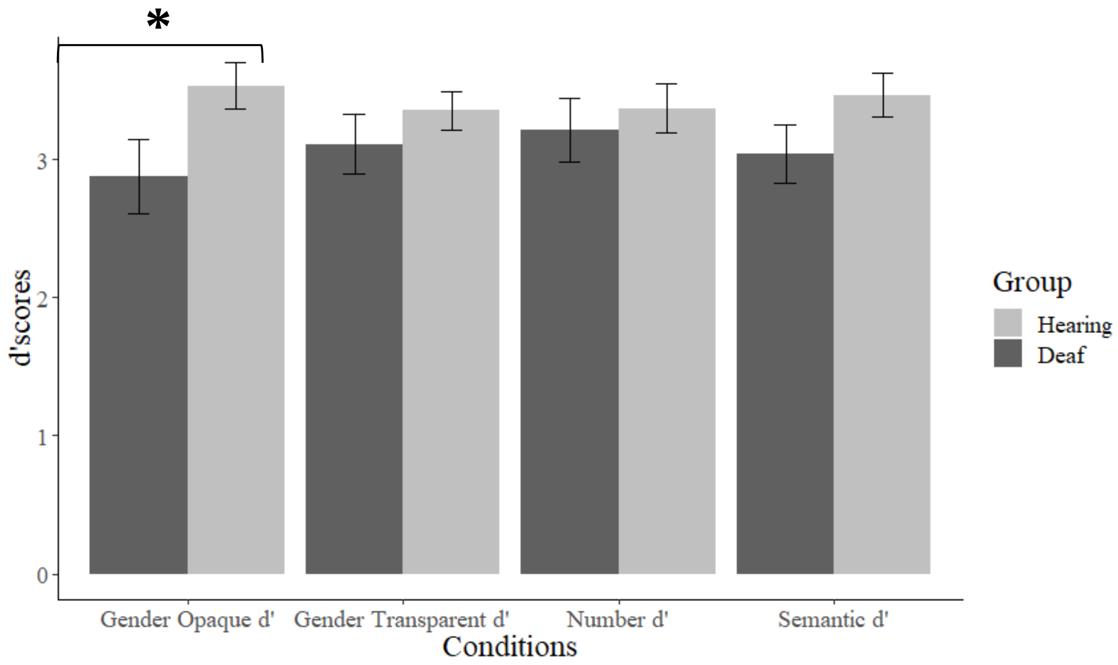

Figure 4.3. End-of-sentence acceptability judgment d-prime scores for hearing and deaf participants. Error bars represent standard error of the mean (SEM). A d-prime of 0 indicates chance performance on the acceptability judgment task and a d-prime of 4 indicates near-perfect discrimination between control and violated sentences.

4.3.3 ERP measures

The ERP grand average time-locked to the onset of the target words and the topographic distributions of average potentials for the four conditions are presented in Figures 4.4 – 4.11. For the hearing group, 12.4% of the trials were excluded due to artifacts or incorrect responses, and for the deaf group the number of excluded trials was 14.7%. A 2 (group: hearing, deaf) by 4 (condition: semantic, number, transparent gender, opaque gender) ANOVA showed that there was no main difference in the number of trials excluded between the two groups (*F*(1, 288) = 2.58, *p* = .10) or across conditions (*F*(3, 288) = 0.23, *p* = .87).

4.3.3.1 Semantic condition

Figure 4.4 shows ERPs in response to the congruence manipulation in the Semantic condition for the hearing and deaf groups and figure 4.5 the topographic distribution of average potentials for each of the time-windows of interest. Visual inspection of ERP waveforms for the Semantic condition revealed differences between congruent and incongruent sentences for both groups. Specifically, for both groups there was a greater negativity peaking around 400ms for the incongruent condition. This effect started slightly earlier for the deaf (before 400ms) than for the hearing (after 400ms). This negativity was followed by a posterior positivity that peaked after 600 ms following stimulus onset and lasted more or less until 1000ms. Statistical results are shown for each of the time-windows of interest.

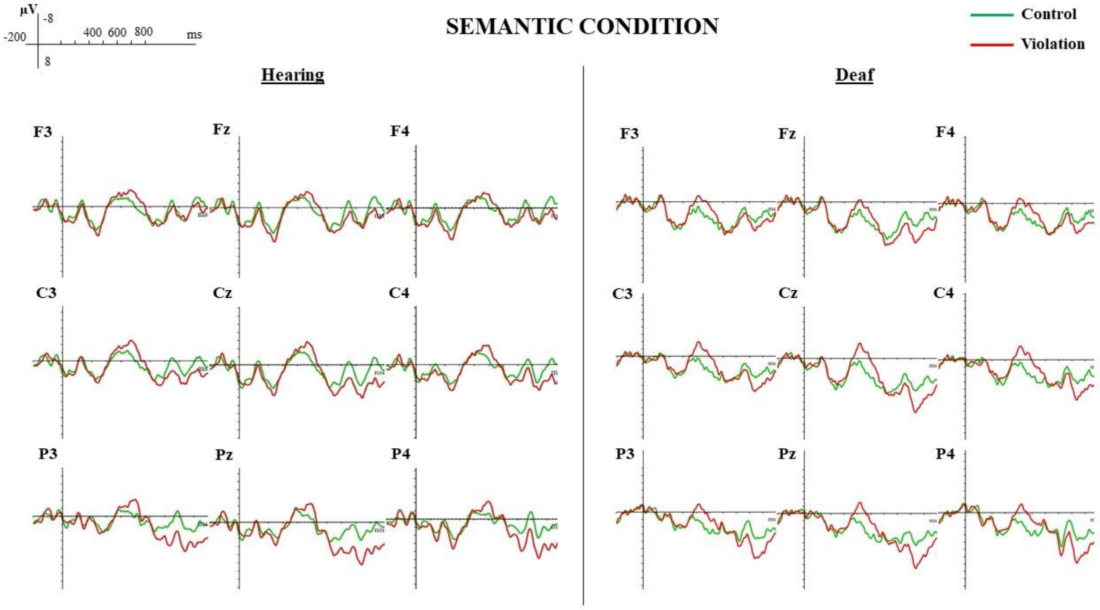

Figure 4.4. ERPs in response to the congruence manipulation in the Semantic condition for the hearing and deaf group.

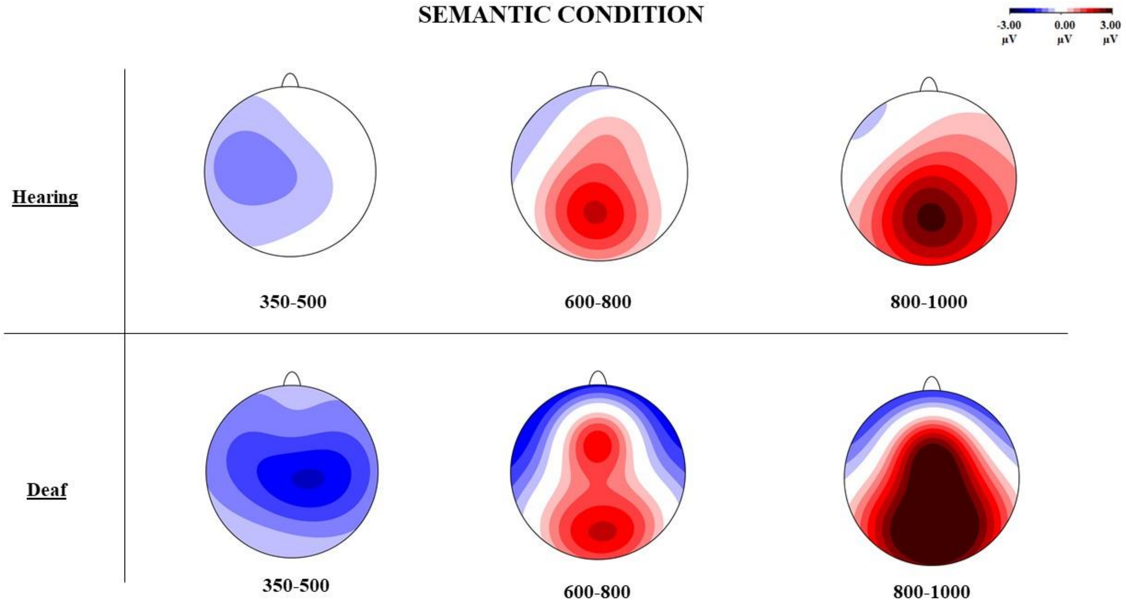

Figure 4.5. Topographic distributions of average potentials for the hearing and deaf group in the Semantic condition.

350-500 ms time-window

A 2 x 2 x 3 x 3 ANOVA[17] was run revealing a main effect of Group (*F*(1,36) = 5.79, *p* = .02) and a marginal main effect of Congruence (*F*(1,36) = 3.32, *p* = .07). Additionally, an interaction between Group and Congruence was found (*F*(1,36) = 4.93, *p* = .03). Post-hoc analysis showed a significant difference between the congruent and incongruent condition for the deaf group (*t*(18) = 4.60, *p* < .001), and a marginal difference for the hearing group (*t*(18) = 1.99, *p* = .06). There was no difference in the mean ERP amplitudes for incongruent sentences in both groups (*t*(35.60) = -1.30, *p* = .19), but there was a significant difference in mean amplitude of congruent sentences (*t*(35.98) = -3.29, *p* = .004), with more negative responses to correct sentences in hearing compared to deaf readers.

This marginal difference observed in the hearing group could be due to the fact that the N400 effect started slightly later for the hearing readers in comparison to the deaf readers, as can be seen in the waveforms in figure 4.4. Therefore, to ensure that there was an effect for the hearing group a statistical analysis in the 400-550 time-window (i.e. 50ms later than the established epoch) was run, revealing a significant main effect of Group (*F*(1,36) = 7.09, *p* = .01) and Congruence (*F*(1,36) = 5.36, *p* = .02), and only a marginal interaction between Group and Congruence (*F*(1,36) = 4.93, *p* = .06).

600-800 ms time-window

A between-group analysis in this time-window showed no main effects of Group (*F*(1,36) = 2.63, *p* = .11) or Congruence (*F*(1,36) = 1.79, *p* = .18). A significant interaction

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[17] As explained in chapter 3, a 2 x 2 x 3 x 3 ANOVA was conducted considering the following factors: Group (hearing vs. deaf) x Congruence (congruent vs. incongruent) x Anteriority (anterior, central, posterior) x Laterality (left, medial, right).

between Congruence and Anteriority (*F*(2,72) = 6.00, *p* = .01) was observed as well as a quadruple interaction between Group x Congruence x Laterality x Anteriority (*F*(4,144) = 2.95, *p* = .04). Post-hoc analysis for the Congruence x Anteriority interaction revealed only a marginal effect in posterior areas (*t*(37) = -2.48, *p* = .05).

In order to further investigate group differences as a result of the four-way interaction, a within-group analysis[18] was carried out for each group. For the hearing group, this time-window did not yield any significant main effects, but a significant interaction between Congruence and Anteriority was observed (*F*(2,36) = 5.95, *p* = .02). Simple effects, however, did not reveal any significant topographic differences for the Congruent–Incongruent contrast. Similarly, for the deaf group, no main effect of Congruence was found. A marginal interaction between Congruence x Anteriority (*F*(2,36) = 3.38, *p* = .07) and Congruence x Laterality (*F*(2,36) = 2.91, *p* = .08) was observed, but simple effects did not yield any significant topographic differences for the Congruent–Incongruent contrast.

800-1000 ms time-window

In this later time-window, a between-group analysis revealed a significant main effect of Group (*F*(1,36) = 6.23, *p* = .01) and Congruence (*F*(1,36) = 4.69, *p* = .03). Moreover, a significant interaction between Congruence and Anteriority (*F*(2,72) = 13.04, *p* < .001) was also observed. A post-hoc analysis revealed significant differences between Congruent and Incongruent sentences only in central and posterior areas (anterior: *t*(37) = -0.90, *p* = .37; central: *t*(37) = -3.31, *p* = .01; posterior: *t*(37) = -4.67, *p* < .001).

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[18] A 2 x 3 x 3 ANOVA was conducted for the within-group analysis considering the following factors: Congruence (congruent vs. incongruent) x Anteriority (anterior, central, posterior) x Laterality (left, medial, right).

Semantic condition: summary of the effects

Both groups showed a similar response to semantically incongruent sentences. First came a broadly-distributed negativity in the 350-500 ms time-window, a typical N400 effect. Although there was a marginal difference between groups this was due to a slightly later response by the hearing readers (as shown by the plots in figure 4.4 and confirmed by analyzing a later time-window); reasons for this delayed response will be considered in the discussion below (section 4.3). Subsequently, both groups showed a P600 effect: a weak central-posterior positivity that began in the 600-800 ms window and became stronger in the 800-1000 ms window.

4.3.3.2 Number condition

Visual inspection of ERP waveforms for the number condition revealed robust differences between congruent and incongruent sentences in both groups. ERPs for this condition are shown in Figure 4.6, and topographic maps in Figure 4.7. Specifically, for both groups we observe a negativity peaking around 400ms for the incongruent condition. This negativity was followed by a positivity that had a focus in posterior electrodes in the hearing group but was stronger and more widely distributed in the deaf group. Statistical results are presented for each of the selected time-windows.

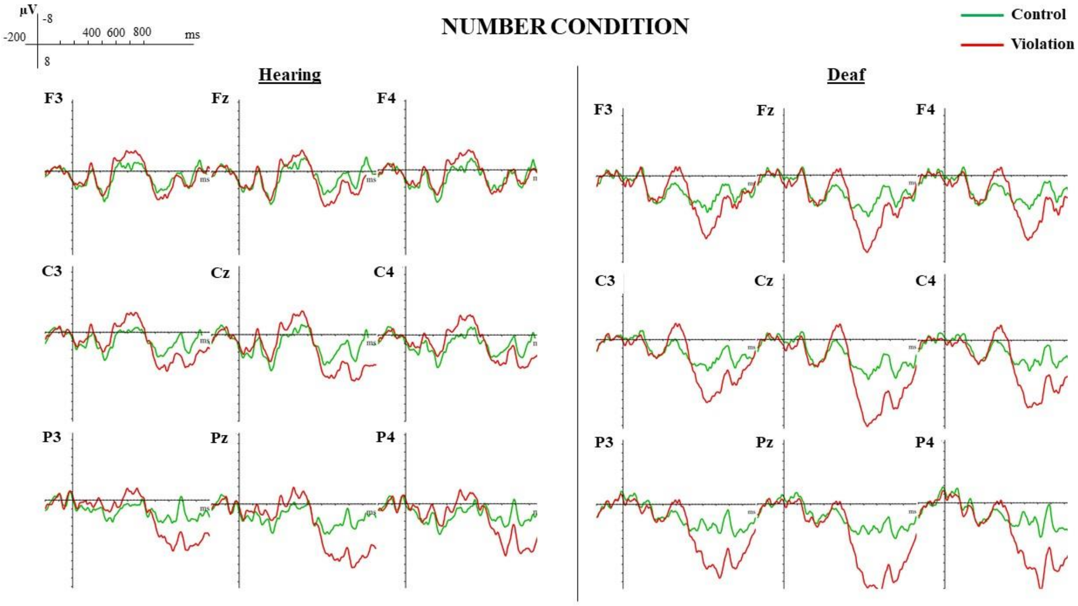

Figure 4.6. ERPs in response to the congruence manipulation in the Number condition for the hearing and deaf group.

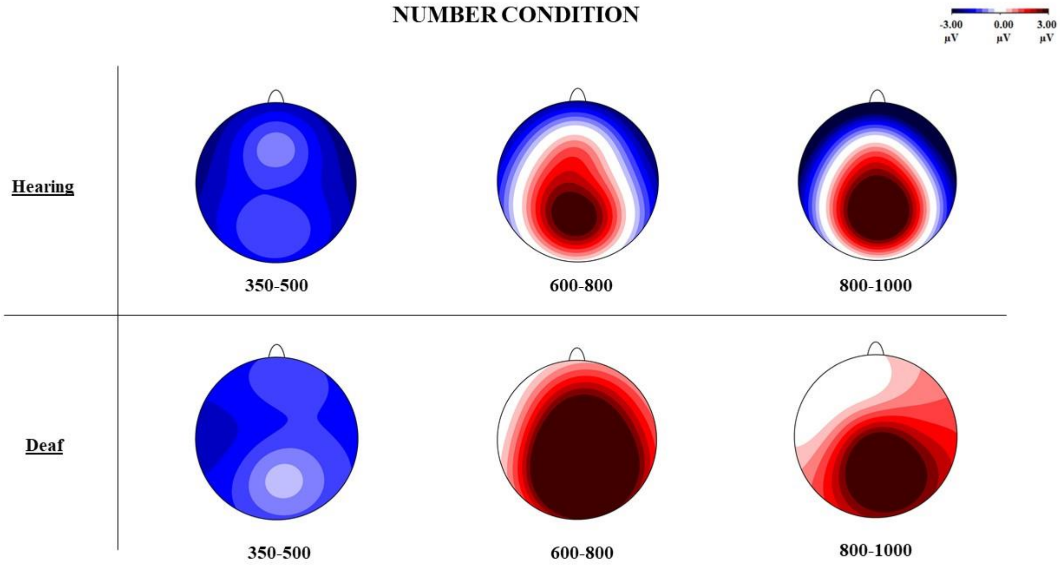

Figure 4.7. Topographic distributions of average potentials for the hearing and deaf group in the Number condition.

350-500 ms time-window

A between-group analysis revealed a main effect of Group (*F*(1,36) = 6.97, *p* = .01) and Congruence (*F*(1,36) = 12.32, *p* = .001). Additionally, a significant three-way interaction between Congruence x Anteriority x Laterality was observed (*F*(4,144) = 3.49, *p* = .01). A post-hoc analysis revealed a broadly distributed negativity pattern that was more robust on the left side of the scalp and in central areas (left-anterior: *t*(37) = 4.74, *p* < .001; medial-anterior: *t*(37) = 2.96, *p* = .005; right-anterior: *t*(37) = 4.59, *p* < .001; left-central: *t*(37) = 5.31, *p* < .001; medial-central: *t*(37) = 4.04, *p* < .001; right-central: *t*(37) = 4.64, *p* < .001; left-posterior: *t*(37) = 4.58, *p* < .001; medial-posterior: *t*(37) = 3.50, *p* = .001; right-posterior: *t*(37) = 3.70, *p* = .001). There were no Group x Congruence interactions.

600-800 ms time-window

In this time-window, a between-group analysis revealed a main effect of Group (*F*(1,36) = 7.05, *p* = .01) and a marginally significant main effect of Congruence (*F*(1,36) = 3.41, *p* = .07). Significant interactions between Congruence and Anteriority (*F*(2,72) = 7.95, *p* = .004) and Congruence and Laterality (*F*(2,72) = 8.01, *p* < .001), showed that for both groups the effect of Congruence was broadly distributed on the scalp and more robust in central-posterior regions (anterior: *t*(37) = -2.72, *p* = .009; central: *t*(37) = -4.64, *p* < .001; posterior: *t*(37) = -6.05, *p* < .001) and in medial regions (left: *t*(37) = -4.60, *p* < .001; medial: *t*(37) = -5.16, *p* < .001; right: *t*(37) = -4.06, *p* < .001).

Although a significant effect was observed for both groups, there were also significant group differences in relation to the Congruence and Topographic factors.

Specifically, a significant interaction between Group and Congruence ($F(1,36) = 5.88$, $p = .02$) was found and a post-hoc analysis showed that the effect in this time-window was only marginal for the hearing group ($t(18) = -1.73$, $p = .09$), but very robust for the deaf ($t(18) = -5.65$, $p < .001$), and that the deaf group elicited a greater positive response to the incongruent sentences in comparison to the hearing group ($t(35.55) = -2.92$, $p = .01$). Furthermore, a three-way interaction between Group x Congruence x Laterality ($F(2,72) = 4.79$, $p = .01$) and a four-way interaction Group x Congruence x Anteriority x Laterality ($F(4,144) = 3.00$, $p = .03$) also yielded significant effects. A within-group analysis[19] was carried out for each group to check for these group differences between Congruence and Topographic factors.

Within-group analysis: hearing group

For the hearing group, a marginal main effect of Congruence was observed ($F(1,18) = 3.02$, $p = .09$) as well as an interaction between Congruence and Anteriority ($F(2,36) = 12.02$, $p < .001$) and Congruence and Laterality ($F(2,36) = 6.98$, $p = .004$). Post hoc analysis of these interactions showed only a marginally significant effect in posterior areas (anterior: $t(18) = -0.77$, $p = .44$; central: $t(18) = -1.61$, $p = .24$; posterior: $t(18) = -2.54$, $p = .06$), and no significant effect on left, medial or right areas of the scalp (left: $t(18) = -1.96$, $p = .13$; medial: $t(18) = -2.14$, $p = .13$; right: $t(18) = -0.96$, $p = .34$).

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[19] A 2 x 3 x 3 ANOVA was conducted for the within-group analysis considering the following factors: Congruence (congruent vs. incongruent) x Anteriority (anterior, central, posterior) x Laterality (left, medial, right).

Within-group analysis: deaf group

In contrast, for the deaf group, the within-group analysis yielded a robust main effect of Congruence (*F*(1,18) = 32.01, *p* < .001). We also observed an interaction between Congruence and Anteriority (*F*(2,36) = 17.13, *p* < .001) and Congruence and Laterality (*F*(2,72) = 20.59, *p* < .001) as well as a triple interaction between Congruence x Anteriority x Laterality (*F*(4,72) = 6.49, *p* < .001). A post-hoc analysis showed that the effect of Congruence was broadly distributed over the scalp, although more robust in central and posterior areas (left-anterior: *t*(18) = -2.60, *p* = .01; medial-anterior: *t*(18) = -3.07, *p* = .01; right-anterior: *t*(18) = -3.42, *p* = .008; left-central: *t*(18) = -5.01, *p* < .001; medial-central: *t*(18) = -5.57, *p* < .001; right-central: *t*(18) = -5.99, *p* < .001; left-posterior: *t*(18) = -6.05, *p* < .001; medial-posterior: *t*(18) = -7.48, *p* < .001; right-posterior: *t*(18) = -6.79, *p* < .001).

800-1000 ms time-window

Within this time-window, a between-group analysis revealed a significant main effect of Group (*F*(1,36) = 8.23, *p* = .006) and Congruence (*F*(1,36) = 7.81, *p* = .008). Moreover, an interaction between Congruence and Anteriority (*F*(2,72) = 21.52, *p* < .001) and Congruence and Laterality (*F*(2,72) = 13.82, *p* < .001) yielded significant effects, showing that for both groups there were significant differences between congruent and incongruent sentences (i.e. P600 effect) only in central and posterior areas (anterior: *t*(37) = -0.76, *p* = .45; central: *t*(37) = -4.27, *p* < .001; posterior: *t*(37) = -7.27, *p* < .001) and more robust effects in medial areas (left: *t*(37) = -3.49, *p* = .001; medial: *t*(37) = -4.75, *p* < .001; right: *t*(37) = -3.78, *p* = .001).

Number condition: summary of the effects

Both groups showed a similar response to number violated sentences. In the 350-500 ms time-window, a negativity with a broad distribution, although with a more robust effect in left and central areas, was observed. Violations also elicited a P600 (i.e. P600a and P600b) effect for both groups. However, this effect differed slightly in its initial stages (i.e. P600a): hearing showed a weaker P600 onset with a tendency to be left lateralized; deaf showed a strong broad effect with slight right lateralization.

4.3.3.3 Gender Transparent condition

Visual inspection of ERP waveforms for the Gender Transparent condition revealed differences between congruent and incongruent sentences in both groups. ERPs for this condition are shown in Figure 4.8. Topographical maps of this condition are shown in Figure 4.9. Specifically, for both groups we observe a greater negativity for the incongruent condition peaking between 400ms and 500ms. This negativity was followed by a positive deflection that was strongest in posterior sites for both groups. Statistical results are presented for each of the selected time-windows.

350-500 ms time-window

A between-group analysis revealed that in this time-window only main effects of Group (*F*(1,36) = 5.89, *p* = .02) and Congruence (*F*(1,36) = 6.39, *p* = .01). No interactions or groups differences between experimental factor (i.e. Congruence) and topographical factors (i.e. Anteriority or Laterality) were observed. However, despite the absence of this significant interaction, visual inspection clearly shows that effects for hearing and deaf readers are quite different in this time-window (see figures 4.8 and 4.9). Therefore, to better characterize the data, we opted to carry out separate analyses for hearing and deaf readers (Gillon Dowens et al., 2010).

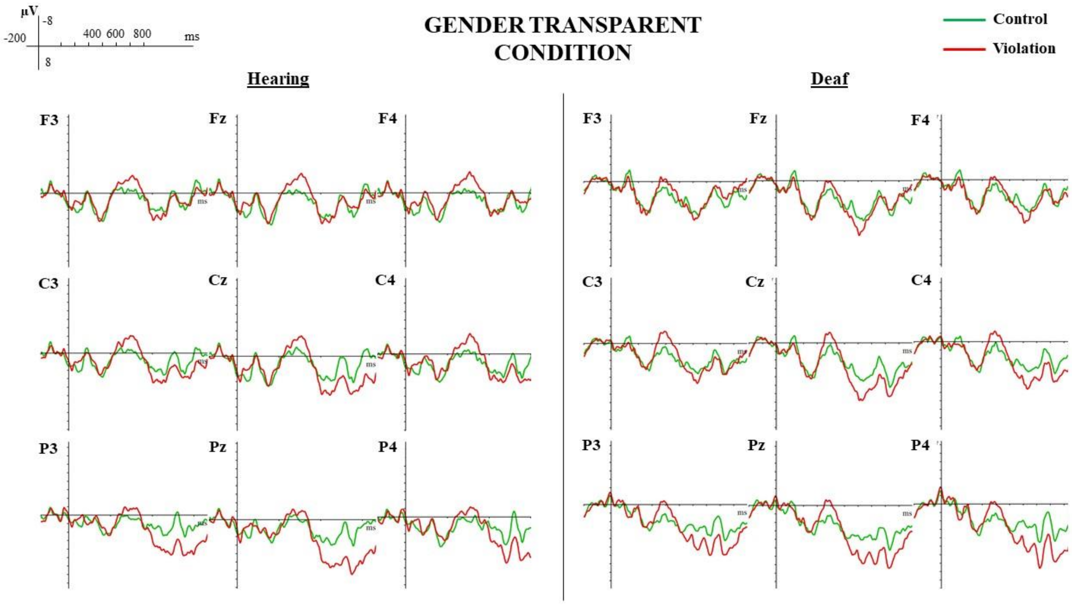

Figure 4.8. ERPs in response to the congruence manipulation in the Gender Transparent condition for the hearing and deaf group.

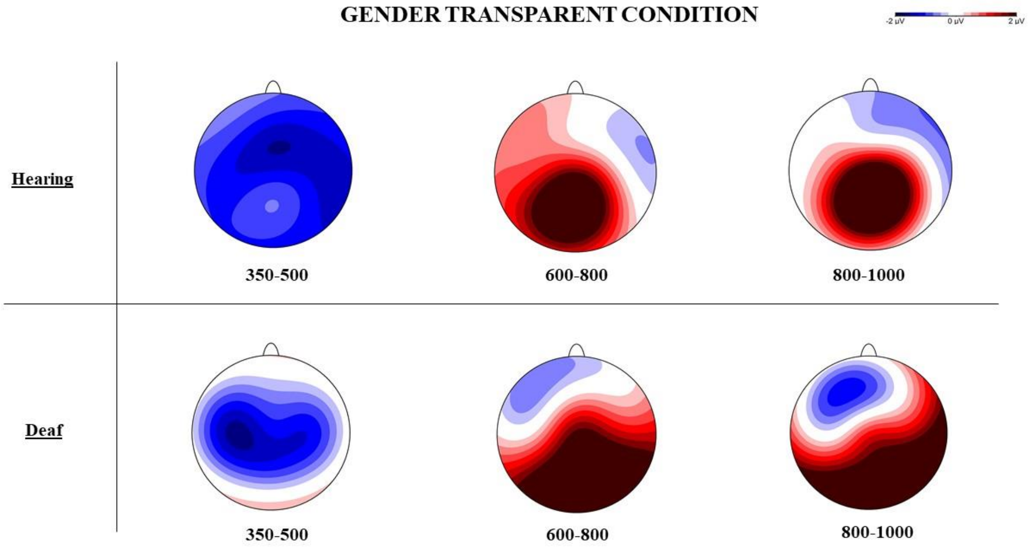

Figure 4.9. Topographic distributions of average potentials for the hearing and deaf group in the Gender Transparent condition.

Within-group analysis: hearing group

A within-group ANOVA for the hearing group revealed a significant main effect of Congruence (*F*(1,18) = 4.95, *p* = .03) and a marginal interaction between Congruence and Anteriority (*F*(2,36) = 3.10, *p* = .07). Post-hoc analysis showed that there was a significant negativity only in anterior areas although a marginal effect in central areas was also present (anterior: *t*(18) = 2.84, *p* = .03; central: *t*(18) = 2.28, *p* = .06; posterior: *t*(18) = 1.40, *p* = .17). These results indicate the presence of an anterior negativity for the hearing group.

Within-group analysis: deaf group

For the deaf group, a within-group analysis revealed a significant main effect of Congruence (*F*(1,18) = 5.49, *p* = .03) and a three-way interaction between Congruence x Anteriority x Laterality (*F*(4,72) = 4.63, *p* = .007). Post-hoc analysis showed that there was a significant effect of Congruence for the deaf group only in central and posterior areas of the scalp (left-anterior: *t*(18) = 2.01, *p* = .17; medial-anterior: *t*(18) = 0.70, *p* = .49; right-anterior: *t*(18) = 1.54, *p* = .28; left-central: *t*(18) = 3.20, *p* = .01; medial-central: *t*(18) = 2.02, *p* = .05; right-central: *t*(18) = 2.53, *p* = .04; left-posterior: *t*(18) = 2.48, *p* = .02; medial-posterior: *t*(18) = 2.67, *p* = .02; right-posterior: *t*(18) = 2.35, *p* = .02), indicating that this negativity has a topography similar to that of the classical N400 effect as opposed to the LAN effect.

600-800 ms time-window

In this time-window, a between-group analysis revealed a main effect of Congruence (*F*(1,36) = 5.74, *p* = .02) and no main effect of Group (*F*(1,36) = 1.80, *p* = .18). This epoch also yielded a robust interaction between Congruence and Anteriority (*F*(2,72) = 13.07, *p* < .001) as well as a marginal interaction between Congruence and Laterality (*F*(2,72) = 2.91, *p* = .06), showing that for both groups the effect was distributed across central and posterior areas but more robust in posterior areas (anterior: *t*(37) = -0.76, *p* = .44; central: *t*(37) = -3.27, *p* = .004; posterior: *t*(37) = -6.18, *p* < .001) and broadly distributed laterally (left: *t*(37) = -3.39, *p* = .001; medial: *t*(37) = -3.53, *p* = .001; right: *t*(37) = -3.55, *p* = .001). Moreover, a marginal group difference between Group x Congruence x Laterality (*F*(2,72) = 2.78, *p* = .06) was also observed, revealing an effect that was more left-lateralized for the hearing (left: *t*(18) = -2.76, *p* = .02; medial: *t*(18) = -2.61, *p* = .03; right: *t*(34.89) = -1.82, *p* = .08) and more right-lateralized for the deaf (left: *t*(18) = -2.00, *p* = .05; medial: *t*(18) = -2.34, *p* = .03; right: *t*(34.89) = -3.17, *p* = .01).

800-1000 ms time-window

In this later time-window, a between-group analysis revealed a marginal main effect of Group (*F*(1,36) = 3.40, *p* = .07) and a main effect of Congruence (*F*(1,36) = 9.40, *p* = .004). Significant interactions between experimental factors and topographical factors were also observed. Specifically, an interaction between Congruence and Anteriority (*F*(2,72) = 20.84, *p* < .001), Congruence and Laterality (*F*(2,72) = 5.99, *p* = .004) as well as a three-way interaction between Congruence x Anteriority x Laterality (*F*(4,144) = 2.76, *p* = .04) were found. Post-hoc analysis showed that the effect was distributed across posterior areas and also took in right central areas (left-anterior: *t*(37) = 1.58, *p* = .36; medial-anterior: *t*(37) = -0.26, *p* = .82 right-anterior-: *t*(37) = -0.21, *p* = .82; left-central: *t*(37) = -1.76, *p* = .08; medial-central: *t*(37) = -2.38, *p* = .04; right-central-: *t*(37) = -4.80, *p* < .001; left-posterior: *t*(37) = -5.33, *p* < .001; medial-posterior: *t*(37) = -5.16, *p* < .001; right-posterior: *t*(37) = -6.64, *p* < .001).

Additionally, similar to the previous time-window, this epoch yielded a significant group difference between Group x Congruence x Laterality (*F*(2,72) = 4.76, *p* = .01), showing that for the hearing the effect was broadly distributed laterally (left: *t*(18) = -2.46, *p* = .04; medial: *t*(18) = -3.46, *p* = .005; right: *t*(18) = -4.07, *p* = .001) in comparison to the deaf, who showed an effect only on the right side of the scalp (left: *t*(18) = -0.79, *p* = .43; medial: *t*(18) = -1.08, *p* = .29; right: *t*(18) = -2.81, *p* = .01).

Gender Transparent condition: summary of the effects

In this condition, both groups showed a general negativity but with different topographies: the hearing group elicited an anterior negativity (AN) and the deaf group showed a central-posterior negativity that resembled a N400 effect. Moreover, a similar central-posterior P600a effect was found for both groups, although the hearing presented a more left-lateralized effect, and deaf a right-lateralized P600. Similarly, there was a central-posterior P600b for both groups, with a more right lateralized effect for the deaf.

4.3.3.4 Gender Opaque condition

Visual inspection of ERP waveforms for the Gender Opaque condition revealed differences between congruent and incongruent sentences in both groups. ERPs for this condition are shown in Figure 4.10. Specifically, for both groups we observe a greater negativity for the incongruent condition peaking around 400ms. This negativity was followed by a posterior positivity that started 600ms after the stimulus onset but differed between groups in magnitude and distribution: the hearing group showed a strong effect in central-posterior electrodes while the deaf group had a subtle effect in the medial and right side of posterior electrodes. Topographical maps are presented in Figure 4.11. Statistical results are presented for each of the selected time-windows.

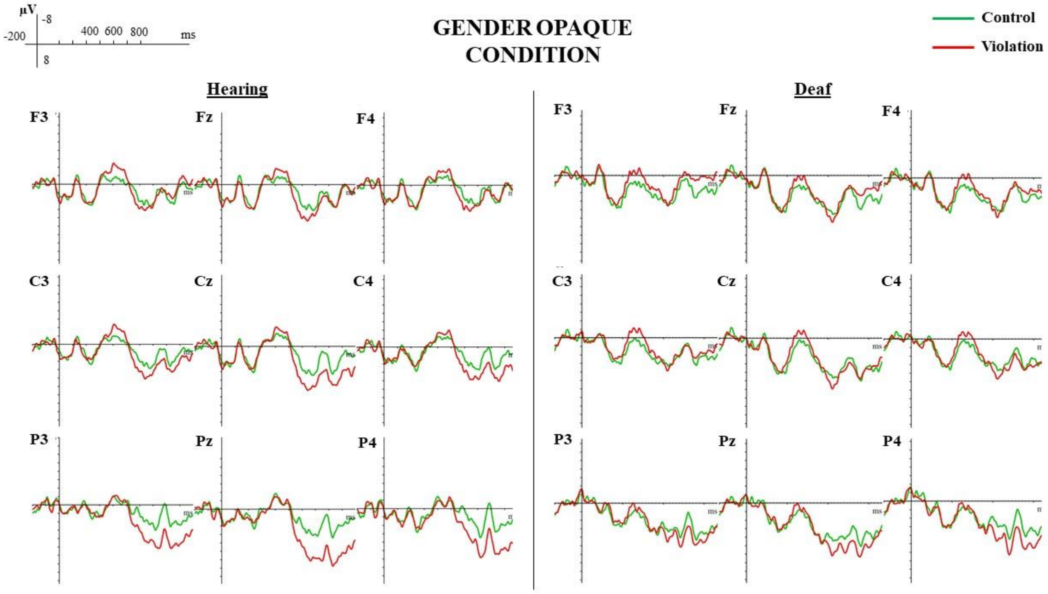

Figure 4.10. ERPs in response to the congruence manipulation in the Gender Opaque condition for the hearing and deaf group.

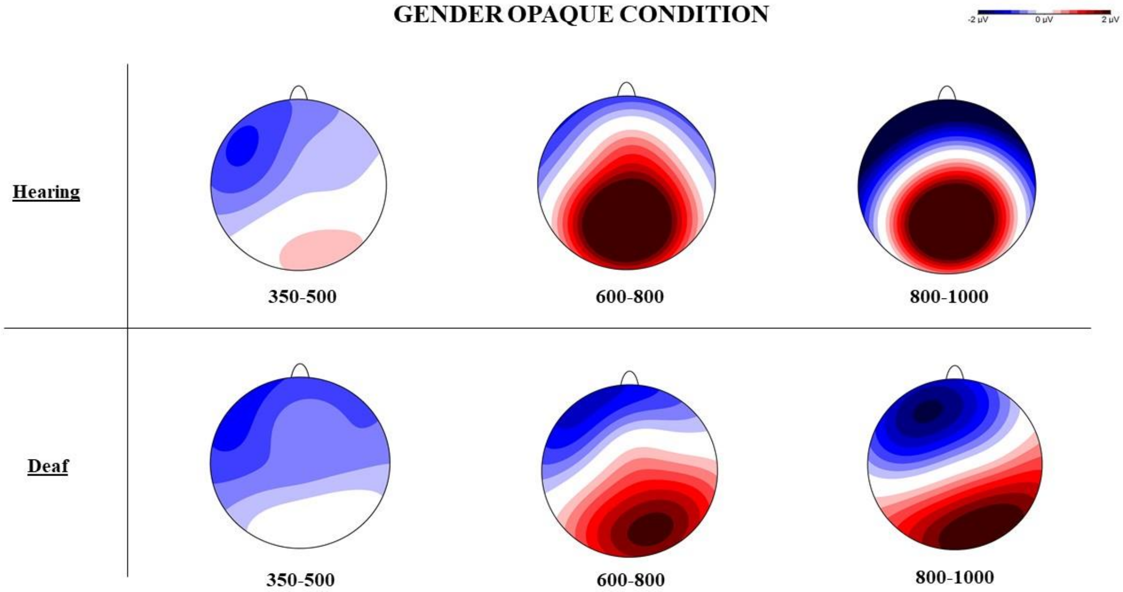

Figure 4.11. Topographic distributions of average potentials for the hearing and deaf group in the Gender Opaque condition.

350-500 ms time-window

In this time-window, a between-group analysis revealed a main effect of Group (*F*(1,36) = 7.29, *p* = .01), but no main effect of Congruence (*F*(1,36) = 2.28, *p* = .13). An interaction between Congruence x Anteriority (*F*(2,72) = 3.81, *p* = .04) and Congruence x Laterality (*F*(2,72) = 3.23, *p* = .04) was observed. Post-hoc analysis of these interactions revealed a significant effect localized in anterior and central areas (anterior: *t*(37) = 2.78, *p* = .02; central: *t*(37) = 2.56, *p* = .02; posterior: *t*(37) = 1.22, *p* = .22) and on the left side of the scalp (left: *t*(37) = 3.71, *p* = .002; medial: *t*(37) = 2.20, *p* = .06; right: *t*(37) = 1.45, *p* = .15), suggesting the presence of a central-anterior negativity.

600-800 ms time-window

In this time-window, a between-group analysis revealed a main effect of Congruence (*F*(1,36) = 5.67, *p* = .02) and no main effect of Group (*F*(1,36) = 0.11, *p* = .73). Furthermore, this epoch yielded a robust interaction between Congruence and Anteriority (*F*(2,72) = 15.88, *p* < .001) as well as a marginal three-way interaction between Congruence x Anteriority x Laterality (*F*(4,144) = 2.31, *p* = .09), showing that for both groups there was an effect on the right side of central areas and distributed across posterior areas (left-anterior: *t*(37) = 0.40, *p* = .68; medial-anterior: *t*(37) = -0.50, *p* = .68; right-anterior: *t*(37) = -0.83, *p* = .68; left-central: *t*(37) = -1.74, *p* = .13; medial-central: *t*(37) = -1.54, *p* = .13; right-central: *t*(37) = -2.89, *p* = .01; left-posterior: *t*(37) = -4.05, *p* < .001; medial-posterior: *t*(37) = -3.63, *p* < .001; right-posterior: *t*(37) = -4.28, *p* < .001).

800-1000 ms time-window

A between-group analysis revealed no significant main effects within this later time-window. However, a robust interaction between Congruence and Anteriority ($F(2,72) = 22.21$, $p < .001$) and a three-way interaction between Congruence x Anteriority x Laterality ($F(4,144) = 3.57$, $p = .02$) were found. Post-hoc analysis showed an effect that was stronger in posterior areas and more robust on the right side of the scalp (left-anterior: $t(37) = 1.98$, $p = .16$; medial-anterior: $t(37) = 0.74$, $p = .70$; right-anterior: $t(37) = 0.38$, $p = .70$; left-central: $t(37) = -0.46$, $p = .87$; medial-central: $t(37) = -0.16$, $p = .87$; right-central: $t(37) = -2.44$, $p = .05$; left-posterior: $t(37) = -2.79$, $p = .01$; medial-posterior: $t(37) = -2.61$, $p = .01$; right-posterior: $t(37) = -3.73$, $p = .001$).

Gender Opaque condition: summary of the effects

Both groups showed a similar biphasic pattern LAN/P600 effect for gender opaque violations. The LAN effect was observed on the left side of central-anterior areas. A P600a was also elicited for this type of disagreement and the effect was localized in central-posterior areas. The P600b showed the same bilateral posterior pattern, although slightly more robust on the right side of the scalp.

4.3.3.5 Summary of the ERP results

Table 4.5 presents a summary of the ERP results for the all four conditions of the experiment.

Table 4.5. Summary of the ERP results for the four conditions.

Condition	Hearing	Deaf
Semantic	N400 + P600ab	N400 + P600ab
Number	N400-like + P600ab	N400-like + P600ab
Gender Transparent	(L)AN + P600ab	N400-like + P600ab
Gender Opaque	LAN + P600ab	LAN + P600ab

4.3.4 Post-EEG task

As detailed in chapter 3, after the EEG session participants performed a lexical decision task (LD) and a gender identification task on a selection of the nouns in the stimuli material to check their knowledge of the vocabulary used in the experiment (for more information on the materials see section 3.2).

Results

The two groups performed similarly on both tasks, as can be seen from the plots in figures 4.12 and 4.13. There was no difference between the groups in the accuracy scores for either the LD task (Maximum possible score = 260; Hearing: M = 241.52, SD = 13.42; Deaf: M = 243.05, SD = 9.42; $t(36) = 0.40$, $p = .68$) or the gender identification task (Maximum possible score = 80; Hearing: M = 76.10, SD = 6.80; Deaf: M = 77.21, SD = 2.14; $t(36) = 0.67$, $p = .50$). Although there were two outliers in the hearing group (one in the LD task, and another in the gender identification task – see Figures 4.12 and 4.13, respectively), analysis without these participants did not change the overall results, so we decided to maintain them. Moreover, d-scores obtained from the acceptability judgment task for both subjects were very similar to the average of group response. Generally, results from the two post-EEG task confirm that both groups were familiar with the words presented in the main experiment and were able to detect incongruences in the sentences due to semantic or gender anomalies.

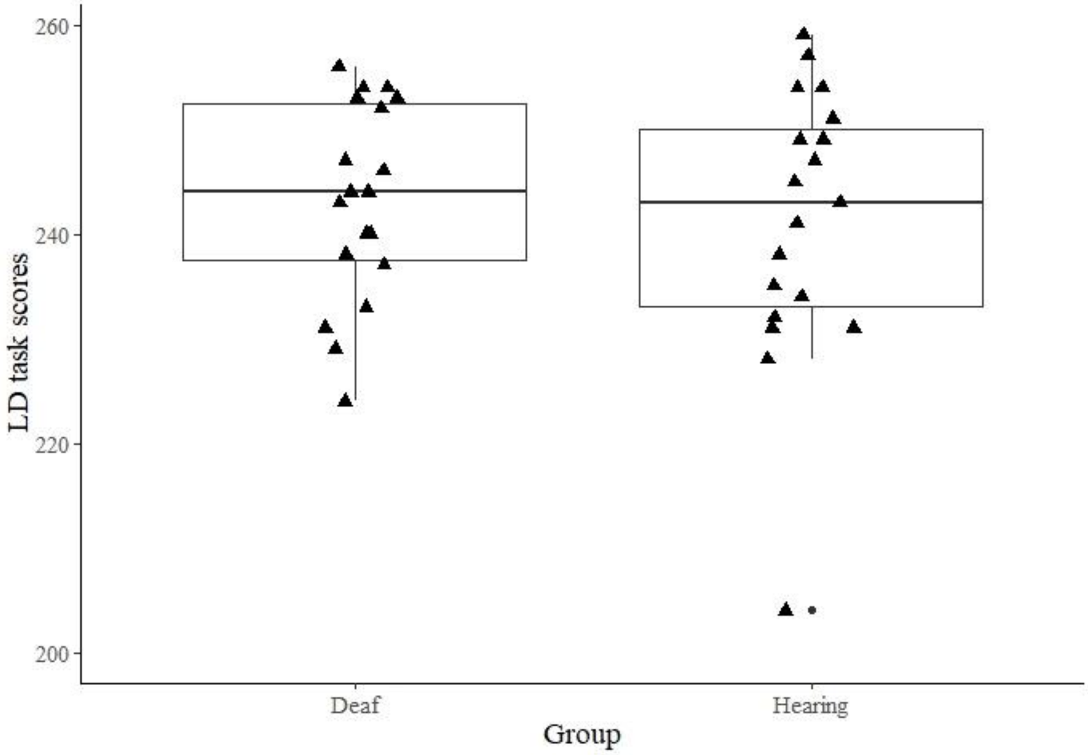

Figure 4.12. Distribution of lexical decision (LD) task scores for deaf and hearing participants. There was no significant difference between hearing and deaf participants' performance. Outlier is represented by the black dot.

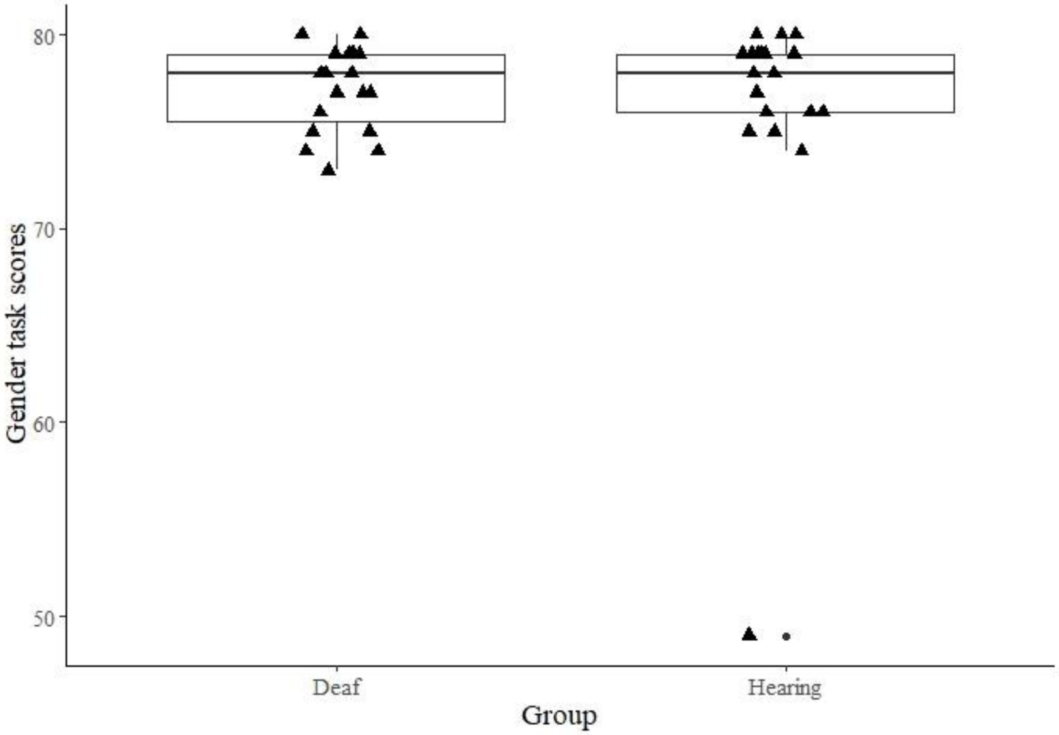

Figure 4.13. Distribution of gender identification task scores for deaf and hearing participants. There was no significant difference between hearing and deaf participants' performance. Outlier is represented by the black dot.

4.3.5 Individual differences analysis

4.3.5.1 Correlations between different ERP effects

Previous studies have suggested that a biphasic N400-P600 pattern of ERP responses may be a reflection of individual differences (Tanner et al., 2014, 2013; Tanner & Van Hell, 2014). Although results of the ERP grand average at the group level may show a biphasic pattern, inspection at the individual level can show a mixed pattern with some subjects presenting only a N400 effect, others presenting only a P600, and a few with both effects. In the present data, visual inspection of individual waveforms in the four experimental conditions showed that the biphasic N400/LAN-P600 was, in fact, not observed for all participants' ERP responses. Therefore, in order to identify the relationship between these ERP effects a further investigation of individuals' brain responses was conducted replicating the methods used in previous studies (following (Tanner et al., 2014; Tanner & Van Hell, 2014).

The mean effect size for congruency was calculated in two regions of interest (ROIs) for each individual. The regions were a central parietal ROI (C3, Cz, C3, CP1, CP2, P3, Pz, P4), where N400 and P600 effects are typically stronger, and a frontal central ROI[20] (F3, Fz, F4, FC1, FC2, C3, Cz, C3) where the LAN/AN effects are usually located. Within these ROIs, we calculated each individual's LAN/N400 effect magnitude (grammatical minus ungrammatical condition in the 350–500ms time-window) and P600 effect magnitude (ungrammatical minus grammatical condition in the 600–1000ms time-window) separately. A correlation analysis between the magnitude of the ERP effects (i.e., N400-P600 and LAN-P600, as appropriate) was run for each condition in both groups.

Since the sample size used in the present study was not very large, conducting correlation analyses can be problematic because data points with extreme values may introduce a false sense of relationship (Goodwin & Leech, 2006; Schönbrodt & Perugini, 2013). It is not a common practice to clean for outliers when analyzing individual differences in ERPs (e.g. Tanner et al., 2014, 2013; Tanner & Van Hell, 2014); extreme mean amplitude values elicited by a given participant may just be unlikely but still valid data (B. H. Cohen, 2001). However, to give a sense of how robust any significant correlations are, we ran an additional correlation analysis after removing outliers (2.5

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[20] Although previous studies running an individual analyses took into account electrodes only from central and posterior areas, I also looked at central-anterior electrodes, since for the Gender Transparent condition there was evidence of a LAN-like effect for the hearing group, and in the Gender Opaque condition there was evidence of a LAN effect for both hearing and deaf groups.

standard deviations from the mean).[21] Additionally, to overcome the issue of reduced power due to the sample size, we also performed a correlation analysis on the combined group (hearing and deaf together) to ascertain whether an effect emerges with a larger sample size. Again, when a significant effect appeared, we checked whether outliers were driving the effect in the combined group (also 2.5 standard deviations from the mean).

Semantic condition: N400 ~ P600

For the hearing group, no significant correlation between the N400 and P600 effects was found[22]. In contrast, for the deaf group, a significant negative correlation between the N400 and the P600 effect was observed ($r(17) = -.54$, $p = .01$). A correlation analysis without outliers (2.5 SDs from the mean: 2 outliers were removed) revealed a very similar pattern with a significant negative correlation ($r(15) = -.55$, $p = .02$). Figure 4.14 illustrate this correlation (with and without outliers) for the deaf group. The analysis on the combined group failed to reveal a significant correlation.

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[21] To make sure that outliers were not masking correlations, for those cases where no significant correlation was found we also ran the analysis without outliers. In no instance did a significant correlation appear.

[22] Since the hearing group showed a more robust N400 effect in the Semantic condition in a slightly later time-window (i.e. 400-550ms; see section 4.2.3), we ran a correlation analysis in this epoch but found no significant correlation.

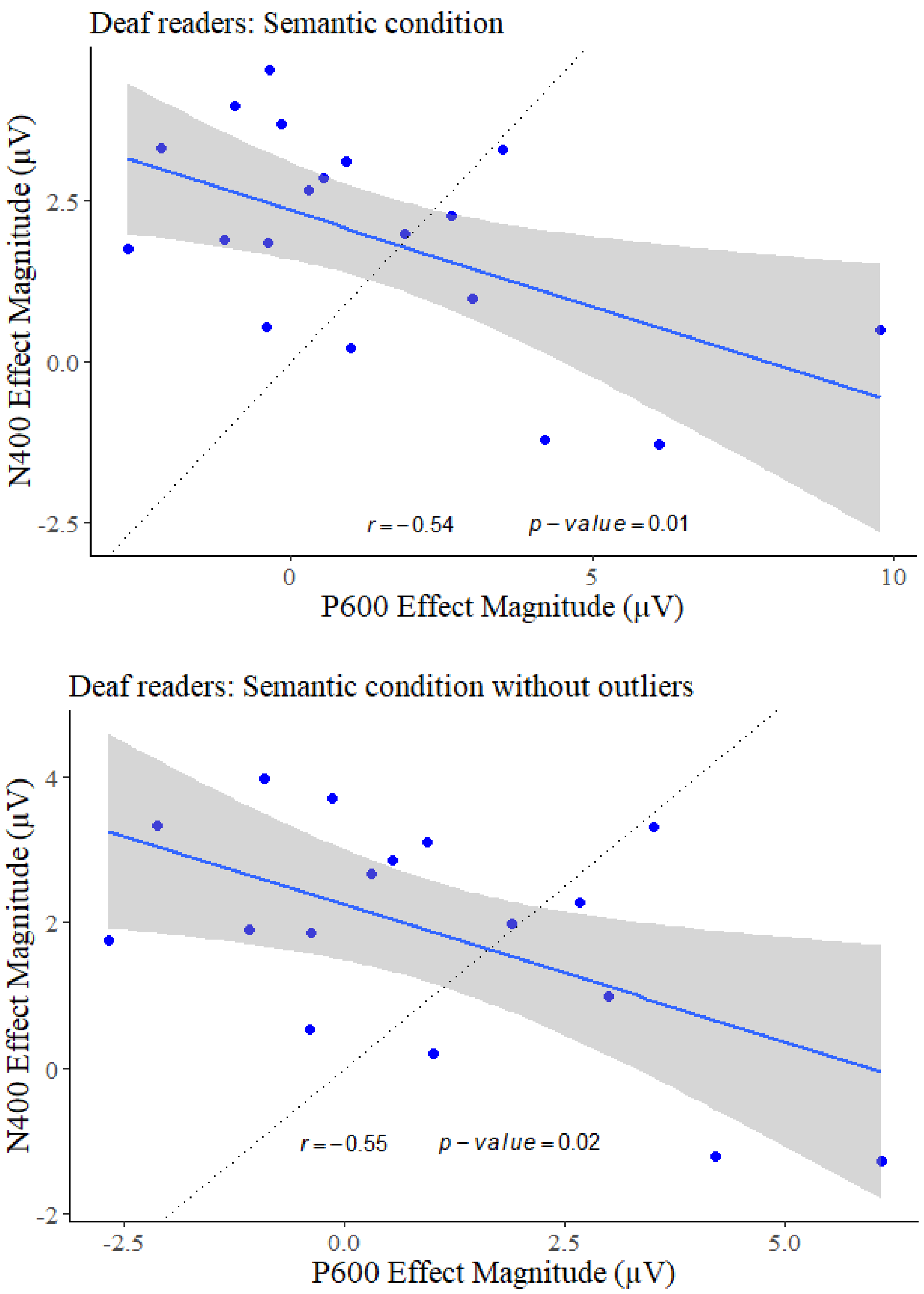

Figure 4.14. Scatterplots showing the relationship between N400 and P600 effect magnitudes for the deaf group in the Semantic condition with outliers (top) and without outliers (bottom), averaged within a central-parietal ROI (C3, Cz, C4, CP1, CP2, P3, Pz, P4). The solid line indicates the best-fit line from the correlation analysis for this condition. The dashed lines represent equal N400 and P600 effect magnitudes (i.e. a perfect positive correlation): individuals above/to the left of the dashed line showed primarily an N400 effect to violations, while individuals below/to the right of the dashed line showed primarily a P600 effect.

Number condition: N400 ~ P600

For the Number condition, the hearing group showed a negative correlation between the N400 and P600 effect that was marginal in significance (but did not become significant on removing outliers). In the deaf group, these two ERP effects also showed trend to a negative correlation, but this relationship was very weak and did not reach significance. The combined-group analysis is marginally significant ($r(36) = -.31$, $p = .05$), but when outliers are removed (2.5 SDs from the mean: 5 outliers were removed) this relationship became clearly significant ($r(31) = -.40$, $p = .01$). Thus, there appears to be a sturdy negative correlation between N400 and P600 effect size in this condition.

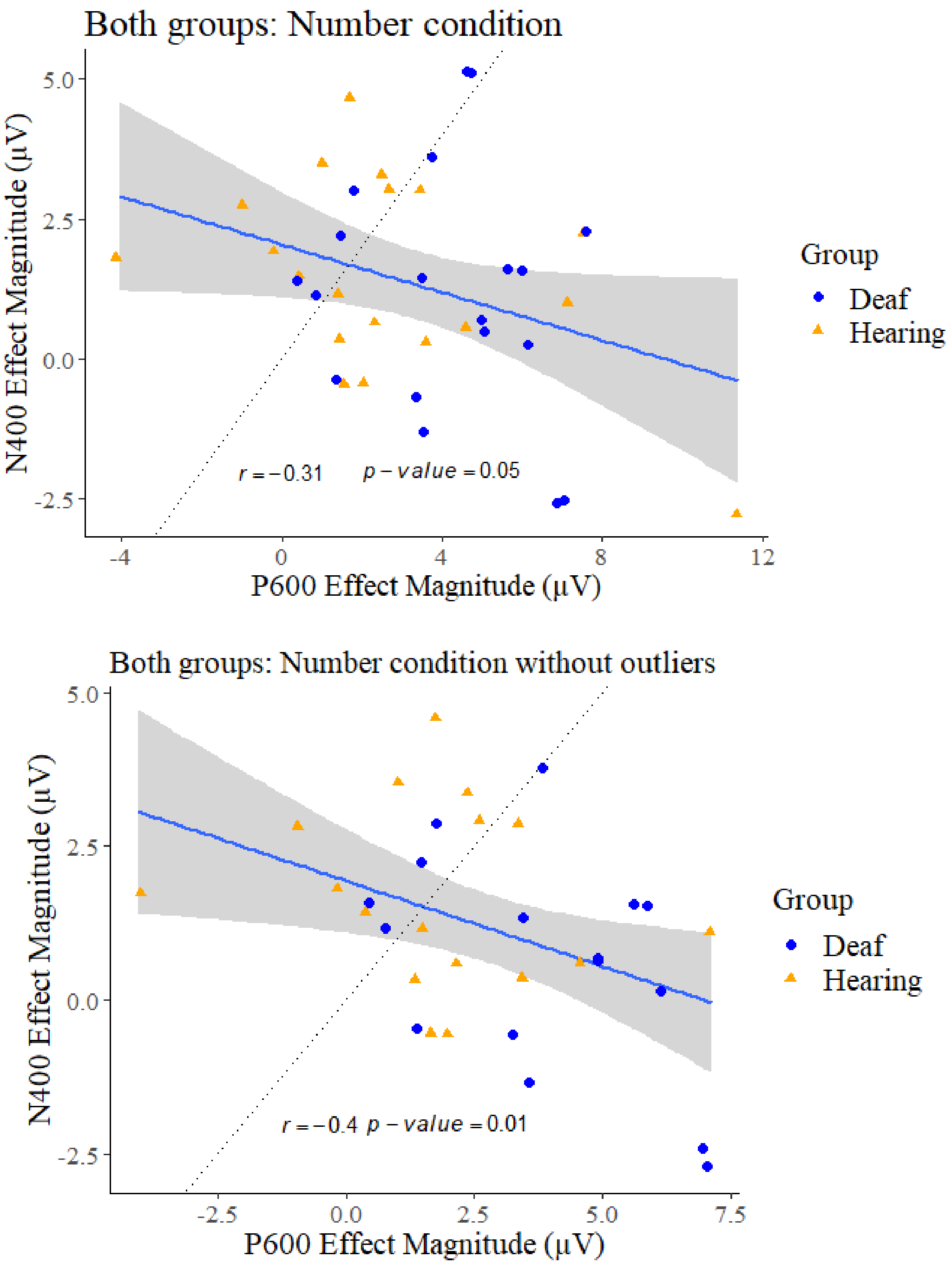

Figure 4.15. Scatterplots showing the relationship between N400 and P600 effect magnitudes in both groups for the Number condition with all data points (top) and without outliers (bottom), averaged within a central-parietal ROI (C3, Cz, C4, CP1, CP2, P3, Pz, P4). The solid line indicates the best-fit line from the correlation analysis for this condition. The dashed lines represent equal N400 and P600 effect magnitudes (i.e. a perfect positive correlation): individuals above/to the left of the dashed line showed primarily an N400 effect to violations, while individuals below/to the right of the dashed line showed primarily a P600 effect.

Gender Transparent: N400 ~ P600

In this condition, using a central-posterior ROI (C3, Cz, C4, CP1, CP2, P3, Pz, P4) to measure the magnitude of the N400 and P600 effects, the hearing group showed a strong negative correlation between the N400-like and the P600 effect ($r(17) = -.70$, $p < .001$), but this effect disappears when outliers are removed (2.5 SDs from the mean: 3 outliers were removed). These correlations can be seen in Figure 4.16. For the deaf group, the correlation between ERP effects in this condition did not reach significance. The combined-group analysis is also significant ($r(36) = -.47$, $p = .002$), but again the effect disappears when outliers are removed (2.5 SDs from the mean: 4 outliers were removed). Figure 4.17 illustrates these correlations for the combined analysis. As such, there is no evidence for a robust effect: a few outliers in the hearing group seem to be driving a spurious correlation.

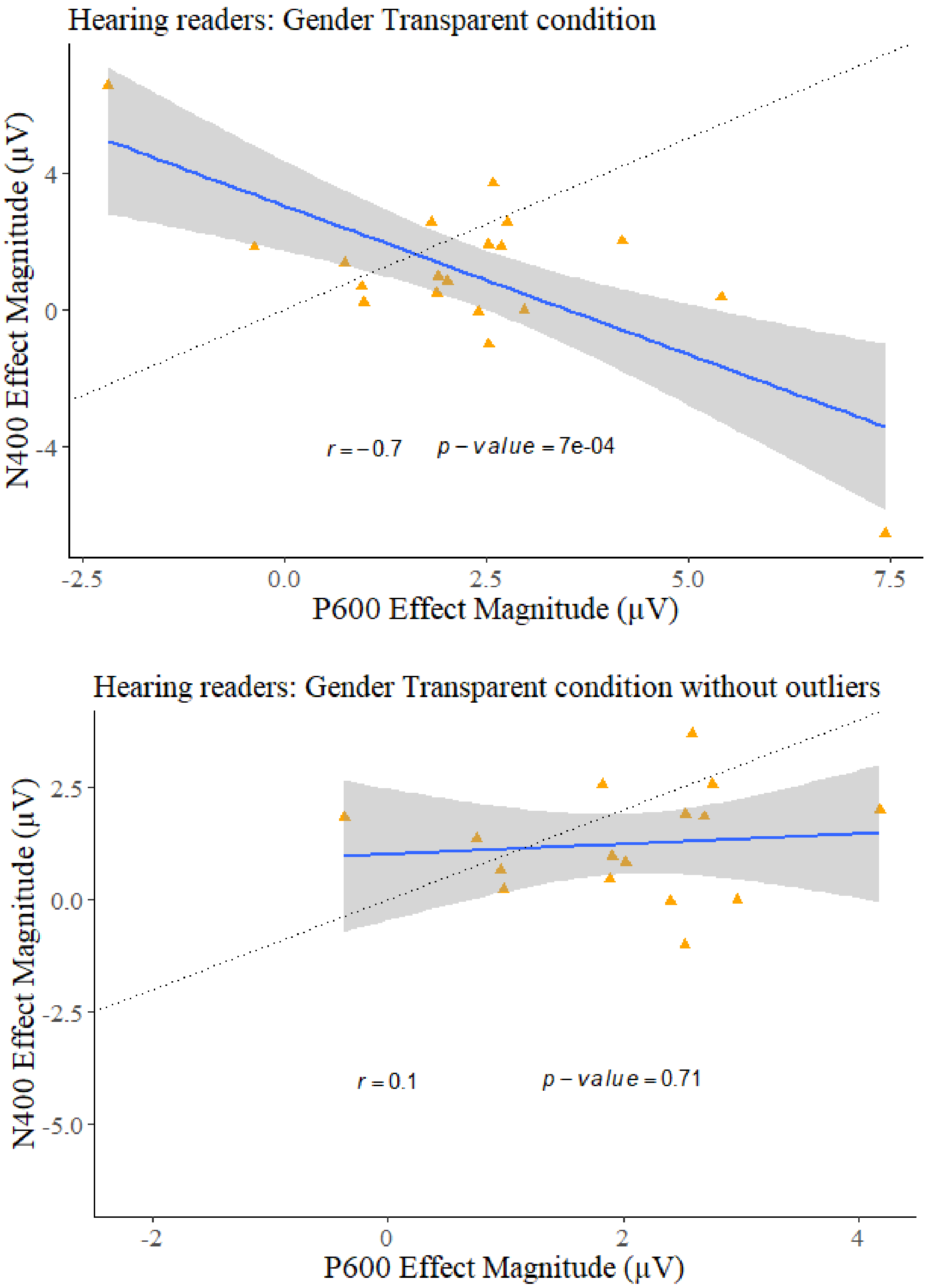

Figure 4.16. Scatterplots showing the relationship between N400 and P600 effect magnitudes in the hearing group for the Gender Transparent condition with and without outliers, averaged within a central-parietal ROI (C3, Cz, C4, CP1, CP2, P3, Pz, P4). The solid line indicates the best-fit line from the correlation analysis for this condition. The dashed lines represent equal N400 and P600 effect magnitudes: individuals below/to the right of the dashed line showed primarily a P600 effect, while individuals above/to the left of the dashed line showed mainly a N400-like effect.

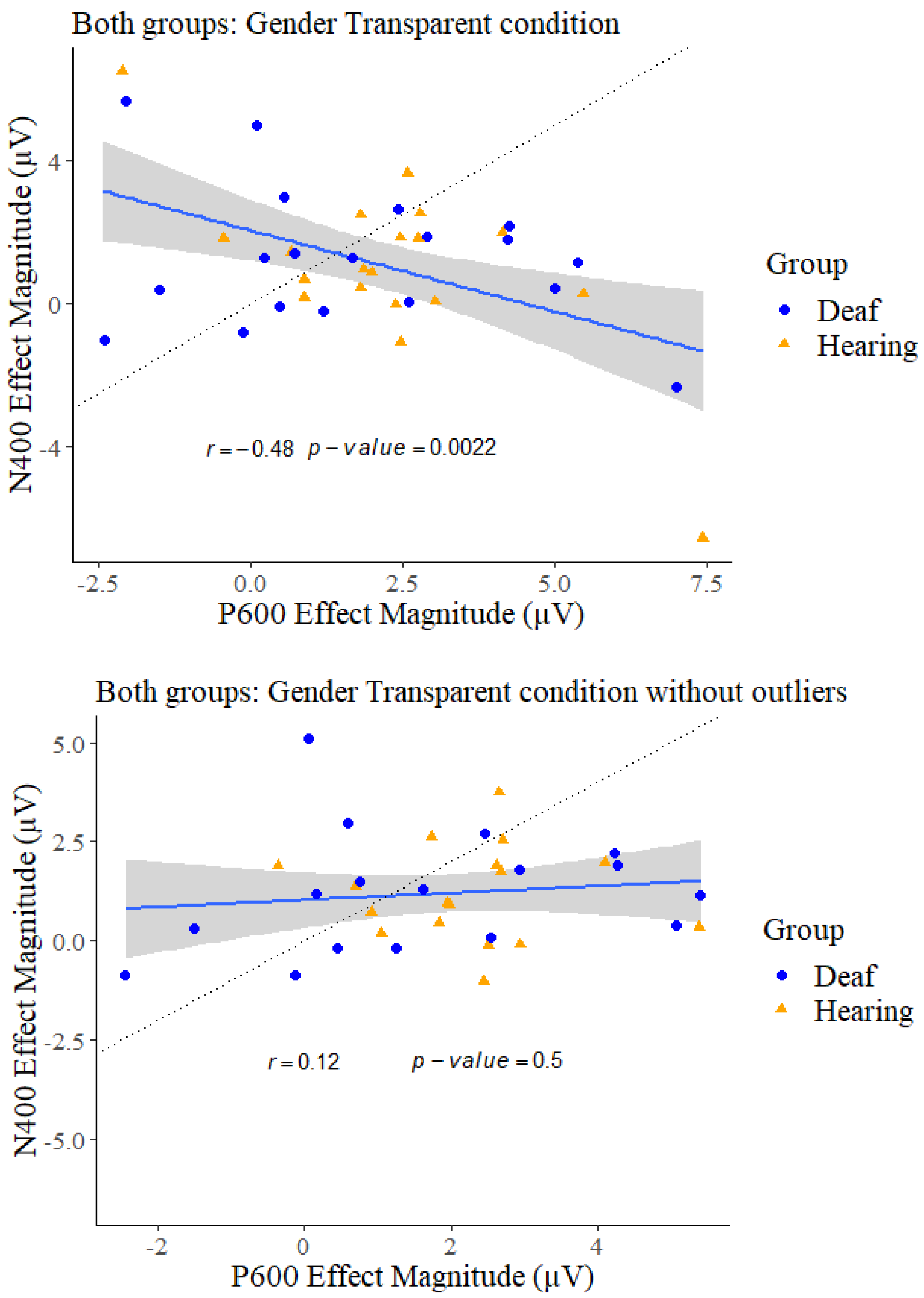

Figure 4.17. Scatterplots showing the relationship between N400 and P600 effect magnitudes for both hearing and deaf groups for the Gender Transparent condition with all data (top) and without outliers (bottom), averaged within a central-parietal ROI (C3, Cz, C4, CP1, CP2, P3, Pz, P4). The solid line indicates the best-fit line from the correlation analysis for this condition. The dashed lines represent equal N400 and P600 effect magnitudes: individuals below/to the right of the dashed line showed primarily a P600 effect, while individuals above/to the left of the dashed line showed mainly a N400-like effect.

Gender Transparent: (L)AN ~ P600 (only hearing[23])

As explained before, since the within-group analysis showed that the negativity found for the hearing group was significant only at central-anterior areas, a different correlation analysis was also running taking into account a central-anterior ROI (F3, Fz, F4, FC1, FC2, C3, Cz, C3) for the early negativity in order to verify the relationship between this AN effect and the P600 effect (maintaining the central-posterior ROI for the P600). The correlation between the AN effect and the P600 was significant and negative ($r(17) = -.69$, $p < .001$), but removing outliers made this correlation disappear (2.5 SDs from the mean: 3 outliers were removed). This correlation is shown in Figure 4.18. Therefore, there is still no evidence for a robust effect here and, again, a few outliers in the hearing group seem to be driving a spurious correlation. The lack of a negative correlation between the early negativity and the later positivity does not support Tanner's (Tanner et al., 2013, 2014) claim a given individual tends to have one response or the other and that the (L)AN appears as a result of averaging over these different types of response.

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[23] Although there was no evidence of a (L)AN effect for the deaf group I also performed a correlation analysis for this group using this central anterior ROI. The correlation was not significant but showed a negative trend between the negativity in anterior electrodes and the positivity in posterior electrodes.

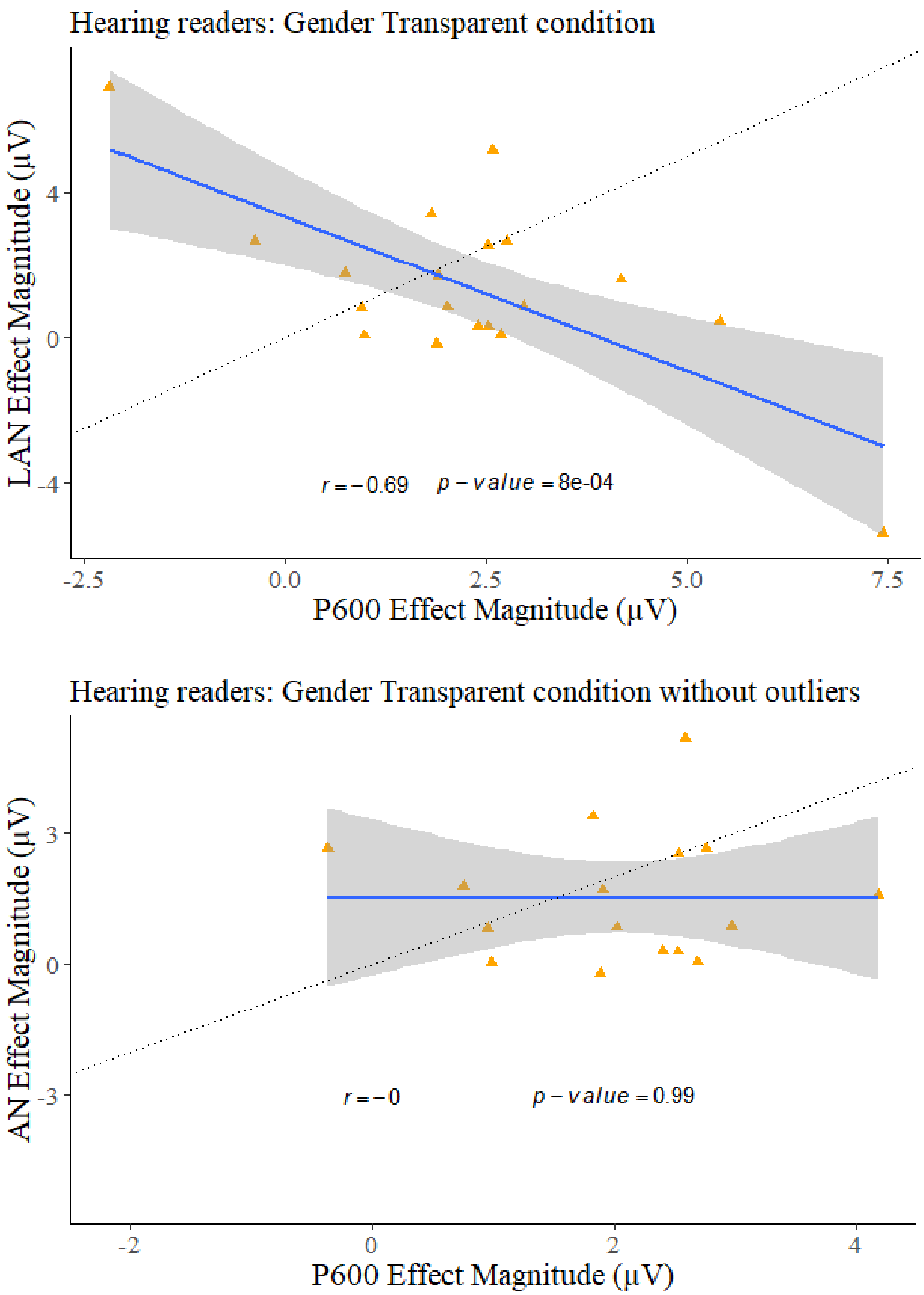


Figure 4.18. Scatterplots showing the relationship between LAN and P600 effect magnitudes in the hearing group for the Gender Transparent condition, averaged within a central-anterior ROI (F3, Fz, F4, FC1, FC2, C3, Cz, C3) with all data (top) and without outliers (bottom). The solid line indicates the best-fit line from the correlation analysis for this condition. The dashed lines represent equal LAN and P600 effect magnitudes: individuals below/to the right of the dashed line showed primarily a P600 effect, while individuals above/to the left of the dashed line showed mainly an LAN effect.

To see whether individuals did indeed present a (L)AN-like response, I conducted a visual inspection of the topographic maps in the 350-500ms time-window. Figure 4.19 shows that there was a mixed of results in this time-window: some subjects showed a negativity that was N400-like, while others exhibited a negativity that was more similar to an (L)AN effect as its scalp distribution was located in central-frontal sites (e.g. subjects 4, 5, 6, 7, and 18).

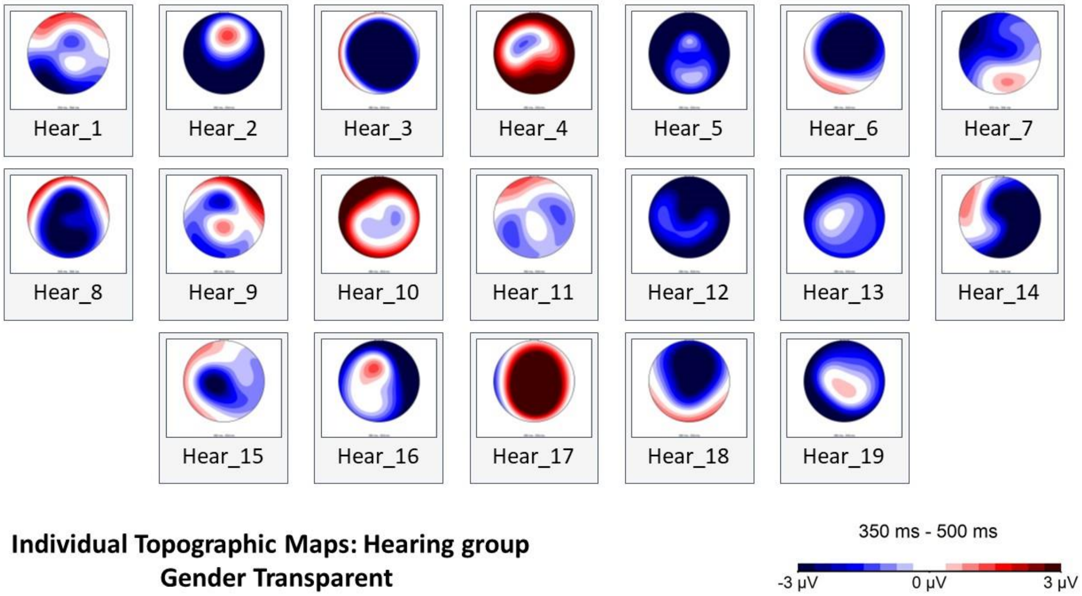


Figure 4.19. Individual topographical maps in the Gender Transparent condition for the hearing group showing that some subjects elicited a broadly distributed negativity rather than a negativity at central-anterior sites, indicating the presence of a mixed pattern of response: a N400 and a (L)AN response.

Gender Opaque: N400/LAN ~ P600

For the Gender Opaque condition, a correlation analysis in the central-posterior ROI to measure the magnitude of the N400 and P600 effects, was run even though statistical results indicated that gender opaque violations elicited a biphasic LAN-P600 pattern for both groups (what would require a central-anterior ROI for the LAN and a central-posterior ROI for the P600). However, following what previous studies have done (Tanner and Van Hell, 2014), we first considered a central-posterior ROI (for both N400 and P600) to see whether there was any evidence that the LAN observed was the result of averaging N400 and P600 responses, as proposed by Tanner and colleagues. If this is the case, we expect a negative correlation for both ROIs analysis (i.e., central-posterior and central-anterior).

The analysis using a central-posterior ROI showed a significant negative correlation for the hearing group ($r(17) = -0.60$, $p = .006$). No outliers were found for this condition. The correlation between these ERP effects for the deaf group was not statistically significant. Interestingly, the analysis using a central-anterior ROI (for the LAN) showed a different pattern of correlation. For the hearing group, a positive relation between the LAN and the P600 emerged ($r(17) = 0.57$, $p = .009$). No outliers were found using this ROI. Figure 4.20 illustrates these two correlations pattern for the hearing group. The correlation between these ERP effects for the deaf group was not statistically significant but showed a similar trend towards a positive correlation between the two effects. Generally, the effect may be weaker in the deaf group and for this reason it does not reach significance with our sample size. The combined-group analysis showed the same picture: a significant negative correlation when a central-posterior ROI was used ($r(36) = -0.43$, $p = .006$) and a significant positive correlation when central anterior ROI was adopted instead ($r(36) = 0.44$, $p = .004$).

No outliers were observed for the combined analysis. These correlations can be seen in Figure 4.21. These correlations show that, for a given individual, the bigger the P600, the bigger the LAN. This suggests that the two effects are present in a given individual, and that the LAN is not a result of averaging over several individuals.

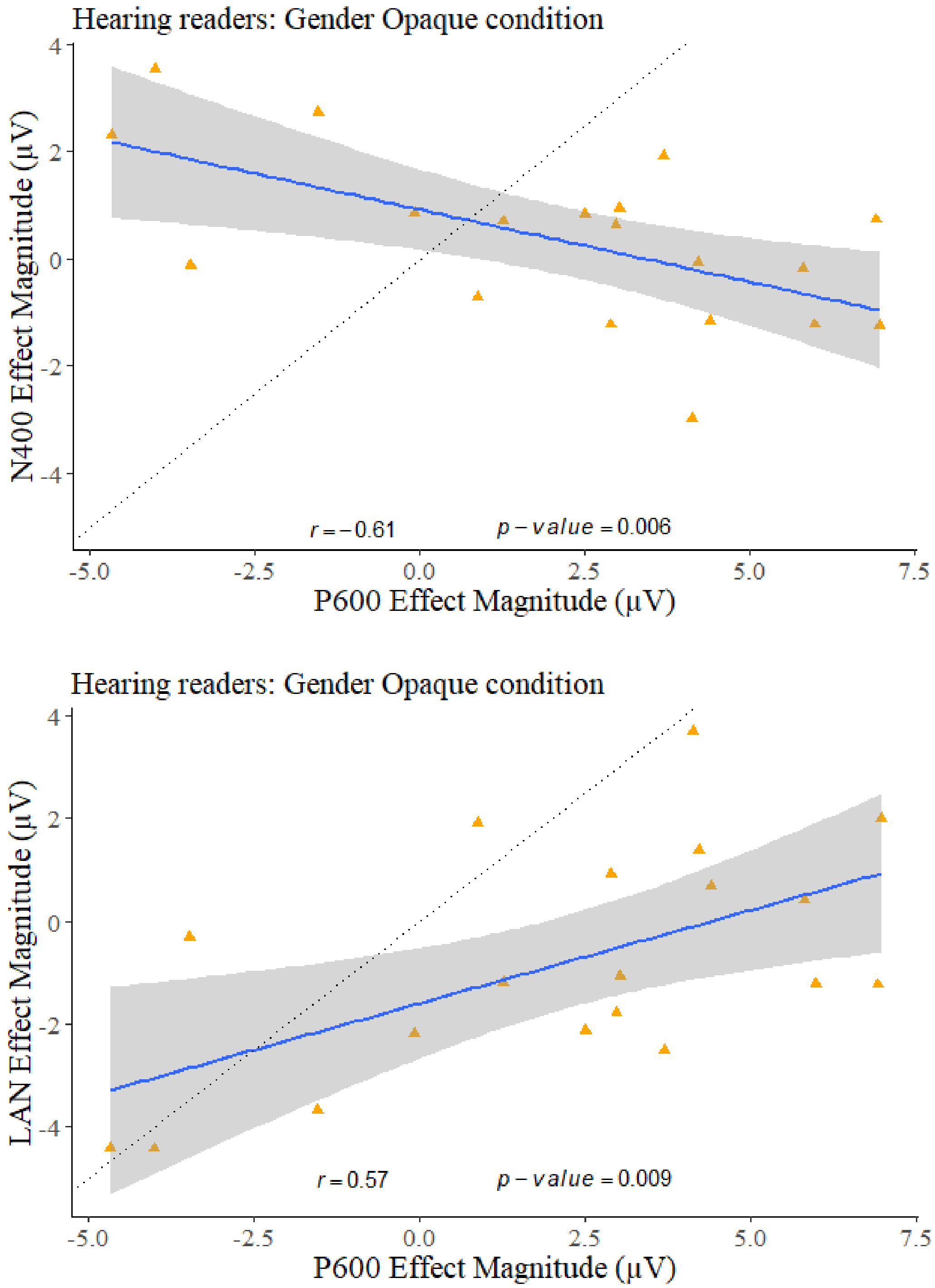


Figure 4.20. Scatterplots showing the relationship between the negativity and the P600 effect found for the hearing group in the Gender Opaque condition. The negativity was first averaged within a central-posterior ROI (top) and within a central-anterior ROI (bottom). The solid line indicates the best-fit line from the correlation analysis for this condition. The dashed lines represent equal LAN/N400 and P600 effect magnitudes: individuals below/to the right of the dashed line showed primarily a P600 effect, while individuals above/to the left of the dashed line showed mainly a LAN or N400 effect.

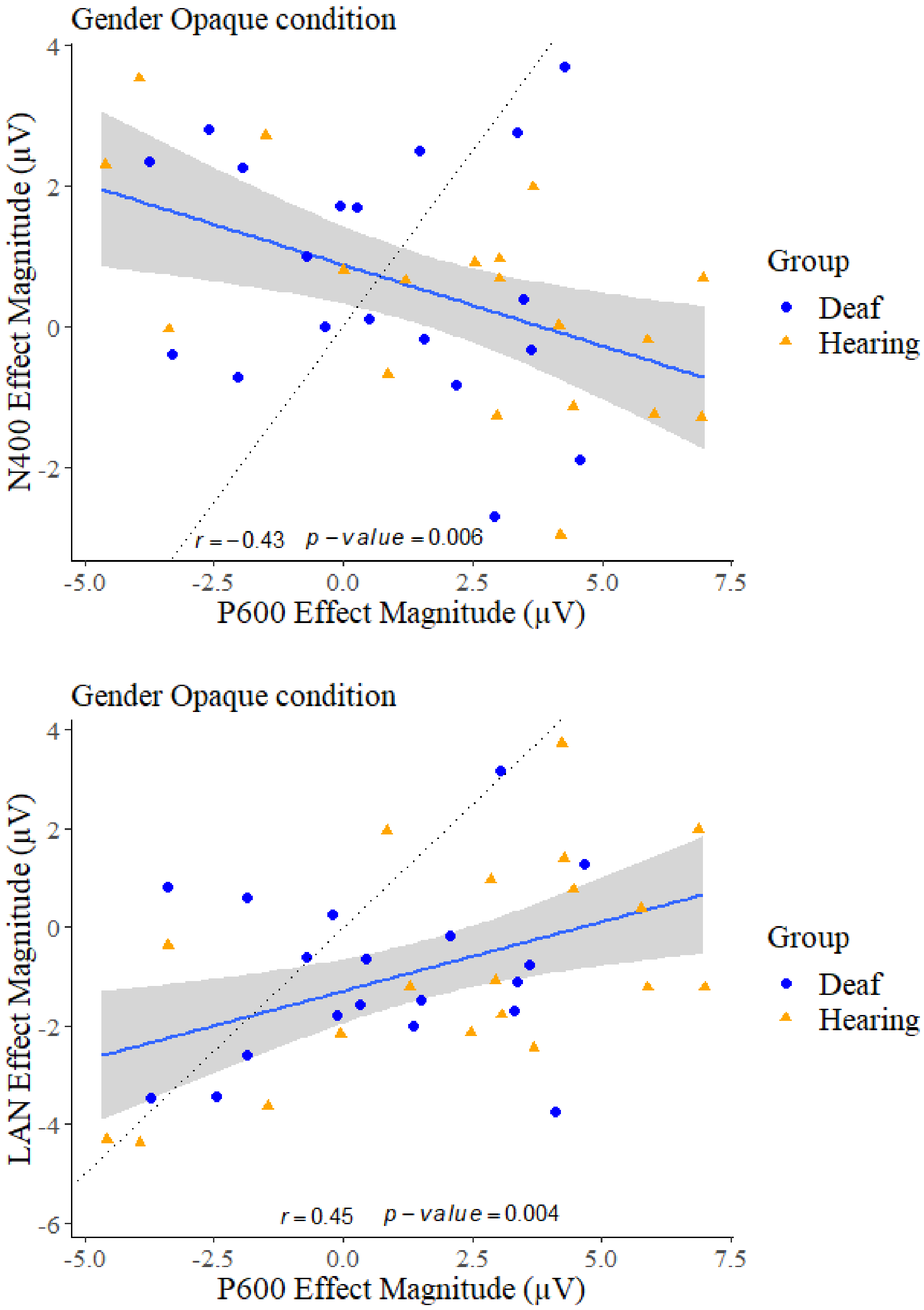
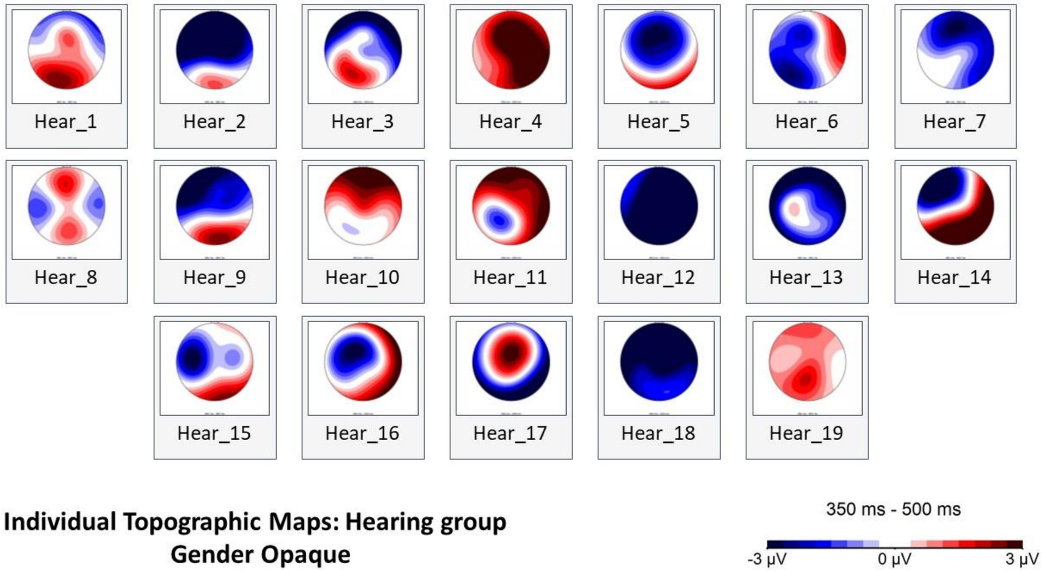


Figure 4.21. Scatterplots showing the relationship between the negativity and the P600 effect found for the both groups in the Gender Opaque condition. The negativity was first averaged within a central-posterior ROI (top) and within a central-anterior ROI (bottom). The solid line indicates the best-fit line from the correlation analysis for this condition. The dashed lines represent equal LAN/N400 and P600 effect magnitudes: individuals below/to the right of the dashed line showed primarily a P600 effect, while individuals above/to the left of the dashed line showed mainly a LAN or N400 effect.

To further understand the nature of the negativity in the early time window, a visual inspection of the topographic maps of both hearing and deaf was performed and they can be seen in Figure 4.22. For the hearing group, there was a prevalence of a central anterior response (LAN/AN), although some subjects presented a more broadly distributed negativity (N400-like). For the deaf group, both types of response were present: a LAN pattern for some subjects and a N400-like pattern for others. In contrast to the Gender Transparent condition, in which the types of responses were more balanced between LAN-like responses and N400-like responses, here in the Gender Opaque condition the LAN pattern was clearer (specially for the hearing group).



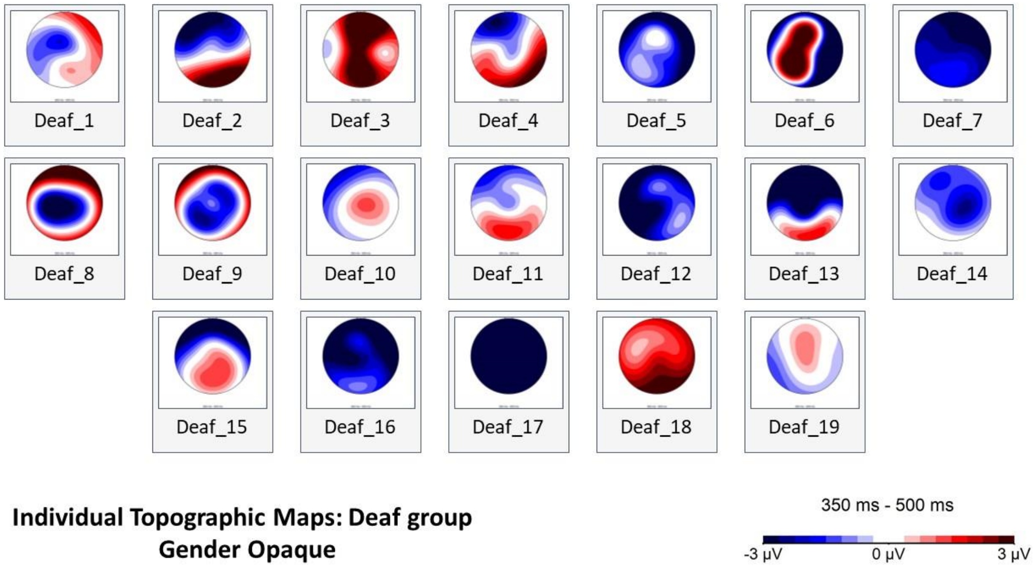


Figure 4.22. Individual topographical maps in the Gender Opaque condition for the hearing (top) and deaf (bottom) group showing that some subjects elicited a broadly distributed negativity rather than a negativity at central-anterior sites, indicating the presence of a mixed pattern of N400 and (L)AN responses.

4.3.5.2 Correlations between ERP and behavioral measures

Additionally, simple correlations of scores for reading comprehension as well as for the sentence acceptability judgment task with the ERP effect magnitudes for the four conditions were calculated (see Table 4.7 and 4.8, respectively). Generally, levels of reading comprehension or the ability to discriminate violated sentences did not correlate with ERP effects. For the deaf group, only d-prime scores from the sentence acceptability task positive correlated with the P600 effect in the Gender Transparent condition ($r(17) = .45$, $p = .04$), while for the hearing group reading comprehension scores negatively correlated with the N400 response in the Number condition.

Second, to examine the many factors that can influence reading levels and to account for some of the variance observed, we ran a multiple regression analysis to investigate whether any behavioral measures were good predictors of ERP effects (e.g. Mehravari et al, 2017). The candidates for predictor variables were reading comprehension, vocabulary, grammar, IQ and years of education. In order to avoid multicollinearity, we created a correlation matrix with all predictor variables (see Appendix F to I). Comprehension and Vocabulary were found to correlate strongly with each other, so only Comprehension was included as a predictor in the model. None of the independent variables explained variance in the ERP effects in either of the groups or in any of the conditions.

4.4 Discussion and conclusions

Overall, the present results showed that high-skilled deaf readers elicit a pattern of ERP responses that is very similar to that observed in (native) hearing readers of Spanish. The findings meet our predictions only partially as we expected that deaf readers would process semantic information but not grammatical information in the same fashion as their hearing peers. However, our results suggest that skilled deaf readers were able to process agreement computation, including gender (transparent and opaque) information, just like hearing readers. Previous studies have proposed that deaf readers process morphosyntactic information differently from their hearing peers and might use semantic strategies during reading tasks to achieve comprehension (e.g. Domínguez & Alegria, 2010; Domínguez et al., 2014; Domínguez et al., 2016; Mehravari et al., 2017). The findings provided here do not fully support this view: high-skilled deaf and hearing readers process both semantic and grammatical information in a similar fashion, with only some differences between the two groups.

4.4.1 Semantic condition

First, results from the Semantic condition showed that both groups were able to discriminate violated sentences from correct sentences, which was evidenced by d-prime scores for the sentence acceptability task.

The EEG responses showed a negativity that peaked around 400ms for incongruent sentences in relation to congruent sentences, with a broad distribution across the scalp that did not differ between groups. This response bears the hallmarks of a N400 effect. However, this effect showed some differences between the two groups: in the 350-500ms time-window, the hearing group elicited a smaller N400 effect in response to the semantic violated sentences in comparison to the deaf group (as illustrated by the marginal main effect of Congruence observed for the hearing readers). This difference was due to a slightly later and weaker response in the hearing group, as was confirmed by analyzing a slightly later time-window (400-550 ms). Here I consider possible explanations for this difference between the hearing and deaf readers.

There was no difference in ERP amplitudes elicited by both groups for incongruent sentences, but instead, there were significant differences in the mean amplitude of responses to the correct sentences. In other words, the hearing showed a more negative response to congruent sentences and this led to a smaller N400 effect. One possible explanation for this difference is that the hearing group was more sensitive to the cloze probability of the target words in the sentences. The N400 amplitude is an inverse function of a word's cloze probability, that is, the probability that a particular word would be chosen to complete a sentence. Thus, a negativity can be also elicited in the context of sentences that do not contain semantic violations, but, instead, contain a meaningful context with low cloze probability words (Kutas, 1993; Kutas & Hillyard, 1984). It is possible that the target words used in the control sentences were not the most expected words within the given context and, therefore, elicited a more negative response for the hearing group, who may be more sensitive to cloze probability since they have greater exposure to the language through the spoken form. The target-words used in the Semantic condition were not controlled for cloze probability (although all sentences were checked by a native Spanish speaker for naturalness), so it is hard to confirm whether this was why the hearing group presented more negative responses to correct sentences.

Additionally, the type of stimuli that was used to create the sentences in this study was different from those used in previous studies. Specifically, we used possessive articles (which do not mark gender in Spanish) instead of definite articles (which do mark gender) at the beginning of the sentences to avoid giving any extra early cues for gender that might be used to compute agreement in the gender conditions. No study has used this sentence format before in a sentence violation paradigm, opting instead for sentences starting with definite articles (Alemán Bañón et al., 2012; Barber & Carreiras, 2005). Thus, the use of possessive articles at the beginning of the sentence could have influenced the level of semantic anticipation of the critical words and, consequently, affected the electrophysiological response elicited by the hearing group, in this case causing a slight delay in the N400 effect. A follow-up study that included both types of sentences would permit a direct comparison and provide a measure of how much this factor affects the N400 response.

Moving on to later time-windows, there was a significant positivity that started 600ms after the onset of the target word. This is in line with other studies that have also observed a late positivity in the presence of semantic violations in both native (Moreno & Kutas, 2005; Ojima et al., 2005; Van de Meerendonk, Kolk, Chwilla, & Vissers, 2009) and L2 learners (Bowden et al., 2013; Moreno & Kutas, 2005; Newman, Tremblay, Nichols, Neville, & Ullman, 2012). Thus, even though the P600 effect is usually related to morphosyntactic processing, it might also reflect the detection of mismatches between the expected and the encountered item and, therefore, triggering reanalysis/repair processes (Molinaro et al., 2008; Sassenhagen, Schlesewsky, & Bornkessel-Schlesewsky, 2014; Van de Meerendonk et al., 2009; for a review see Molinaro et al., 2011). According to other authors, a biphasic pattern for semantic violations can be explained by different factors such as individual differences, working memory, and contextual constraint (Kos, Van den Brink, & Hagoort, 2012).

These two effects were related in the deaf but not the hearing group: the N400 and the P600 effects were negatively correlated only for the deaf group (and this result was stable even when extreme values were removed). This indicates that individuals in this group tended to rely either on processes indexed by N400 or on processes indexed by P600 (see Figure 4.14 above). Although previous studies have reported a positivity after the classical elicited negativity for semantic violation, no correlation analysis was conducted in these studies to further understand the relationship of these two effects, often disregarding the role of this biphasic N400-P600 pattern in a semantic context. Therefore, I suggest that even in the absence of grammatical violations, readers may engage different types of linguistic processes such as combinatorial processes (indexed by the P600) rather than semantic-related type of processing (indexed by the N400) as seems to be the case for deaf readers in this study. For example, Kuperberg (2007) proposes a non-syntactocentric and dynamic model of language processing in which at least two interactive although dissociable routes can be engaged during language comprehension: one that reflects a semantic memory-based system responsible of the modulation of the N400; and another responsible for processing combinatorial input related to morphosyntactic information as well as to thematic–semantic constraints, which modulates the P600. The type of sentence and violation presented, the type of task required (e.g. end-of-sentence grammatical judgment task), and even individual differences or working memory capacity might give rise to a P600 effect in the absence of grammatical violations (Kuperberg, 2007). Data from the individual analysis showed that deaf readers tend to show either one or the other effects (illustrated by the significant negative correlation between N400 and P600). This suggests that in the deaf group, which route is used depends on individual differences. The next question is, why are individual differences important for the deaf group but not the hearing group? This difference could be due to the heterogeneity in language experience as well as education observed for the deaf group (see table 4.2 for details on linguistic and academic profile of deaf readers). In contrast, hearing readers showed less variability in the way they acquire their first language and how they are taught to read during school years.

The non-syntactocentric account proposed by Kuperberg resembles the declarative/procedural model proposed by Ullman (2001, 2004), which also suggests that during language comprehension two systems participate in the processing and retrieval of linguistic information: the declarative and procedural memory systems (for more information on this model see section 2.2.3). Ullman (2016) posits that although these two systems are different in nature, the same piece of information can be acquired through one system or another, depending on the way this information is taught. For example, one might learn syntax implicitly through procedural memory, such as native speakers learning syntax rules while learning to communicate in their L1, or explicitly through declarative memory, such as deaf readers acquiring a new type of grammar in a classroom setting. Therefore, the negative correlation between N400 and P600 presented by the deaf group suggests that the way deaf readers learn to read (implicitly or explicitly) would influence how they retrieve information during language comprehension.

Finally, there were no discernable relationships between ERP effects and behavioral measures. (Although the hearing group showed a positive correlation between grammatical abilities and N400 amplitude, this relationship disappeared when the analysis was run in the time-window where the effect was significant for the hearing group (i.e. 400-550ms).).

To summarize the findings in this condition, we found that for semantic violations elicited a typical response in both hearing and deaf readers: a N400 followed by a P600. Additionally, the deaf group showed a negative correlation between these two ERP effects, suggesting that individual differences in this group lead to one type of response or another, possibly reflecting variability in how each deaf individual learns to read.

4.4.2 Number condition

For the Number condition, results from the sentence acceptability task showed that both groups were able to discriminate violated sentences from correct sentences, with no significant difference in scores between the two groups.

ERP results showed that both groups elicited a biphasic N400-P600 response. In the 350-500ms time-window, a broadly distributed negativity showing the characteristics of a N400 response was observed for both hearing and deaf readers. In the 600-1000ms time-window, there was a positivity after 600ms for both groups, although this effect presented a different topographic distribution in the 600-800ms time-window (P600a) for hearing and deaf. Specifically, the hearing group showed a significant P600a effect on the left and central portions of the scalp, but only a marginal effect over posterior areas. In contrast, the deaf group showed a very robust P600a effect that was significant over central and posterior areas. The P600b (800-1000ms) was very similar for both groups, yielding a significant effect over central and posterior areas of the scalp.

4.4.2.1 N400 effect

Overall, no previous study that investigated number violations has reported an N400-like response for this type of grammatical error. Most of the available evidence showed either a biphasic LAN-P600 effect (Barber & Carreiras, 2005; Gillon Dowens et al., 2010), or only a P600 effect (Alemán Bañón et al., 2012, 2014; Alemán Bañón & Rothman, 2016; Nevins, Dillon, Malhotra, & Phillips, 2007). Although there is no previous evidence for an N400 effect in the context of number violations in the scientific literature, the presence of the N400 for other morphosyntactic errors has been reported (Guajardo & Wicha, 2014; Hagoort, 2003; Mancini et al., 2013; Tanner & Van Hell, 2014). I now turn to these findings to consider possible explanations for the presence of an N400 for number violations, such as the impact of markedness and of syntactic violations on semantic processing.

Previous studies reported that ERP effects are more robust in the presence of marked lexical items such as plural in comparison to singular (Alemán Bañón & Rothman, 2016). Tanner and Van Hell (2014) argue that orthographic markers might affect predictions during parsing computation and an N400 response can be the result of a failure to meet these expectations, especially in the case of Spanish, a morphologically rich language that presents a lot of agreement cues. Other studies have also presented evidence that orthographical information can be used to predict upcoming words in a sentence (e.g. Laszlo & Federmeier, 2009). These cues might induce readers to rely more on orthographical markers as predictors of agreement operations, especially when the task explicitly requires participants to respond whether sentences are correct or not. Although we controlled for markedness in the Number and Semantic conditions (half of the sentences presented were in plural and the other half in singular), the overall number of sentences presented in plural (i.e. marked) was different than those presented in singular (i.e. unmarked), since the sentences in the Gender Transparent and Gender Opaque conditions were formed only in singular, and this could have impacted the ERP responses.

Alternatively, the N400 response for number violation might represent the cost of semantic integration during language comprehension. According to (Hagoort, 2003), the processing costs during the integration of a word's meaning into the ongoing sentence interpretation can vary and this might result in modulations of the N400 amplitude. Thus, there is an asymmetry between semantic and syntactic analysis during sentence comprehension, such that semantic integration is harder in the presence of morphosyntactic errors while syntactic analysis is generally unaffected by semantic integration problems (for a different view see Kuperberg, 2007). Therefore, the incongruent items included in the Number condition might have affected the integration of this (violated) target word in the ongoing sentence what could have contributed to the elicitation and modulation of the N400.

Although we are considering these two explanations as separated points, they might actually be part of different cognitive processes that are modulating the N400 effect. However, more recently, some efforts were made trying to reconcile both prediction and semantic integration processes. For example, Nieuwland and colleagues (2019) conducted a large-scale ERP study to investigate if the N400 effect reflects either predictive processes *or* semantic integration processes or is rather reflecting a cascade of semantic activation and integration processes. The authors found that the N400 effect is possibly a reflection of combined activity of distinct, but related, cognitive processes (Nieuwland et al., 2019). Therefore, both syntactic prediction processes due to markedness and semantic integration offer plausible explanations for the presence of an N400 for number violations.

Additionally, there is an on-going debate in the literature concerning the nature of negative effects around 400ms: what many authors claim to be a LAN is considered to be a N400 by others (Guajardo & Wicha, 2014). The broad topography of the negativity in the number violation precludes categorizing it as a LAN effect, but the relationship between this early negativity and the later positivity will provide new insight into the nature of the negativity (section 4.3.2.4). Before looking at the link between the two effects, I now turn to the later positivity.

4.4.2.2 P600 effect

Sentences with number violation also elicited a P600 for both groups. This effect differed slightly between groups in the P600a time-window (i.e. 600-800ms). Specifically, the hearing group only showed a significant P600a effect on the left and medial portions of the scalp as the effect over posterior areas was only marginal. Differently, the deaf group showed a broadly distributed P600 effect in this time-window. In the later time-window (i.e. 800-1000ms) the effect was comparable in both groups, with a central-posterior distribution over the scalp. As explained in chapter 2 (see section 2.1.2), the P600 effect has been associated with different processing stages (Barber & Carreiras, 2005; Kaan et al., 2000; Molinaro et al., 2011). In the early time-window (i.e. 600-800ms) the positive deflection represents difficulties in integration, while the second stage (i.e. 800-1000ms) is related to the processes of reanalysis and repair. Therefore, there was a difference during the integration phase since the hearing group elicited a smaller P600a component for violations compared to the deaf group. This smaller effect for the hearing group in the first period of the P600 could be due to a spatiotemporal overlap between the N400 and P600 effects, resulting in a smaller P600a (Brouwer & Crocker, 2017). Here, I present four possibilities might explain why deaf readers showed a stronger P600a response to anomalous sentences.

Firstly, the unification model of syntactic processing proposed by (Hagoort, 2003) posits that complex syntactic structures are more difficult to process and the P600 indexes the amount of time required to unify syntactic chunks into one phrasal configuration. This unification takes longer in the case of more complex syntactic structures, thereby increasing the amplitude of the P600. Although deaf readers may achieve high levels of literacy, their lack of access to the spoken language might cause problems processing syntactic complexity and errors, making the sentence acceptability task more complex to perform for the deaf than for the hearing readers. Previous behavioral data from a self-paced reading task in English showed that although both hearing and deaf readers slow down their reading pace when encountering a subject-verb violation this effect is extended in time for deaf readers suggesting that the way they process agreement is different from hearing readers (Breadmore et al., 2014). Looking at the topographic distribution of the P600a (Figure 4.23 below), we can see that this effect was broadly distributed for the deaf group, while more focused for the hearing group. Pakulak & Neville (2011) showed that non-natives tend to elicit a type of P600 effect in response to grammatical violations that is more widespread spatially, sometimes extending across anterior sites, and this positivity tend to be larger compared to native speakers’ response. Therefore, this widely distributed effect for the deaf group could be an indication that deaf readers need to use more cognitive resources to integrate number errors in comparison to hearing participants. The fact that deaf readers are less experienced with the spoken language could explain their need to recruit more cognitive resources to process agreement errors.

Secondly, we cannot discard that this larger P600a could be linked to working memory processes. Some studies have showed that individuals with a larger verbal working memory capacity elicit P600 effects with larger amplitude (Kim, Oines, & Miyake, 2018). One could speculate that if deaf readers were strongly relying on the available marked items to perform agreement, this large P600 effect for the deaf group could indicate an increase on verbal working memory load as that they were holding more orthographical information in their working memory in comparison to the hearing group. This possibility is more speculative though as we did not measure or controlled for working memory capacity across participants. Moreover, since there was no difference in the later phase of the P600 between the groups it is unlikely that differences in working memory capacity would impact only one phase of the P600.

Thirdly, another alternative explanation for this group difference in the P600a has to do with a connection between this effect and discourse-level information (Kuperberg, 2007). Although the stimuli presented in this experiment were sentences rather than extended discourse, sentences also require the construction of a discourse model, especially with respect to the referents involved in the events being described. Number mismatches may cause clashes in the discourse representation of the number of referents being referred to in a given sentence. Thus, number disagreement may cause a disruption in the construction of the discourse model for deaf readers, giving rise to a more prominent P600a effect. This would suggest that deaf readers' treatment of number has a greater semantic/discursive import compared to hearing readers, who treat it as a morphosyntactic feature.

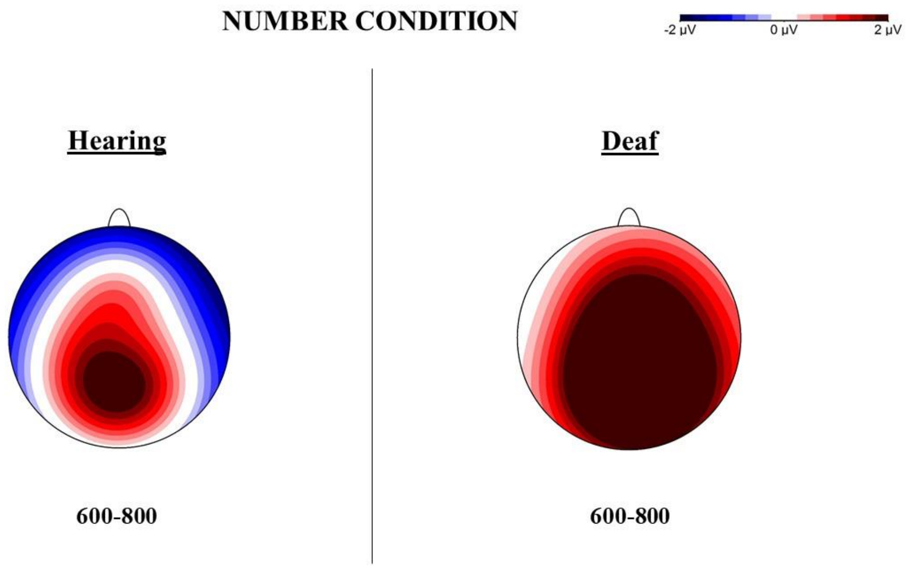


Figure 4.23. Topographic distributions of average potentials for the hearing and deaf group in the Number condition in the 600-800 ms time-window (P600a).

Finally, the fourth possibility is that deaf readers make greater use of orthographic cues to generate predictions. Having strong predictions would cause problems upon encountering the violations and, consequently, with sentence integration (Luck & Kappenman, 2012). According to Kaan and colleagues the P600 reflects the amount of resources used for syntactic integration processes in terms of combining the current input with generated syntactic predictions (Kaan et al., 2000). Previous findings suggest that deaf readers take advantage of visual cues to process reading more efficiently. For example, evidence from eye-tracking studies demonstrated that deaf readers, in general, process more visual information within a fixation than do hearing readers (Bélanger, Slattery, et al., 2012), and high-skilled deaf readers are “more efficient” than hearing readers at processing words within a single eye-fixation (Bélanger & Rayner, 2015; Bélanger et al., 2018). Behavioral studies also showed that high-skilled deaf readers are more sensitive to orthographic cues than hearing readers as they do not make use of phonological information during word processing (Bélanger, Baum, et al., 2012; Fariña et al., 2017). Furthermore, the correspondence between form and function for number marking in Spanish is completely consistent (in a way that gender – which may be transparent or opaque – is not), making it likely that deaf generate predictions for morphosyntactic forms based on orthographic cues. Therefore, this reading strategy could have impacted the amplitude of the P600 during the integration phase for the deaf readers in the sense that they showed a greater reaction to a visual, orthographic mismatch relative to the hearing readers.

This last account contradicts the *keyword strategy*, according to which deaf readers pay more attention to content words than to the syntactic structure in general. However, it is possible that the type of task has modulated the results observed here and when deaf individuals read texts in a natural environment, they might use the keyword strategy to efficiently achieve comprehension. Since participants were explicitly asked to judge whether the sentences were correct or not, this might have influenced deaf readers to pay more attention to the available orthographical cues in order to spot morphosyntactic anomalies. For example, Kolk and colleagues (Kolk, Chwilla, Van Herten, & Oor, 2003) showed that the type of task used (sentence acceptability judgments task vs. reading comprehension task) can modulate ERP responses. In future studies, it would be interesting to use a different task, such as comprehension questions, so agreement computation would be performed in a more natural manner as paying attention to the sentence structure would not be the main task. I will further discuss the limitations of this study in chapter 6.

To summarize, we hypothesize four possible explanations that could be underlined the difference in the P600a effect between hearing and deaf readers. We discussed that this difference could be because deaf readers were having greater difficulty handling syntactic complexity, recruiting more cognitive resources to process the violations. We also brought up the possibility that individual differences in working memory could have impacted P600 responses elicited by the deaf, or that deaf readers were having problems integrating the number violations at the discourse level, or even making greater use of predictions based on the regularity of number marking in Spanish. These explanations are not mutually exclusive, and each factor (syntactic complexity, individual variability in working memory, discourse integration and syntactic prediction) may play a contributing role to the differing P600a effect in the deaf readers compared to the hearing readers. Teasing apart these effects is fertile ground for future research.

The P600 effect found in the second time-window (800-1000 ms) was fairly comparable for both groups and fits previous findings for native Spanish readers: a positivity with a posterior distribution over the scalp (Alemán Bañón et al., 2012; Alemán Bañón & Rothman, 2016; Tanner & Van Hell, 2014). The second phase of the P600 has been attributed to reanalysis and repair processes and some studies showed that this stage sometimes can be absent for second language learners that have not achieved high-levels of proficiency (Gillon Dowens et al., 2010), which was not the case for the deaf participants in the present study.

4.4.2.3 Relation between early and late effects

Previous ERP studies with native readers suggest that there is variability in how native readers engage different cognitive mechanisms during language processing (Kuperberg, 2007; Tanner & Van Hell, 2014). For example, Tanner and colleagues claim that the biphasic pattern observed in the ERP grand mean does not reflect the actual individual responses since visual inspections of individuals' responses usually reveal either an N400-only or P600-only pattern. According to this view, native readers can be classified within a continuum of types of ERP responses: N400-dominant individuals who rely primarily on word or orthographical form-based predictions of upcoming items (e.g., verb or gender agreement predictions), and P600-dominant individuals who rely primarily on combinatorial morphosyntactic constraints.

To investigate the possibility that this biphasic pattern was reflecting different types of individual responses, we performed an analysis at the individual level. We found a trend towards a negative correlation between the N400 and the P600 for both groups; combining the groups (to increase statistical power) revealed a significant negative correlation between the ERP responses (and this correlation withstood the removal of outliers: see section 4.2.5.1 for further details). In line with Tanner's proposal, this finding suggests that for both groups responses were either N400-like or P600-like for any given individual: some people are treating the number mismatch as a more semantic anomaly or unexpected event (indexed by the N400) whereas others are processing it as a morphosyntactic violation (indexed by the P600).

This suggests that the different types of ERP response – a N400 or a P600 – to the number violations depend on the individual in question and allows us to reassess the explanations we considered in section 4.3.2.1 for the somewhat surprising appearance of the early negativity in the number violations. We considered that possibility that either markedness or semantic integration played a role in triggering the N400. Since all participants saw the same number of marked and unmarked items, markedness explains neither why individuals differed in the magnitude of their ERP effects nor why these effects were negatively correlated at the individual level. In contrast, semantic integration may align with individual variation: a given individual may treat a number violation as a more semantic mismatch (given the clear semantic import of number) or as a more morphosyntactic mismatch (since number is marked morphosyntactically), and this will be reflected as a N400-dominant or P600-dominant response. This indicates that, even among typical readers, there may be variability in how number is represented and how number agreement is processed, and merits further investigation to examine this intersection of semantics and morphosyntax.

4.4.3 Gender Transparent condition

For the Gender Transparent condition, scores from the sentence acceptability task showed that both groups were able to discriminate violated from correct sentences.

Moreover, ERP results for the Gender Transparent condition showed that, in general, both groups presented a similar electrophysiological response to ungrammatical sentences. Specifically, hearing and deaf readers showed a negativity in the 350-500 ms time-window for incorrect sentences relative to correct sentences. Although there was no interaction between Congruence and Topography or Group in this time-window, visual inspection of waveforms and topographical maps (see figures 4.8 and 4.9, respectively) suggested that the negativity had a different topographical distribution for both groups and motivated a within-group analysis for each group. This analysis revealed that for the hearing group, the negativity was significant in frontal areas (and marginal in central areas), suggesting a

(L)AN effect; in contrast, for the deaf group, the negativity was significant only in central-posterior areas, indicating a type of response that was more similar to a N400 effect.

Additionally, both groups showed a P600 effect for violations with a classical central-posterior distribution; the effect was more left lateralized for the hearing group, while the deaf group showed a more right-lateralized effect.

4.3.3.1 (L)AN and N400 effect

Previous studies of gender processing showed that a biphasic LAN-P600 effect is usually observed in response to gender violations (Barber & Carreiras, 2005; Barber et al., 2004; Molinaro et al., 2008). Our findings reveal an anterior negativity for the hearing group and a central-posterior negativity for the deaf group, and in this section, I consider each of these effects in turn.

The anterior negativity for the hearing group does not present the typical left biased distribution of the LAN effect. Previous evidence showed that the LAN effect is not necessarily always left biased, and bilateral anterior negativity has been previously reported in the literature although these studies did not present the same type of (gender) agreement manipulation that we used here (e.g. Hinojosa, Martín-Loeches, Casado, Muñoz, & Rubia, 2003; Leinonen, Brattico, Järvenpää, & Krause, 2008). Notwithstanding, it is important to note that the available evidence of a LAN effect for gender violations is mainly from studies that used local violations (Barber & Carreiras, 2005; Barber et al., 2004; Molinaro et al., 2008) rather than studies that used violations beyond a single noun phrase (Alemán Bañón et al., 2012, 2014) such as the noun-predicative adjective disagreement used here. It is possible that the distance between the noun and the adjective (with the verb in between) required more work from the working memory (in contrast to local violations), causing a modulation of the magnitude and distribution of the LAN. (Note that this is different from the number condition, in which the intervening verb also carried information about number agreement.)

In the case of deaf readers, results showed an N400-like response to gender transparent violations. This type of effect is not what is usually observed for gender violations, suggesting that deaf readers process gender agreement differently from their hearing peers, at least in the presence of transparent nouns.

One explanation for the presence of a N400 response for gender violation is that, similar to number violation, this negativity for deaf readers represents the cost of semantic integration during language comprehension (Hagoort, 2003). For example, Guajardo and Wicha (2014) reported a N400 effect for post-nominal adjectives that disagreed in (grammatical) gender with the noun in the presence of a highly constraining context. These authors explain that this could have been due to problems during semantic integration caused by the gender agreement error. However, the manipulation of the experiment presented by Guajardo and colleagues included highly constraining sentences, which was not the case here. Nevertheless, this argument does not offer a convincing explanation for why the deaf group should show a N400 and the hearing group a (L)AN effect. Consequently, the N400 as an index of semantic integration makes more sense for number than for gender since number has a semantic component that is interpretable, while grammatical gender does not.

As discussed in chapter 2 (see section 2.2), lexical access may be constrained by the available visual cues during language comprehension, which could lead to a modulation of the N400 effect (DeLong, Urbach, & Kutas, 2005; Hagoort et al., 2009). It has been shown that deaf readers have an enhanced visual perceptual span, make use of visual cues when they are available to read (Bélanger et al., 2018; Bélanger, Slattery, et al., 2012; Domínguez & Alegria, 2010; Domínguez et al., 2014; Yan, Pan, Bélanger, & Shu, 2015). Deaf readers may have been using orthographic cues to support agreement performance: in this condition transparent nouns carried explicit gender information, and participants could anticipate the agreement with the adjective.

This interpretation would indicate that deaf readers generally take advantage of orthographical cues to perform agreement during reading comprehension. For example, Cunnings posits that some learners such as L2 readers rely more heavily on certain types of cues such as cues derived from explicit (morphosyntactic) agreement features. This relates to the distinction between lexical and form-based routes (see section 2.2.1 for further details on the dual-route for gender agreement). Both routes are available and can be taken depending of the characteristics and regularities of the noun being retrieved (e.g., transparent nouns). Even native speakers are sensitive to the presence of these orthographical cues, although they usually perform gender agreement in a more automatic manner, not treating transparent and opaque nouns differently (Caffarra et al., 2014). Additionally, other factors, such as language proficiency, or the way grammatical dependencies were acquired during school years, might influence the reader to process gender agreement via one route or another, possibly depending of what is more efficient during parsing computation. However, since deaf individuals only acquire gender information through the writing (i.e. written Spanish), they might process this information differently from their hearing peers, for example, using the form-based route to predict syntactic relations, and keep alternating the use of the two routes to access gender information depending on the circumstances and information available. Therefore, the option of using one route or another may underlie the difference in topography of the negativity found for hearing and deaf readers.

One question that arises is whether the context provided by the specific task in our experiment could be cause deaf readers to focus more on these orthographical cues compared to their hearing peers. In other words, more than using visual cues during reading as a default strategy during parsing computation, it could be the case that deaf participants were making use of these orthographical cues as a consequence of the sentence acceptability task. Deaf readers might have found it easier to take advantage of the available visual cues between the noun and the adjective to perform the task successfully. This could have influenced the elicited ERP responses for this condition, resulting in a N400-like response, rather than a (L)AN response for this group. I will discuss this further in chapter 6 when presenting possible limitations of this study.

In summary, the different types of response between the two groups seem to point to a greater reliance by the deaf readers on the consistent visual cues that are available when resolving agreement with nouns that mark gender transparently.

4.3.3.2 P600 effect

The positivity found after 600ms in both groups showed a topographical pattern that was similarly described in previous studies as a P600 effect (Alemán Bañón et al., 2012; Barber & Carreiras, 2005; Caffarra et al., 2017; Caffarra et al., 2014; Molinaro et al., 2011): a central-posterior positivity that was stronger on the back part of the scalp, especially in its second phase (i.e. 800-1000 ms). Although both groups presented a comparable P600 effect for sentence violations relative to correct sentences, there was a small difference in laterality in the first phase of the P600 (i.e. 600-800 ms). Specifically, the hearing group showed a more broadly distributed central-posterior effect that was slightly stronger on the left side of the scalp, while the deaf group did not show this positivity on the left side, only on the right side of the scalp. There has been little discussion in the literature on the laterality of the P600 effect, making it difficult to provide a functional interpretation for this difference. Since the earlier window showed functionally distinct effects in each group (i.e. AN versus N400), it may be the case that this impacts the distribution of the P600 effect. Alternatively, the different topographies may reflect different neural sources. Since the current state of knowledge does not allow me to say more on this, I leave the matter to future research.

In summary, Gender Transparent violations elicited ERP responses related to integration of the disagreement with the previous sentence fragment (P600a), and reanalysis/repair processes (P600b), indicating that hearing and deaf readers were processing these ungrammatical sentences in a similar fashion.

4.3.3.3 Relation between early and late effects

The relation between the early negative and later positive ERP effects reveals whether the response is truly biphasic at the individual level, and thus provides further insight into the nature of each response, particularly the early negativity. For the hearing group, a negative correlation between the early effect and the P600 would indicate that the negativity is actually a N400 (that gives rise to an apparent LAN effect when averaging across individuals) as proposed by Tanner and colleagues (Tanner et al., 2014). However, although the individual analysis showed a negative correlation between the two effects, this relationship was unstable and disappeared after cleaning for possible outliers. Furthermore, visual inspection of the topographic responses of the participants showed that some individuals did produce a (L)AN-like response. This provides converging evidence to treat this early negativity in the hearing group as an (L)AN, and as functionally distinct from the response in the deaf readers. In the deaf group, there was no correlation between the N400 effect and the P600, indicating that the deaf readers did not tend to show either one effect or the other (as was the case for number violations), and suggesting that there was variability in the relative magnitude of the two effects across participants.

The interindividual variation across the groups supports the interpretation of the effects as AN-P600 for the hearing group and a N400-P600 for the deaf group, highlighting that in this condition, the two groups processed the agreement relation differently.

4.4.4 Gender Opaque condition

For the Gender Opaque condition, scores for the sentence acceptability task showed that hearing readers outperformed deaf readers. Interestingly, ERP data for both hearing and deaf showed a similar pattern of results: in the 350-500 ms time-window, gender violations elicited a significant central-anterior negativity that was followed by a central-posterior positivity after 600 ms. In the first phase of the P600 (i.e. 600-800 ms) the effect was significant on the right side of central areas and more robust and more broadly distributed in posterior areas; the second phase of the P600 effect (i.e. 800-1000 ms) showed a similar pattern, with a small effect on the right side of central areas and a broader distribution in posterior areas.

4.3.4.1 (L)AN effect

The early anterior negativity is in line with the available literature on gender processing showing that violations of gender agreement usually elicit a LAN-P600 pattern (Alemán Bañón et al., 2012; Barber & Carreiras, 2005; Barber et al., 2004; Caffarra & Barber, 2015; Caffarra et al., 2014). The LAN component has been associated with early and automatic detection of morphosyntactic agreement processes (Friederici, Hahne, et al., 2002). Again, the negativity found here was not clearly left lateralized as occurs in the classical LAN effect (see Friederici, Hahne, et al., 2002), similar to what was observed for the hearing group in the gender transparent condition. Rather, the negativity was significant mainly in anterior and central areas, but with no difference in laterality (therefore, an AN effect).

Although this result confirmed our expectation that hearing readers would elicit a LAN for Gender Opaque, it raises the question as to why deaf readers elicited this type of response for this condition but not for Gender Transparent. Gender Opaque nouns do not provide visual/orthographical cues about gender, especially if they are not preceded by an article that gives an indication of the gender information, so readers cannot take advantage of these explicit markers. Differences in the ERP responses elicited by deaf readers between, on one hand, Gender Transparent and Number condition, and on the other, Gender Opaque, suggest that depending on what information these readers have to resolve agreement, different routes can be taken to process grammatical structure. In other words, the presence of the AN effect in the Gender Opaque condition in contrast to the N400-like effect found for Number and Gender Transparent indicate that deaf readers might use different cognitive resources to perform agreement depending on the contextual and orthographical cues available.

4.3.4.2 P600 effect

The Gender Opaque condition also elicited a posterior positivity for both groups that was consistent with the P600 effect found in previous studies on gender violations. The effect was showed a tendency to be on the right side of central-posterior areas in both groups. Again, this lateral distribution is difficult to interpret since little is known about the laterality of the P600 effect. Since both groups showed a similar effect in the earlier (350-500 ms) time-window and the lateralization of the P600 is the same for both groups, this lends support to the suggestion (in section 4.3.3.2) that the difference in laterality of the P600 in the Gender Transparent condition was a consequence of the differences in the earlier negativity.

Therefore, there were no differences between hearing and deaf readers in the integration or reanalysis/repair processes for Gender Opaque violations.

4.3.4.3 Relation between early and late effects

The analysis of the effects at the individual level revealed a curious pattern: when adopting a central-posterior ROI, there was a negative correlation between the early negativity and the later positivity; in contrast, when a central-anterior ROI was used for the negativity, a positive correlation emerged. We used both ROIs because previous studies have only considered a central-posterior ROI to calculate the correlation between the negativity and the P600. Tanner and colleagues (2014) justified this decision based on visual inspection of the topographical maps, which indicated that the individual response patterns corresponded more to a central-posterior pattern than to a central-anterior negativity. Our visual inspection, however, indicated otherwise: the hearing group showed a prevalence of a central-anterior response, and this type of response was also present in the deaf group (see figure 4.22).

The negative correlation between the early negativity and the later positivity is in line with Tanner's claim that individual variability gives rise to an effect that looks like a LAN when averaging over individuals. However, measuring the negativity over a more anterior area produces a positive correlation, indicating that for a given individual, the larger his/her (anterior) negative effect, the larger his/her later positive effect. This finding does not fit well with Tanner's explanation and suggests that the earlier anterior negativity does indeed exist at the individual level and is not necessarily a result of averaging, in line with other recent findings (Caffarra, Mendoza & Davidson, 2019).

The individual analysis confirms that the hearing and deaf groups processed the Gender Opaque violations in a similar manner and provides further evidence for treating the early negativity as a real effect that reflected morphosyntactic processing.

4.4.5 Overall Summary

Our findings in the Semantic condition confirmed our predictions that both hearing and deaf readers would elicit a similar pattern of response to incongruent sentences: a classical N400 effect followed by a P600. We speculated that individual differences in the deaf group showing that these readers use one type of response or another may reflect variability in how each deaf individual learns to read.

ERP results for the Number condition showed that both groups elicited a biphasic N400-P600 response, confirming our predictions for the deaf group but not for the hearing group, for whom we expected a classical biphasic LAN-P600 response to grammatical violations. The hearing participants were matched with the deaf readers on various measures of language and reading ability, and this may go some way to explaining this somewhat anomalous response in the early time window. We also considered markedness and semantic integration to explain the presence of the N400 for number violations in both groups. There were differences between hearing and deaf readers in the P600a, which might be due to the deaf readers having greater difficulty integrating the number violations at the discourse level or making greater use of predictions based on the regularity of number marking in Spanish. The negative correlation between the N400 and P600 in the individual analysis showed that a given individual may treat a number violation as a more semantic mismatch (given the clear semantic import of number) or as a more morphosyntactic mismatch (since number is marked morphosyntactically), and this will be reflected as a N400-dominant or P600-dominant response.

ERP results for the Gender Transparent condition showed that the hearing group elicited a (L)AN-P600 effect[24] in response to ungrammatical sentences, while the deaf group showed a N400-P600 effect. This different pattern of response found for the two groups confirm our predictions: hearing readers make more use of combinatory processes when dealing with morphosyntactic violations, illustrated by the (L)AN-P600 effect; deaf readers rely more on visual cues to perform agreement with nouns that mark gender transparently, demonstrated by the N400-P600 pattern of response.

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[24] Again, the failure to find a clear LAN effect in the hearing group may be due to the fact that this group was matched against the reading skills of the deaf group.

In line with our predictions, scores for the sentence acceptability task in the Gender Opaque condition showed that hearing outperformed deaf readers, indicating that this condition was more problematic for deaf than for hearing since gender opaque nouns do not have orthographical cues that convey gender information. However, this difference did not affect the ERP pattern elicited in response to violations: hearing and deaf readers showed a very similar ERP pattern in response to ungrammatical sentences, that is, a biphasic LAN-P600 effect. These findings confirm our predictions for hearing readers, but not for the deaf group: we had predicted that deaf participants would fail to elicit a LAN and would rather show a N400 effect as an indication of their dependence on semantics.

Generally, the similarity of the results between hearing and deaf readers was surprising since the prediction was that deaf readers would show difficulty in processing morphosyntactic information, especially gender information, due to the absence of this feature in their dominant language (i.e. Spanish Sign Language). It may be that these deaf readers are so proficient that they process morphosyntactic information like native readers. Alternatively, their native-like processing may be due to the fact that Spanish is their first written language. Even though deaf readers do not have a gender feature in their dominant language, acquiring a first written language gives rise to reading processing that may differ from acquiring a second written language. In contrast to deaf readers, L2 learners already have the representation of a written system from their L1. In the next chapter I will attempt to resolve the issue by looking at highly proficient L2 readers of Spanish (whose first language does not have gender agreement but does have a written form).

5. Experiment 2

The proposal that deaf readers should be considered sign-print bilinguals suggests that second language acquisition theories are applicable to further understanding how such readers go about reading (Hoffmeister & Caldwell-Harris, 2014; Piñar, Dussias, & Morford, 2011). However, up to the present time there is no consensus in the literature as to whether deaf readers are more similar to native readers or to L2 learners as they might share similarities and differences with both groups. Another possibility is that they might be a completely different case of bilinguals, and the existing theories of language processing (and acquisition) should be reformulated to account for the case of deaf readers. In chapter 4, I showed that deaf readers elicited a pattern of brain response to incorrect sentences that was very similar to that elicited by native hearing readers during a sentence acceptability judgment task. Nevertheless, the similarities presented in the previous chapter raise two possibilities. On the one hand, proficient deaf readers may process semantic and grammatical errors like native readers of Spanish because written Spanish is the only writing system for which they have a representation. On the other hand, if they are actually behaving like high-proficient L2 readers of Spanish, this would explain why they showed such similarities with the native group. The aim of this chapter is to disentangle these two options. For this, I will present electrophysiological evidence of native English speakers who are high-proficient L2 learners of Spanish who performed the same behavioral and EEG task done by the hearing and deaf readers in chapter 4. The goal is to compare these L2 learners of Spanish with the deaf group, and to see if the L2 group also elicits native-like ERP responses as they also are high-proficient users of Spanish like the deaf readers. Our predictions are that L2 learners will elicit the canonical language-related ERP effects in response to violations, that is, a N400 for the Semantic condition and a P600 for the Number and Gender violations. However, they might fail to elicit a LAN effect in the grammatical conditions as they may have difficulty engaging more automatic processes related to morphosyntactic processing.

5.1 Participants

Two groups of adult participants volunteered to take part in this study: 19 hearing native English speakers who were L2 learners of Spanish (8 females, *mean age* = 30.63, *SD* = 6.92) and the 19 deaf participants who took part in Experiment 1 (13 females, *mean age* = 36.36, *SD* = 8.22). Hearing L2 participants had Spanish as their second language and none of them were proficient in another language that has grammatical gender. All deaf participants had LSE as their dominant language; some also reported knowledge of other signed languages and the written form of other spoken languages (e.g. English), although this knowledge was reported to be basic level. Therefore, both groups were high-proficient L2 readers of Spanish. The groups were matched on vocabulary, IQ, grammar abilities, and years of education (see section 5.3.1 for more details of the language and IQ measures). Language profile as well as years of education of both L2 learners and Deaf readers are shown in Table 5.1.

Table 5.1.
Participants' language profile and academic level. Standard deviation (*SD*) is in parentheses.

Profile	**Group**		**Comparisons**	
	L2	**Deaf**	***t* value**	***p* value**
Spanish level (Self-report 1-5)	4.10 (0.73)	4.36 (0.76)	1.08	.28
LSE level (Self-report 1-5)	0 (0)	4.52 (0.90)	21.80	<.001
Formal Education (years)	25.68 (6.87)	22.42 (4.25)	-1.75	.08

5.2 Methodology

The procedure and materials for this experiment are described in detail in chapter 3.

5.3 Results

5.3.1 Behavioral measures

The behavioral battery used in this experiment to evaluate the level of reading comprehension, vocabulary, grammatical assessment, and IQ for both groups of participants was the same as that used in Experiment 1 (see section chapter 3 for further details of the materials). A summary of the results of those assessments are shown in Table 5.2. In the reading comprehension task, there was a significant difference in performance between the two groups, where L2 learners outperformed deaf readers. Figure 5.1 shows the distribution of the performance of both groups in this task.

Table 5.2.
Mean scores for the behavioral battery used to test participants in language comprehension, vocabulary, grammar knowledge, and IQ. (Standard deviation in parentheses.)

Task	**Group**		**Comparisons**	
	L2	**Deaf**	***t* value**	***p* value**
Comprehension (Max score: 27)	23.05 (2.61)	20.26 (4.53)	-2.32	.02*
Vocabulary (Max score: 192)	153.73 (19.04)	163.00 (16.41)	1.60	.11
Grammar (Max score: 80)	77.68 (3.87)	76.73 (3.07)	-0.83	.40
IQ (Max score: 94)	72.78 (6.66)	72.73 (5.05)	-0.02	.97

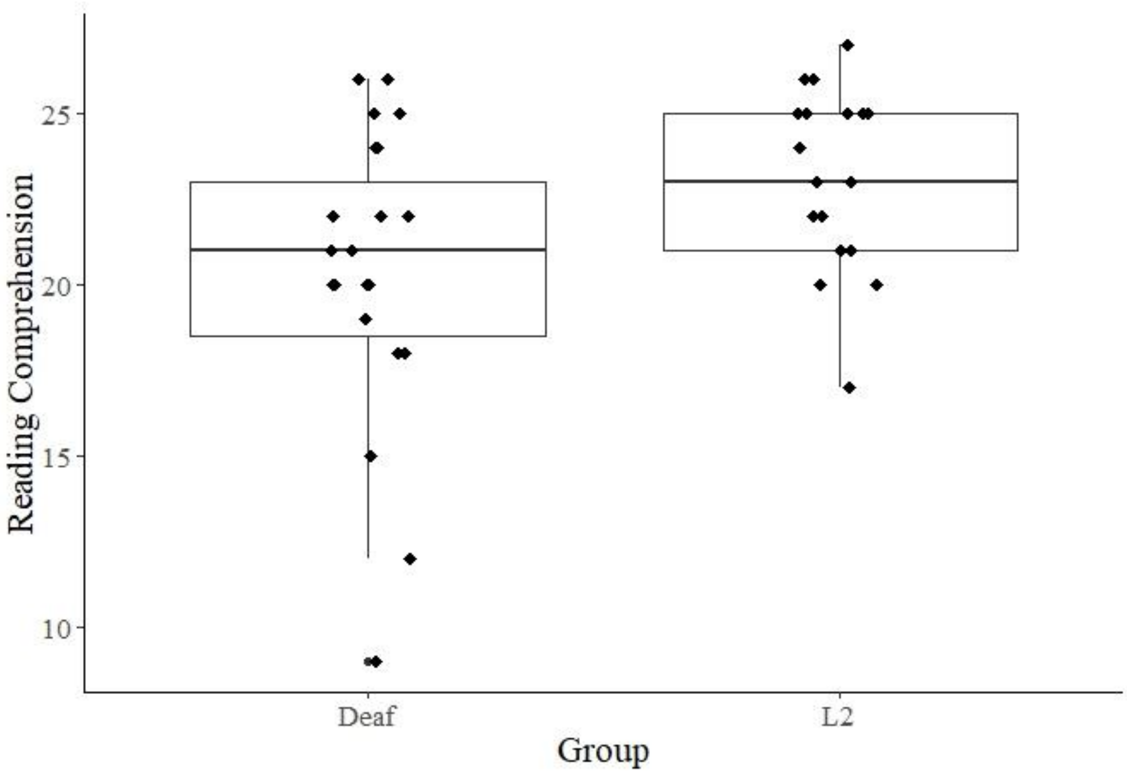


Figure 5.1. Distribution of reading comprehension scores for deaf readers and L2 learners.

5.3.2 EEG: end-of-sentence acceptability judgement task

Responses from the end-of-sentence acceptability judgement task were analyzed to calculate d-prime scores from the four experimental conditions: Semantic, Number, Gender Transparent (GT), and Gender Opaque (GO). Table 5.3 shows the accuracy scores and d-prime values for both groups in each condition. The d-prime results are shown in Figure 5.2. Overall d-prime scores (across all conditions) showed that the deaf group was significantly better at discriminating sentences with violations compared with the L2 group. The deaf group significantly outperformed the L2 group in all conditions, except in the semantic condition.

Table 5.3.
Average percent scores of participants' performance in the end-of-sentence acceptability judgment task and d-prime scores. (Standard deviations in parentheses).

Conditions	**Group accuracy**				**Comparison of d-prime scores**	
	L2		**Deaf**			
	Correct responses (%)	d-prime	Correct responses (%)	d-prime	*t* value	*p* value
Semantic violation	84.3 (15.7)	2.50 (0.98)	88.9 (16.2)	3.02 (0.93)	1.67	.10
Number violation	82.0 (15.7)	2.22 (1.03)	92.0 (12.3)	3.21 (0.99)	3.01	.004*
GT violation	68.6 (20.7)	1.74 (1.10)	92.5 (6.6)	3.17 (0.97)	4.22	<.001*
GO violation	57.2 (20.7)	1.29 (1.00)	86.8 (11.8)	2.87 (1.18)	4.46	<.001*
Overall performance	73.0 (16.3)	1.81 (0.91)	90.45 (8.3)	2.96 (0.95)	3.86	<.001*

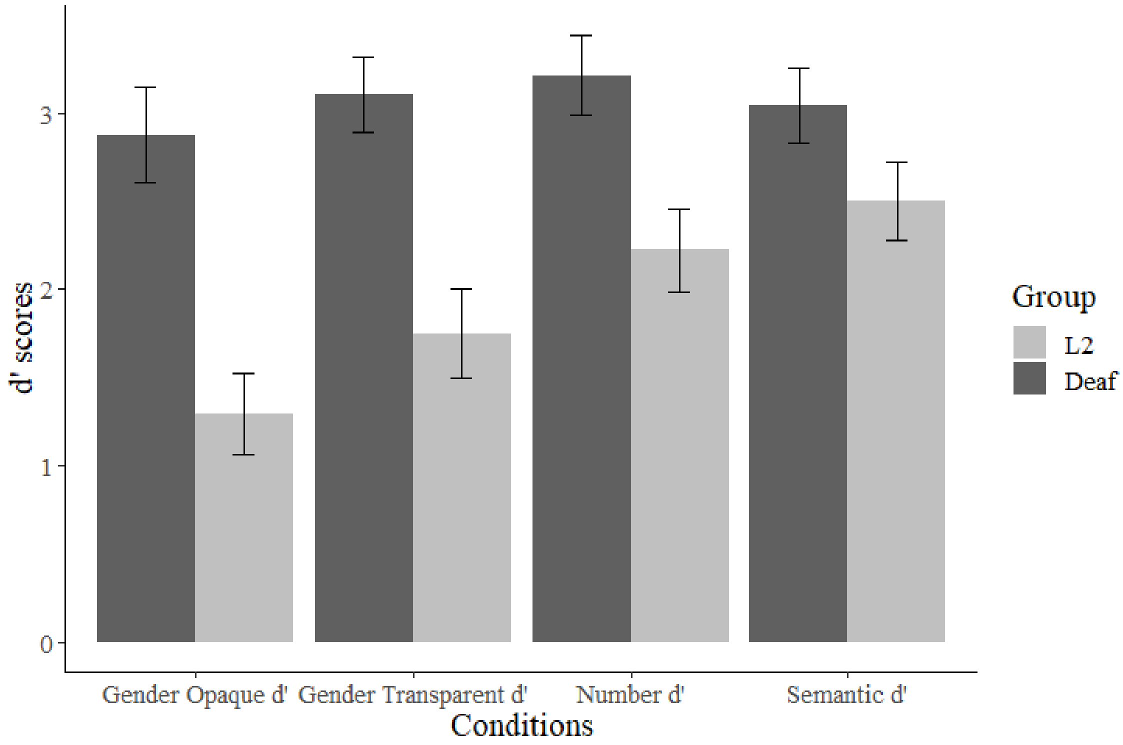


Fig. 5.2. End-of-sentence acceptability judgment d-prime scores for L2 and deaf participants. Error bars represent standard error of the mean (SEM). A d-prime of 0 indicates chance performance on the acceptability judgment task and a d-prime of 4 indicates near-perfect discrimination between control and violated sentences.

5.3.3 ERP measures

The ERP grand average time-locked to the onset of the target words and the topographic distributions of average potentials for the four conditions are presented in Figures 5.3 - 5.10 for each of the conditions.

For the L2 group, 24.95% of the trials were excluded due to artifacts or incorrect responses, and for the deaf group the number of excluded trials were 14.7%. A table with the total number of trials for each group in each of the conditions is presented in the Appendix section (see Appendix J). An ANOVA showed that there was a main difference in the number of trials excluded between the two groups ($F(1,288) = 40.49$, $p < .001$) and across conditions ($F(3,288) = 4.64$, $p = .003$). Therefore, in addition to the analysis with only correct trials we also ran an analysis with all the trials to see if the number of trials lost for the L2 group would change the overall results. The results were the same for both analyses; therefore, here we present the results considering only correct trials.

5.3.3.1 Semantic condition

Figure 5.3 shows average ERPs in response to the congruence manipulation in the Semantic condition for the L2 and the deaf group, and figure 5.4 the topographic distribution of average potentials. Visual inspection of ERP waveforms for the semantic condition revealed differences between congruent and incongruent sentences for both groups. In an early time-window, a greater negativity peaking at around 400ms in central-posterior areas for the incongruent condition was observed for both groups. This negativity was followed by a late posterior positivity (after 800 ms) that was more robust for the deaf group. Statistical results are given for each of the selected time-windows.

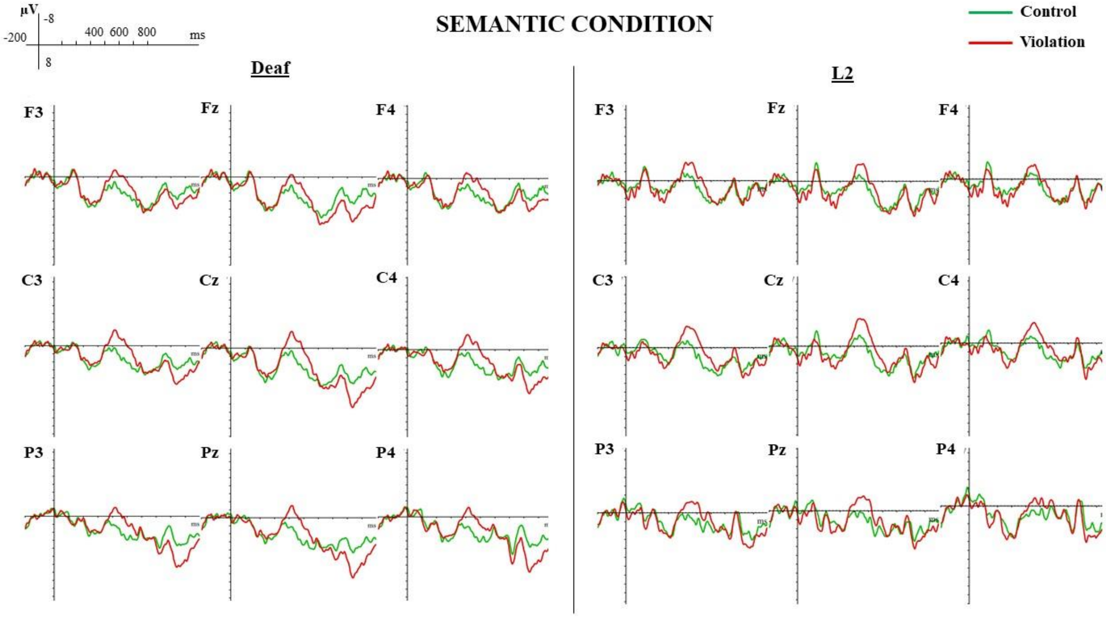


Figure 5.3. ERPs elicited in response to the congruence manipulation in the Semantic condition for the deaf and L2 groups.

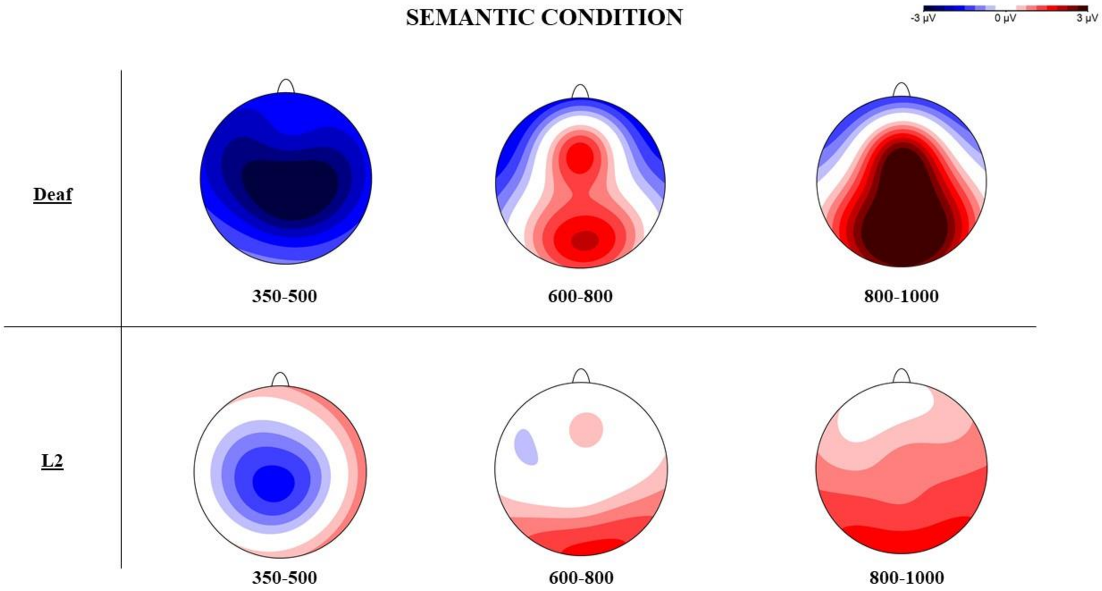


Figure 5.4. Topographic distributions of average potentials for the deaf and L2 groups in the Semantic condition.

350-500 ms time-window

In this time-window, a between-group analysis revealed a main effect of Congruence ($F(1,36) = 6.28$, $p = .01$) and no main effect of Group ($F(1,36) = 1.90$, $p = .17$). This epoch also yielded a triple interaction between Congruence x Anteriority x Laterality ($F(4,144) = 3.63$, $p = .01$). A subsequent post-hoc analysis revealed significant topographic differences for the factor of Congruence. Specifically, although the effect was broadly distributed in the scalp, it was more robust in central and posterior areas (left-anterior: $t(37) = 4.23$, $p < .001$; medial-anterior $t(37) = 3.18$, $p = .002$; right-anterior: $t(37) = 3.57$, $p = .001$; left-central: $t(37) = 5.15$, $p < .001$; medial-central: $t(37) = 4.87$, $p < .001$; right-central: $t(37) = 4.29$, $p < .001$; left-posterior: $t(37) = 4.43$, $p < .001$; medial-posterior $t(37) = 5.20$, $p < .001$; right-posterior: $t(37) = 4.12$, $p < .001$).

600-800 ms time-window

A between-group analysis in this time-window revealed no main effect of Congruence ($F(1,36) = .09$, $p = .76$) or of Group ($F(1,36) = 2.39$, $p = .13$). An interaction between Congruence x Anteriority x Laterality ($F(4,144) = 3.19$, $p = .02$) was observed, however, the post-hoc analysis failed to show any significant topographical differences (all ps > .05).

800-1000 ms time-window

In this later time-window, a between-group analysis revealed no main effect of Congruence ($F(1,36) = 0.72$, $p = .40$) and a marginally significant main effect of Group ($F(1,36) = 3.22$, $p = .08$). A significant interaction between Congruence and Anteriority

(*F*(2,72) = 4.92, *p* = .02) was observed, suggesting topographical differences relative to the Congruence factor. A subsequent post-hoc analysis showed that the effect was significant in central and posterior areas of the scalp (anterior: *t*(37) = -0.47, *p* = .64; central: *t*(37) = -2.49, *p* = .03; posterior: *t*(37) = -3.41, *p* = .004).

Semantic condition: summary of the effects

Both groups showed a N400 effect for semantic violations in the 350-500ms time-window that was stronger in central and posterior areas of the scalp. Similarly, no group differences were observed for the P600 effect: for both groups this positivity was only significant in the later phase (i.e. P600b), that is, in the 800-1000ms time-window.

5.3.3.2 Number condition

Figure 5.5 shows ERPs in response to the congruence manipulation in the Number condition for the L2 and deaf group, and figure 5.6 the topographic distribution of average potentials. Visual inspection of ERP waveforms for this condition revealed differences between congruent and incongruent sentences for both groups. In the 350-500 ms time-window, only the deaf group showed a greater negativity peaking around 400ms for the incongruent condition. This negativity was followed by a positivity after 600ms that was also observed for the L2 group. Statistical results are given for each of the selected time-windows.

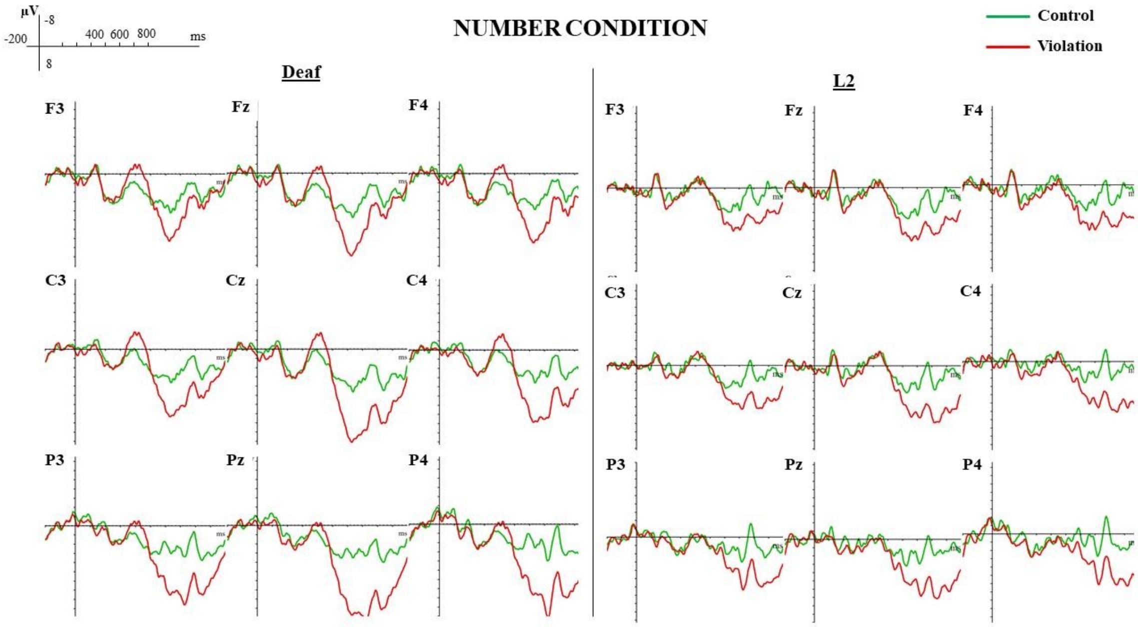


Figure 5.5. ERPs elicited in response to the congruence manipulation in the Number condition for the deaf and L2 groups.

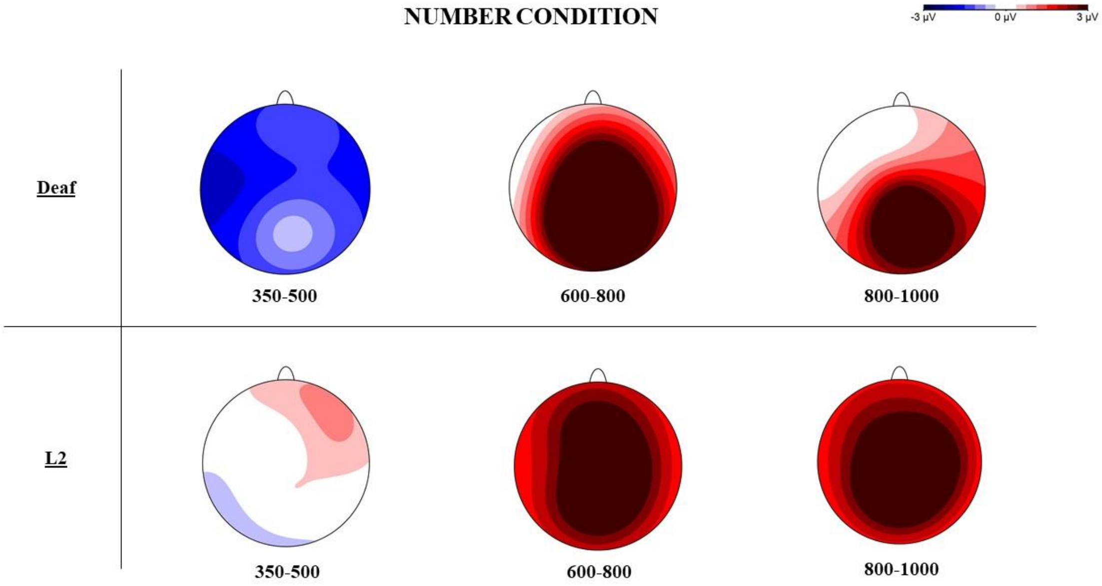


Figure 5.6. Topographic distributions of average potentials for the deaf and L2 groups in the Number condition.

350-500 ms time-window

In this time-window, a between-group analysis revealed no main effect of Congruence (*F*(1,36) = 0.09, *p* = .75) or Group (*F*(1,36) = 1.32, *p* = .25). However, an interaction between Group and Congruence was observed (*F*(2,72) = 4.85, *p* = .03), and a post-hoc analysis revealed that only the deaf group showed a significant effect of Congruence in this time-window (L2: *t*(18) = -0.30, *p* = .76; Deaf: *t*(18) = 2.82, *p* = .02).

600-800 ms time-window

A between-group analysis in this time-window showed a robust main effect of Congruence (*F*(1,36) = 13.11, *p* < .001) and a marginal main effect of Group (*F*(1,36) = 4.02, *p* = .05). A significant interaction between Congruence x Anteriority x Laterality (*F*(4,144) = 8.78, *p* < .001) was observed and a follow-up analysis showed that there was a broadly distributed effect in the scalp that was more robust in medial portions of central and posterior areas (left-anterior: *t*(37) = -3.73, *p* < .001; medial-anterior *t*(37) = -3.76, *p* < .001; right-anterior: *t*(37) = -4.88, *p* < .001; left-central: *t*(37) = -5.93, *p* < .001; medial-central: *t*(37) = -6.69, *p* < .001; right-central: *t*(37) = -6.46, *p* < .001; left-posterior: *t*(37) = -6.02, *p* < .001; medial-posterior *t*(37) = -7.14, *p* < .001; right-posterior: *t*(37) = -5.88, *p* < .001).

Although there was a significant effect for both deaf and L2 readers, this time-window also yielded significant group differences (Group x Congruence x Anteriority: *F*(2,72) = 4.30, *p* = .04). Specifically, a post-hoc analysis showed that deaf readers elicited a stronger P600 effect reflected by differences in central and posterior areas (anterior: *t*(18) = -3.12, *p* = .011; central: *t*(18) = -5.71, *p* < .001; posterior: *t*(18) = -7.07, *p* < .001) in contrast to the L2 group who showed a less robust effect in these areas (anterior: $t(18) = -2.77$, $p = .012$; central: $t(18) = -3.76$, $p = .001$; posterior: $t(18) = -3.14$, $p = .005$).

800-1000 ms time-window

In this later time-window, a between-group analysis revealed a strong main effect of Congruence ($F(1,36) = 38.47$, $p < .001$) and no main effect of Group ($F(1,36) = 0.99$, $p = .32$). A significant three-way interaction between Congruence x Anteriority x Laterality ($F(4,144) = 6.37$, $p < .001$) was observed and a post-hoc analysis showed the effect to be more robust in posterior areas (left-anterior: $t(37) = -1.98$, $p = .05$; medial-anterior $t(37) = -2.88$, $p = .013$; right-anterior: $t(37) = -3.70$, $p = .002$; left-central: $t(37) = -5.70$, $p < .001$; medial-central: $t(37) = -6.24$, $p < .001$; right-central: $t(37) = -7.45$, $p < .001$; left-posterior: $t(37) = -8.68$, $p < .001$; medial-posterior $t(37) = -8.81$, $p < .001$; right-posterior: $t(37) = -8.17$, $p < .001$).

A marginal interaction between Group x Congruence x Anteriority ($F(2,72) = 2.91$, $p = .09$) was found and a follow-up analysis indicated that the P600 effect was more localized and stronger in posterior areas for the deaf group (anterior: $t(18) = -0.70$, $p = .49$; central: $t(18) = -4.27$, $p < .001$; posterior: $t(18) = -7.50$, $p < .001$), in contrast to the L2 group, who showed a more broadly distributed P600 (anterior: $t(18) = -3.59$, $p = .004$; central: $t(18) = -5.66$, $p = .001$; posterior: $t(18) = -5.86$, $p < .001$).

Number condition: summary of the effects

The L2 group did not show any effect in the N400 time-window, in contrast to the deaf group, who showed a significant Congruence effect, although without a clear picture of the location of the effect. In the first phase of the P600 effect (600-800 ms) both groups showed a significant positivity in central and posterior areas, although the deaf group elicited a more robust P600 effect. In the second phase of the P600, the deaf group showed a stronger effect in posterior areas, while the L2 readers elicited an effect that was more broadly distributed across the scalp.

5.3.3.3 Gender Transparent condition

Figure 5.7 shows ERPs in response to the congruence manipulation in the Gender Transparent condition for the L2 and deaf group, and figure 5.8 the topographic distribution of average potentials. Visual inspection of ERP waveforms for the Gender Transparent condition revealed differences between congruent and incongruent sentences for both groups. In an early time-window only the deaf group showed a greater negativity peaking around 400ms for the incongruent condition. Similar to the previous condition, this negativity was followed by a positivity that showed a different scalp distribution for both groups: for the deaf group this positivity was more evident in central-posterior areas of the scalp, while for the L2 group it was more broadly distributed and looked less robust. Statistical results are given for each of the selected time-windows.

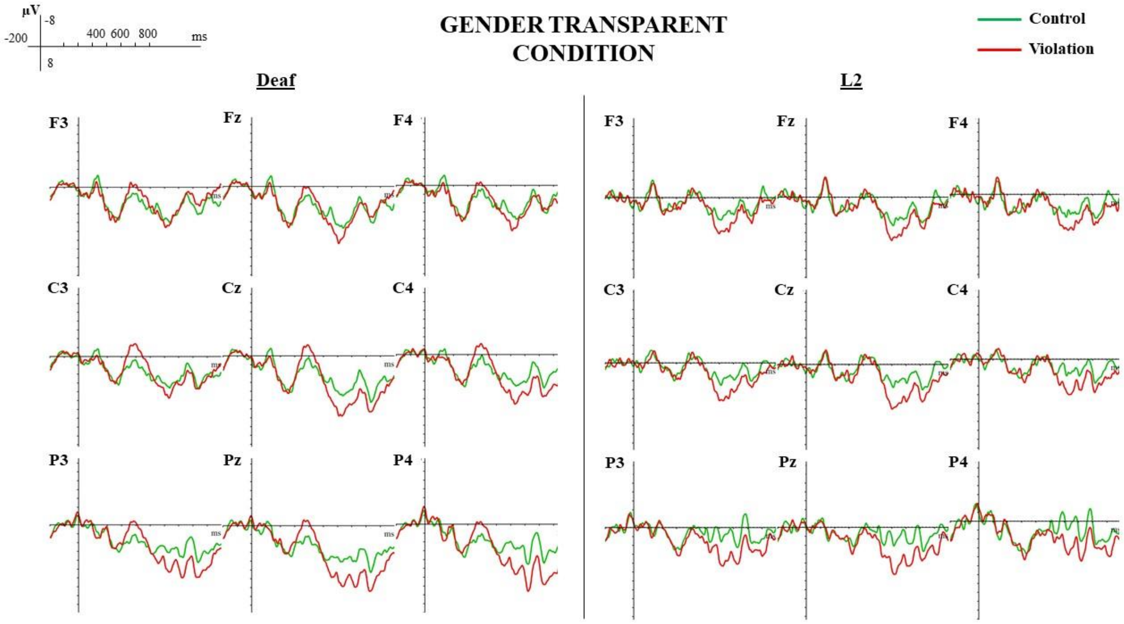


Figure 5.7. ERPs elicited in response to the congruence manipulation in the Gender Transparent condition for the deaf and L2 groups.

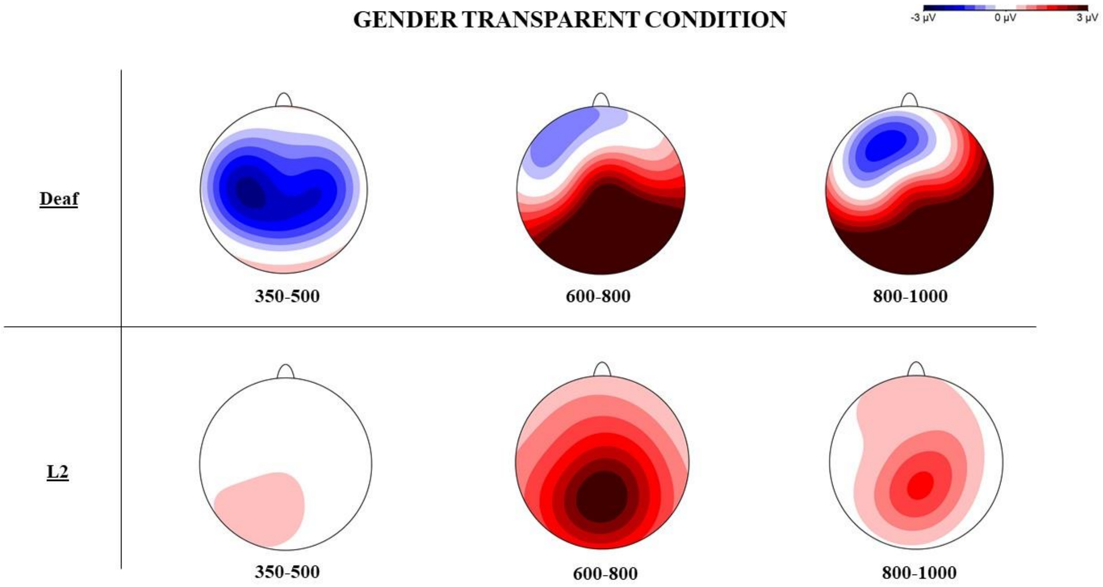


Figure 5.8. Topographic distributions of average potentials for the deaf and L2 groups in the Gender Transparent condition.

350-500 ms time-window

In this time-window, a between-group analysis did not reveal a main effect of Congruence (*F*(1,36) = 0.10, *p* = .74) or a main effect of Group (*F*(1,36) = 0.64, *p* = .42). A marginal interaction between Group and Congruence (*F*(1,36) = 3.15, *p* = .08) showed that this epoch elicited a marginal effect of Congruence for the deaf group (*t*(18) = 2.34, *p* = .06), and no effect for the L2 readers (*t*(18) = -0.30, *p* = .76).

600-800 ms time-window

A between-group analysis in this time-window showed a main effect of Congruence (*F*(1,36) = 5.75, *p* = .02) and a marginal effect of Group (*F*(1,36) = 3.03, *p* = .08). A significant interaction between Congruence and Anteriority (*F*(2,72) = 10.41, *p* = .001) and Congruence and Laterality (*F*(2,72) = 3.88, *p* = .03) was also found. Subsequent post-hoc analysis revealed that, for both groups, there was a significant effect in central-posterior areas (anterior: *t*(37) = -1.64, *p* = .10; central: *t*(37) = -3.45, *p* = .002; posterior: *t*(37) = -5.20, *p* = .001) that was more robust on the right side of the scalp (left: *t*(37) = -3.55, *p* = .001; medial: *t*(37) = -3.55, *p* = .001; right: *t*(37) = -4.05, *p* < .001).

800-1000 ms time-window

In this later time-window, a between-group analysis revealed a main effect of Group (*F*(1,36) = 5.89, *p* = .02), but no main effect of Congruence (*F*(1,36) = 2.17, *p* = .14) was observed. This epoch also yielded important group differences: An interaction between Group x Congruence x Anteriority (*F*(2,72) = 4.70, *p* = .03) and a marginal interaction between Group x Congruence x Laterality (*F*(2,72) = 3.14, *p* = .05). Follow-up analysis of these interactions showed a significant effect for the deaf group in right-posterior areas of the scalp (Anteriority: anterior: *t*(18) = 0.54, *p* = .59; central: *t*(18) = -1.40, *p* = .24; posterior: *t*(18) = -3.18, *p* = .01; Laterality: left: *t*(18) = -0.79, *p* = .43; medial: *t*(18) = -1.08, *p* = .29; right: *t*(18) = -2.81, *p* = .02), while for the L2 group there was only a marginal effect in posterior areas (Anteriority: anterior: *t*(18) = -0.98, *p* = .59; central: *t*(18) = -1.20, *p* = .24; posterior: *t*(18) = -1.75, *p* = .09; Laterality: left: *t*(18) = -1.14, *p* = .43; medial: *t*(18) = -1.43, *p* = .29; right: *t*(18) = -1.44, *p* = .16).

Gender Transparent condition: summary of the effects

In an earlier time-window (350-500 ms) the deaf group showed a marginally significant negativity without a clear topographical distribution due to the absence of an interaction with topographical factors, while the L2 readers did not show any effect in this epoch. Moreover, the 600-800 ms time-window yielded a P600 effect (i.e. P600a) that was mainly localized on the right side of central-posterior areas for both groups. Finally, in the 800-1000 ms time-window, the second phase of the P600 component (i.e. P600b), there was a significant effect only for the deaf group, in right-posterior areas, while the L2 readers showed only a marginal effect in posterior areas.

5.3.3.4 Gender Opaque condition

Figures 5.9 and 5.10 show ERPs in response to the congruence manipulation and the topographic distribution of average potentials in the Gender Opaque condition, respectively, for the L2 and the deaf group. Visual inspection of ERP waveforms for the Gender Opaque condition revealed differences between congruent and incongruent sentences for both groups. In an early time-window, only the deaf group showed a greater negativity that peaked around 400ms and looked more robust in anterior areas for the incongruent condition. This negativity was followed by a posterior positivity that did not look very robust for either of the two groups. Statistical results are given for each of the selected time-windows.

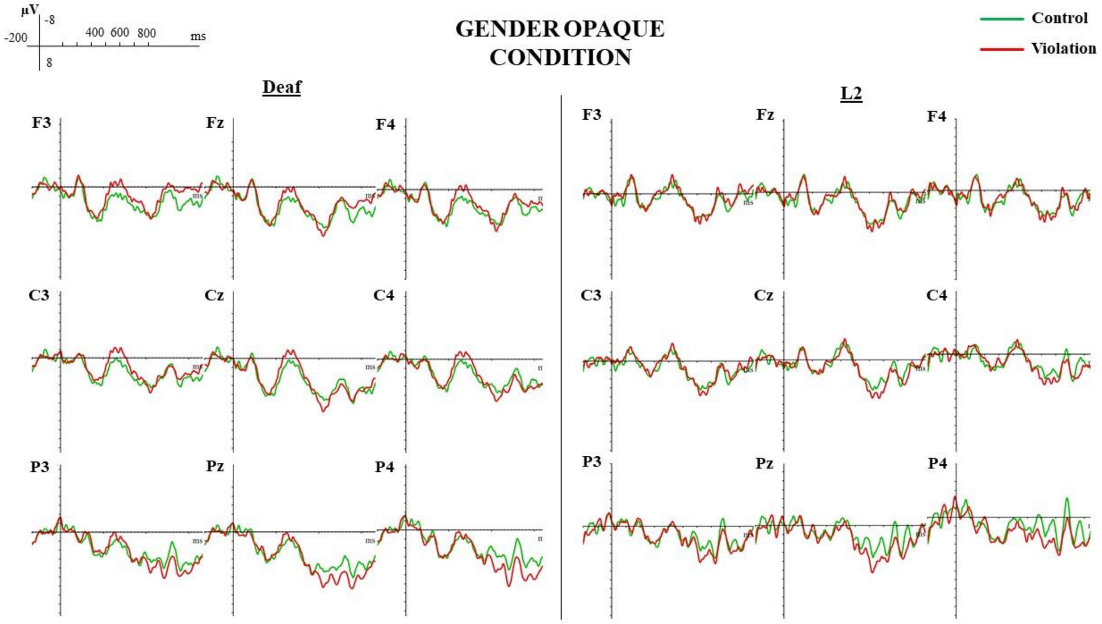


Figure 5.9. ERPs elicited in response to the congruence manipulation in the Gender Opaque condition for the deaf and L2 groups.

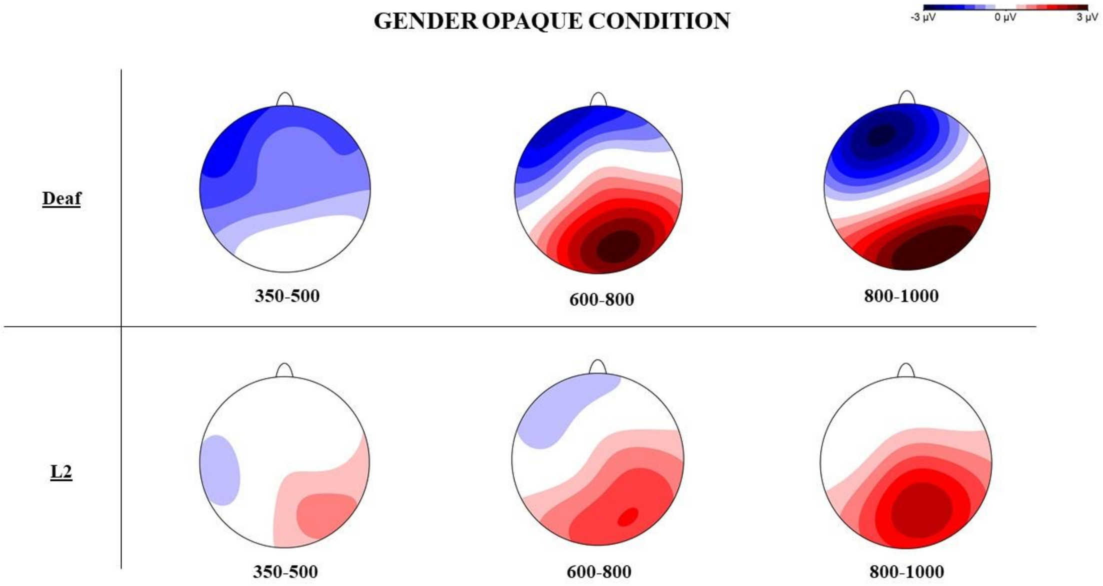


Figure 5.10. Topographic distributions of average potentials for the deaf and L2 groups in the Gender Opaque condition.

350-500 ms time-window

In this time-window, a between-group analysis did not reveal any significant main effects or interactions. However, taking into account that the deaf group showed a significant effect in this time-window for the Gender Opaque condition in the comparison performed between the hearing vs. deaf readers in chapter 4 (see section 4.2.3), and that visual inspections of ERP waveforms and topographic maps clearly show a left-biased negativity in central-anterior areas for the deaf group, a within-group analysis was run to further investigate the absence of this effect in the between-group analysis (cf. Gillon Dowens et al., 2010). This analysis showed no significant effect for the deaf group in this time-window. I will discuss the possible reasons for this null effect in further detail in section 5.3.

600-800 ms time-window

A between-group analysis in this time-window showed no main effect of Group ($F(1,36) = 0.77$, $p = .38$) or Congruence ($F(1,36) = 0.88$, $p = .35$). A significant interaction between Congruence and Anteriority ($F(2,72) = 9.26$, $p = .002$) was found, and a subsequent post-hoc analysis revealed that, for both groups, there was a significant effect only in posterior areas of the scalp (anterior: $t(37) = 0.13$, $p = .88$; central: $t(37) = -1.54$, $p = .26$; posterior: $t(37) = -2.70$, $p = .03$).

800-1000 ms time-window

In this later time-window, a between-group analysis revealed a main effect of Group ($F(1,36) = 4.42$, $p = .04$), but no main effect of Congruence ($F(1,36) = 0.04$, $p = .83$) was observed. There were interactions between Congruence x Anteriority (*F*(2,72) = 4.45, *p* = .02) and Congruence x Laterality (*F*(2,72) = 3.33, *p* = .04). However, post-hoc analysis of these two interactions did not yield any significant comparison (all *p*s > .05). Similarly, although the three-way interaction between Group x Congruence x Anteriority (*F*(2,72) = 4.70, *p* = .03) was found to be significant, the follow-up analysis did not yield any significant simple effects. Since the deaf group showed a significant effect in the ANOVA performed with the hearing group (see chapter 4), a within-group analysis was run for the deaf group: a marginal interaction between Congruence and Anteriority was found but post-hoc analysis failed to show any significant effects (all *p*s > .05).

Gender Opaque condition: summary of the effects

In the earlier time-window (350-500 ms) the between-group analysis revealed no significant effect for either of the two groups. In contrast, the 600-800 ms time-window yielded a P600a effect for both groups which was localized in posterior areas of the scalp. Finally, in the 800-1000 ms time-window no significant effect was found for either of the two groups.

5.3.3.5 Summary of ERP results for all conditions

Table 5.4 summarizes the overall ERP results found for the L2 and the deaf group.

Table 5.4. Summary of the ERP results for the four conditions.

Summary of the results		
Condition	**L2**	**Deaf**
Semantic	N400 + P600b	N400 + P600b
Number	P600ab	N400-like + P600ab
Gender Transparent	P600a	N400-like + P600ab
Gender Opaque	P600a	P600a

5.3.4 Post-EEG task

The same Lexical Decision and Gender decision tasks that were performed by the hearing and deaf groups was also run for the L2 group. Further details of these tasks can be found in chapter 3 (see section 3.2).

Results

Overall, deaf participants outperformed L2 participants in both the lexical decision task and the Gender task. The distribution of scores in these two tasks is presented in Figures 5.11 and 5.12. In the lexical decision task, deaf readers were significantly more accurate than L2 readers on deciding whether the presented lexical item was a word or a pseudoword (Maximum possible score = 260; Deaf: M = 243.05, SD = 9.42; L2: M =

232.05, *SD* = 18.44; *t*(36) = 2.31, *p* = .02). Deaf readers were also better than L2 readers in the gender decision task (Maximum possible score = 80; Deaf: *M* = 77.21, *SD* = 2.14; L2: *M* = 70.21, *SD* = 5.75; *t*(36) = 4.96, *p* < .001). These results show that the L2 group was not so familiar with the lexical items presented in the main experiment or with their gender. This result goes a good way to explaining their low performance in the sentence acceptability judgment task since L2 readers were not very accurate in discriminating violations from control sentences, especially in the case of gender transparent and opaque condition (see section 5.2.2).

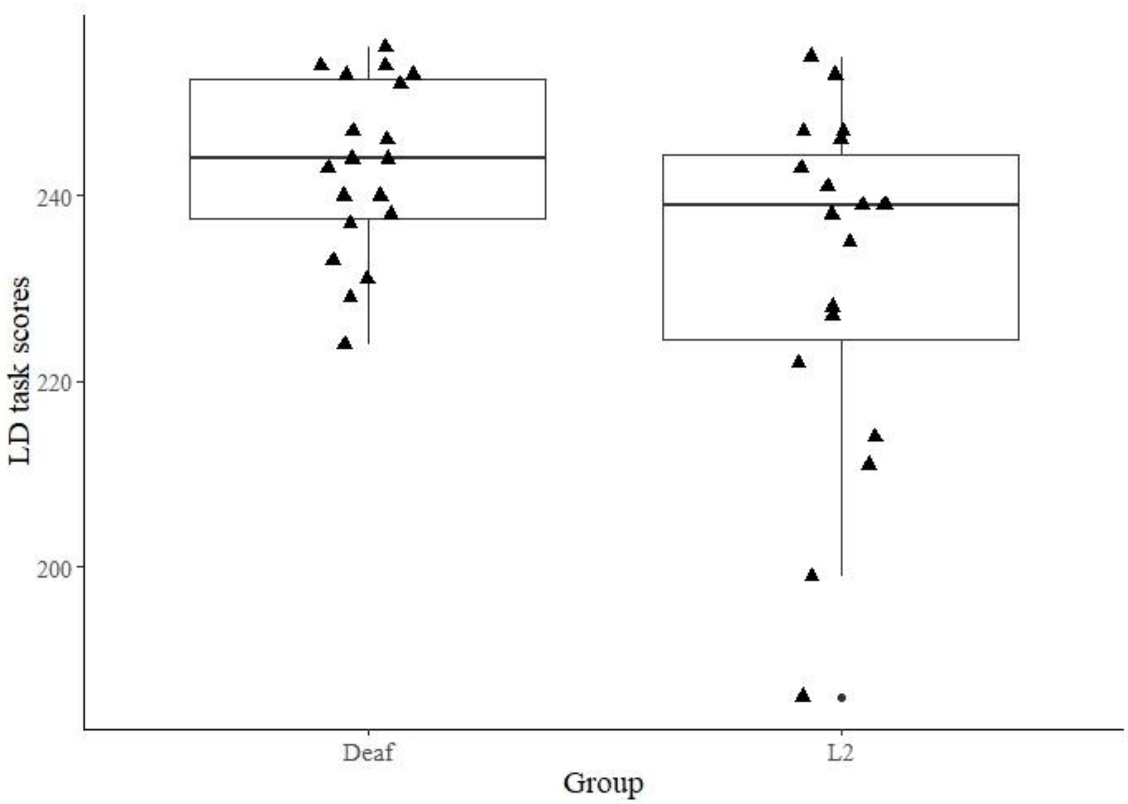


Figure 5.11. Distribution of lexical decision task scores for L2 and deaf participants.

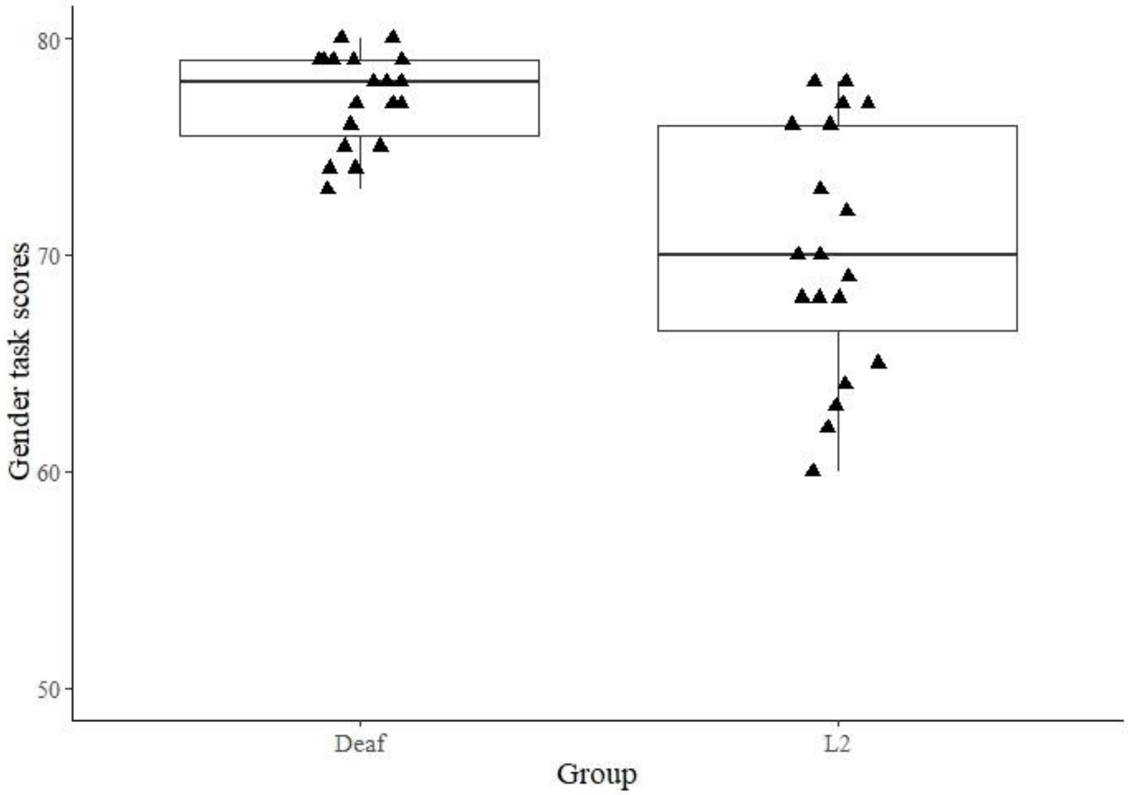


Figure 5.12. Distribution of Gender identification task scores for L2 and deaf participants.

5.3.5 Individual difference analysis

5.3.5.1 Correlations between different ERP effects

As explained in chapter 4 (see section 4.2.5), previous studies have suggested that a biphasic pattern of ERP responses may serve as an indicator of individual differences for both native and second-language learners (Tanner et al., 2014, 2013; Tanner & Van Hell, 2014). Although in the average of ERP responses for the L2 reader groups there was a biphasic response only for the Semantic condition, a visual inspection of individual waveforms in the four conditions showed that some individuals were actually showing a biphasic N400/LAN-P600 pattern. Therefore, in order to identify the relationship between these ERP effects in each of the conditions a further investigation of individuals' electrophysiological profiles was conducted.

Similar to the procedure performed in chapter 4, the mean activity over central-parietal region of interest, namely central-parietal ROI (C3, Cz, C4, CP1, CP2, P3, Pz, P4), where N400 and P600 effects are typically stronger was calculated (following (Tanner et al., 2014; Tanner & Van Hell, 2014), as well as a frontal central ROI (F3, Fz, F4, FC1, FC2, C3, Cz, C3) where the LAN effects are usually located. Subsequently, within these ROIs (i.e. central-posterior for N400 and P600 and frontal-anterior for LAN), I calculated each individual's LAN/N400 effect magnitude (grammatical minus ungrammatical condition in the 350–500ms time-window) and P600 effect magnitude (ungrammatical minus grammatical condition in the 600–1000ms time-window), separately. A correlation analysis between effect magnitudes (i.e. LAN/N400 and P600) was run for each condition in both groups. A visual presentation of these relationships will be shown only for those cases for which there are significant results. Moreover, following the same procedure that was adopted in chapter 4, whenever a significant effect is observed, I perform a follow-up analysis removing outliers (if there are any) to check how reliable the effect is (see section 4.3.5.1 for details).

Semantic condition: N400 ~ P600

The biphasic N400 and P600 effect found in the Semantic condition revealed a different type of relationship between the N400 and the P600 in each group. For the L2 group, no significant correlation between these two effects was found ($r(17) = -.27$, $p = .25$), while that for the deaf group, a significant negative correlation between the N400 and the

P600 effect was observed (*r*(17) = -.54, *p* = .01), even when outliers were removed (2.5 SDs from the mean: 2 outliers were removed; *r*(15) = -.53, *p* = .02). Figure 4.14 illustrates these correlations.

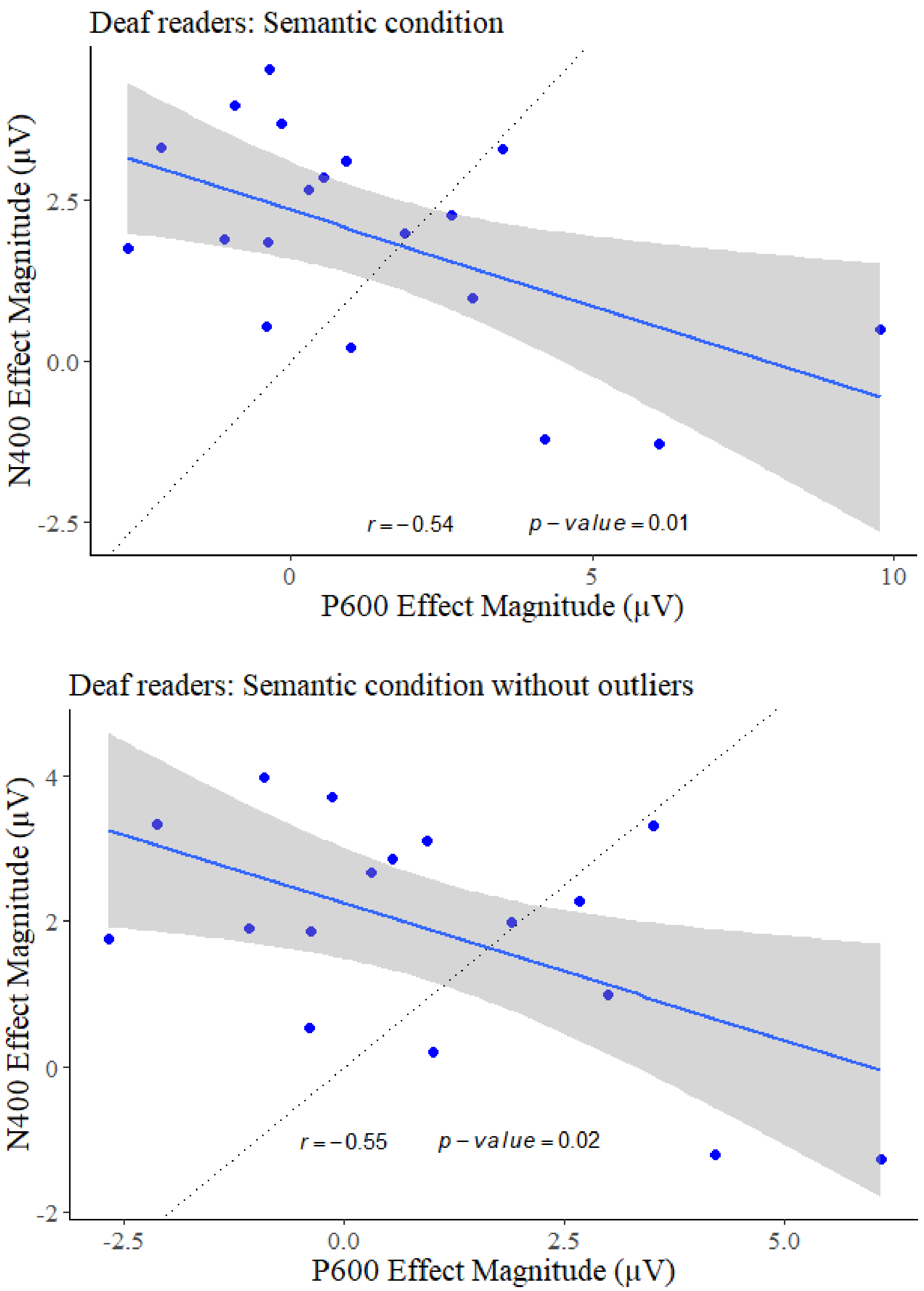


Figure 5.13. Scatterplots showing the relationship between N400 and P600 effect magnitudes for the deaf group in the Semantic condition with outliers (top) and without outliers (bottom), averaged within a central-parietal ROI (C3, Cz, C4, CP1, CP2, P3, Pz, P4). The solid line indicates the best-fit line from the correlation analysis for this condition. The dashed lines represent equal N400 and P600 effect magnitudes (i.e. a perfect positive correlation): individuals above/to the left of the dashed line showed primarily an N400 effect to violations, while individuals below/to the right of the dashed line showed primarily a P600 effect.

Number condition: N400 ~ P600

For the Number condition, the L2 group showed a very robust negative correlation between the N400 and P600 effect ($r(17) = -.78$, $p < .001$), that remained significant after cleaning for outliers (2.5 SDs from the mean: 2 outliers were removed; $r(15) = -.67$, $p = .002$). Both correlations are shown in Figure 5.13. For the deaf group, no significant correlation between these two ERP effects was found ($r(17) = -.19$, $p = .43$).

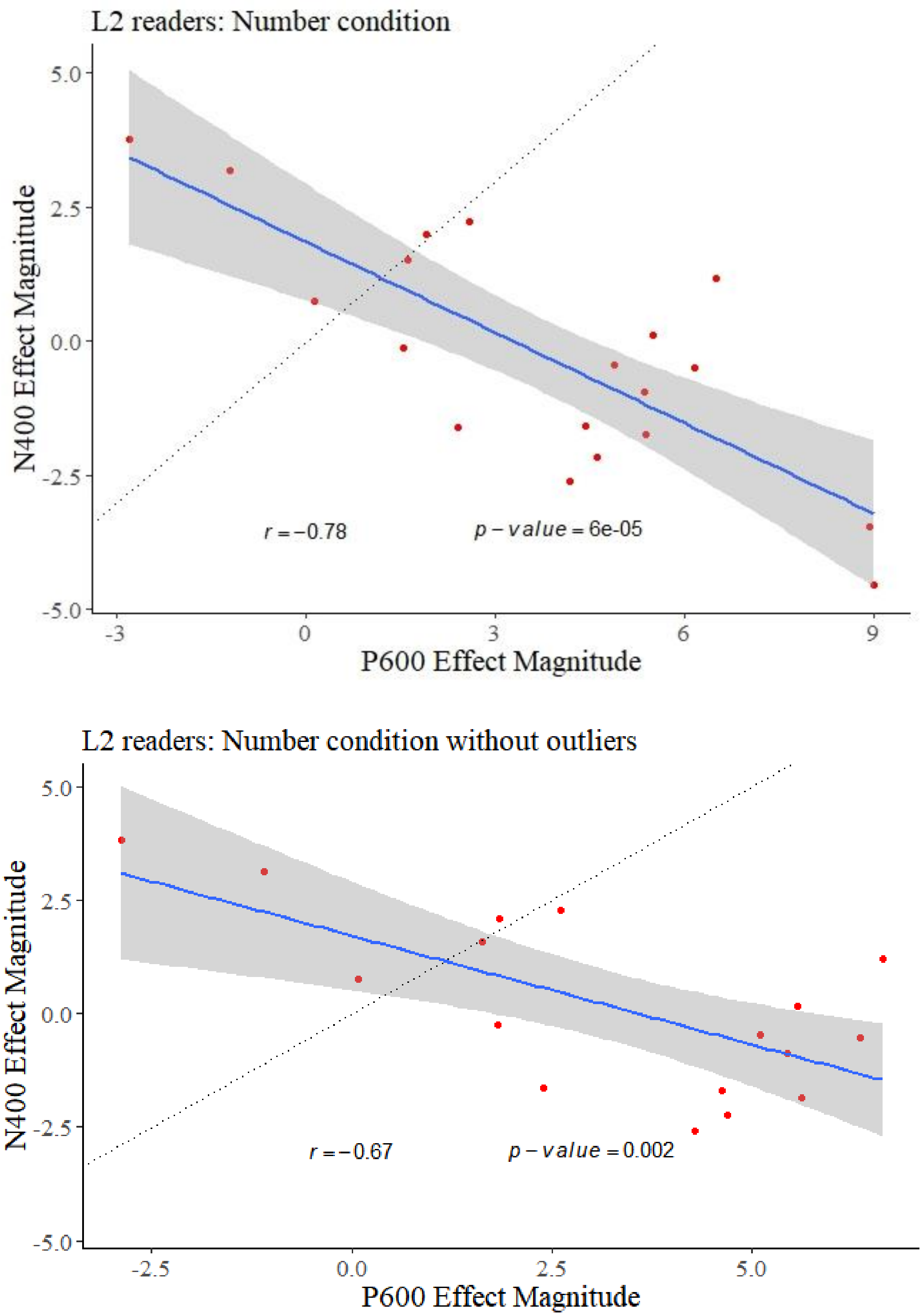


Figure 5.14. Scatterplots showing the relationship between N400 and P600 effect magnitudes for the L2 group in the Number condition with outliers (top) and without outliers (bottom), averaged within a central-parietal ROI (C3, Cz, C4, CP1, CP2, P3, Pz, P4). The solid line indicates the best-fit line from the correlation analysis for this condition. The dashed lines represent equal N400 and P600 effect magnitudes (i.e. a perfect positive correlation): individuals above/to the left of the dashed line showed primarily a N400 effect to violations, while individuals below/to the right of the dashed line showed primarily a P600 effect.

Gender Transparent: N400 ~ P600

In this condition, the L2 group also showed a strong negative correlation between the N400 and the P600 effect ($r(17) = -.71$, $p < .001$), that remained significant after cleaning for outliers (2.5 SDs from the mean: 1 outlier was removed; $r(16) = -.66$, $p = .002$). Results are shown in Figure 5.14. The correlation between these ERP effects for the deaf group did not reach significance ($r(17) = -.26$, $p = .26$).

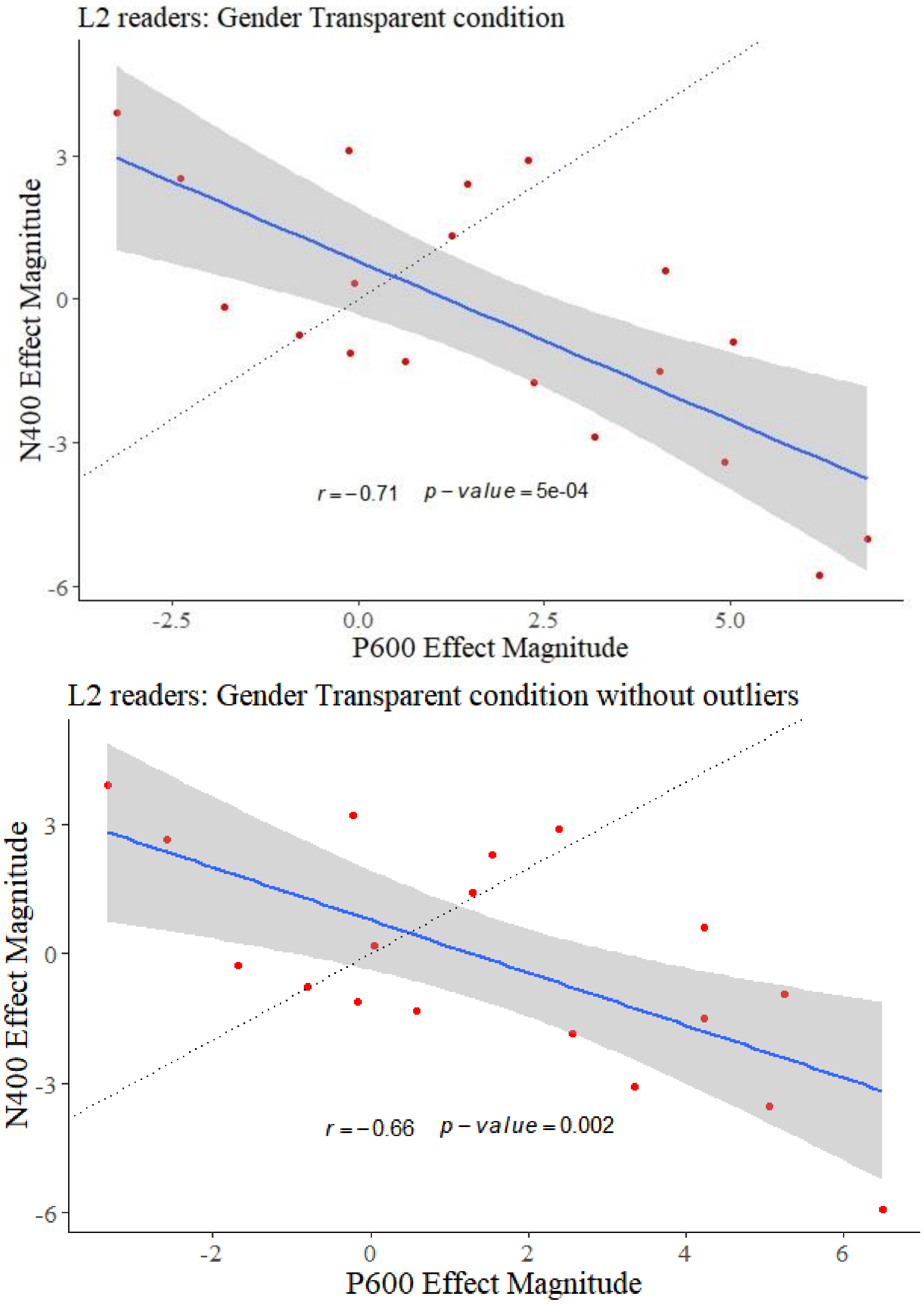
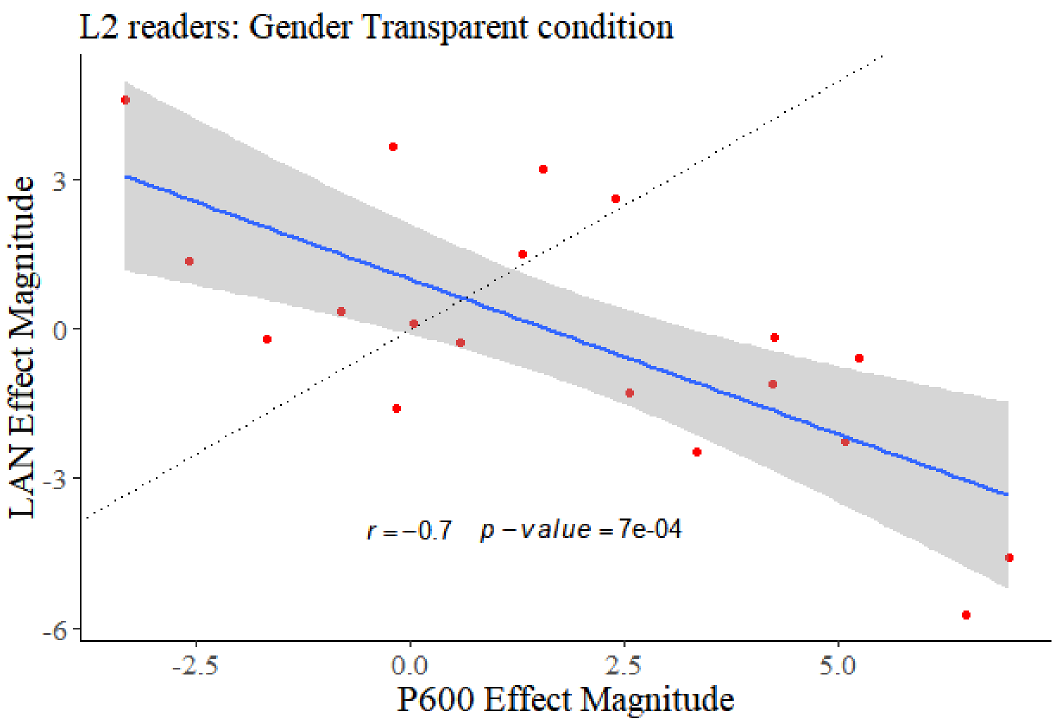


Figure 5.15. Scatterplots showing the relationship between N400 and P600 effect magnitudes for the L2 group in the Gender Transparent condition with outliers (top) and without outliers (bottom), averaged within a central-parietal ROI (C3, Cz, C4, CP1, CP2, P3, Pz, P4). The solid line indicates the best-fit line from the correlation analysis for this condition. The dashed lines represent equal N400 and P600 effect magnitudes (i.e. a perfect positive correlation): individuals above/to the left of the dashed line showed primarily a N400 effect to violations, while individuals below/to the right of the dashed line showed primarily a P600 effect.

Gender Transparent: LAN ~ P600

An individual analysis including a central-anterior ROI was also run to check if this correlation would flip its trend if a central-anterior ROI (where the LAN effect is usually stronger) was used instead, similar to what was performed in chapter 4 for hearing and deaf participants (see section 4.3.5.1). The correlation between the LAN effect and the P600 for the L2 group was significant and negative ($r(16) = -.70$, $p < .001$), very similar to the correlation performed using a central-posterior ROI. Importantly, removing outliers (2.5 SDs from the mean: 1 outlier was removed) did not affect this correlation as it remained significant ($r(16) = -.64$, $p = .003$). Results for this group are shown in Figure 5.15. For the deaf group, the correlation between LAN and P600 in this condition was also negative although did not reach significance.



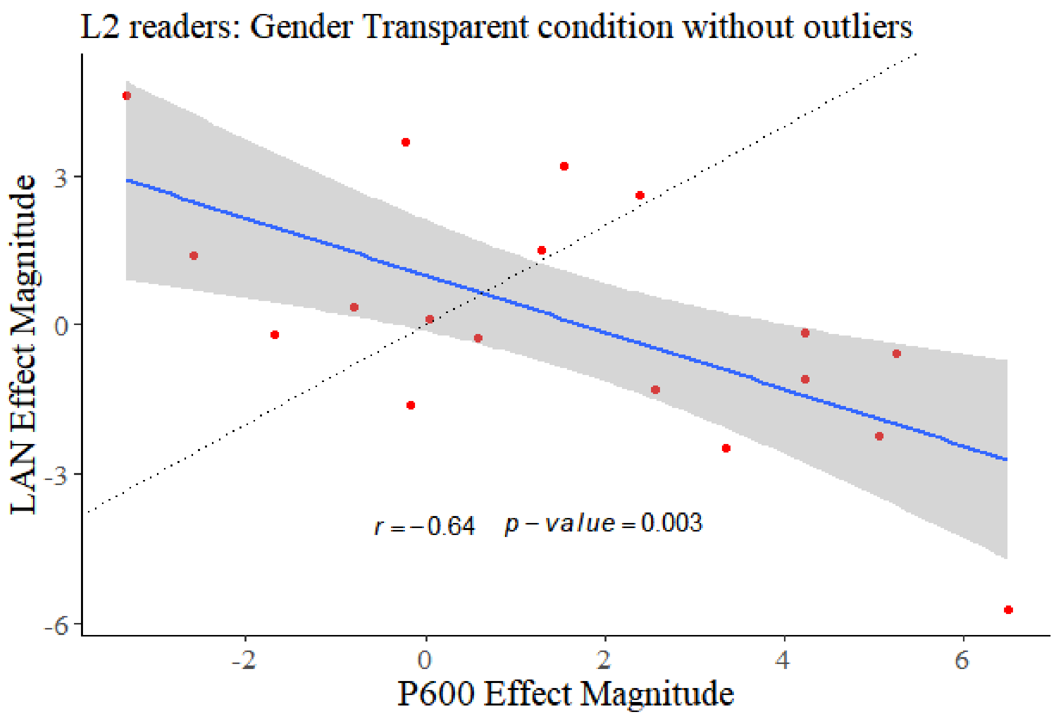


Figure 5.16. Scatterplots showing the relationship between N400 and P600 effect magnitudes for the L2 group in the Gender Transparent condition with outliers (top) and without outliers (bottom), averaged within a central-parietal ROI (C3, Cz, C4, CP1, CP2, P3, Pz, P4). The solid line indicates the best-fit line from the correlation analysis for this condition. The dashed lines represent equal N400 and P600 effect magnitudes (i.e. a perfect positive correlation): individuals above/to the left of the dashed line showed primarily a N400 effect to violations, while individuals below/to the right of the dashed line showed primarily a P600 effect.

Gender Opaque: N400 ~ P600

For the Gender Opaque condition the L2 group also presented a significant negative correlation between the N400 and the P600 effect (*r*(17) = -.74, *p* < .001). No outliers were observed. This result is shown in Figure 5.16. Once more, the correlation between these ERP effects was not statistically significant for the deaf group.

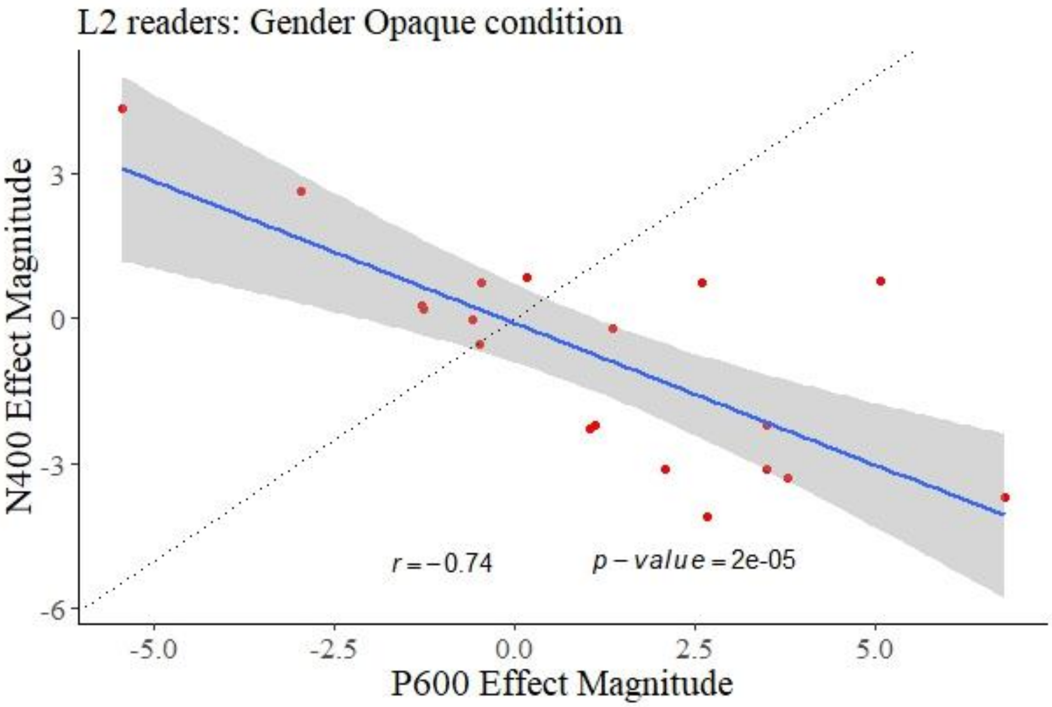


Figure 5.17. Scatterplots showing the relationship between N400 and P600 effect magnitudes for the L2 group in the Gender Opaque condition, averaged within a central-posterior ROI (C3, Cz, C4, CP1, CP2, P3, Pz, P4). The solid line indicates the best-fit line from the correlation analysis for this condition. The dashed lines represent equal N400 and P600 effect magnitudes: individuals below/to the right of the dashed line showed primarily a P600 effect, while individuals above/to the left of the dashed line showed mainly a N400 effect.

Gender Opaque: LAN ~ P600

An individual analysis including a central-anterior ROI was also run for Gender Opaque to check if this correlation would flip its trend if a central-anterior ROI is used instead. Strikingly, this analysis yielded a strong positive correlation between the LAN and the P600 effect for the L2 group (*r*(17) = .62, *p* = .004; see Figure 5.17). No outliers were present for this group. No significant correlation was observed for the deaf group.

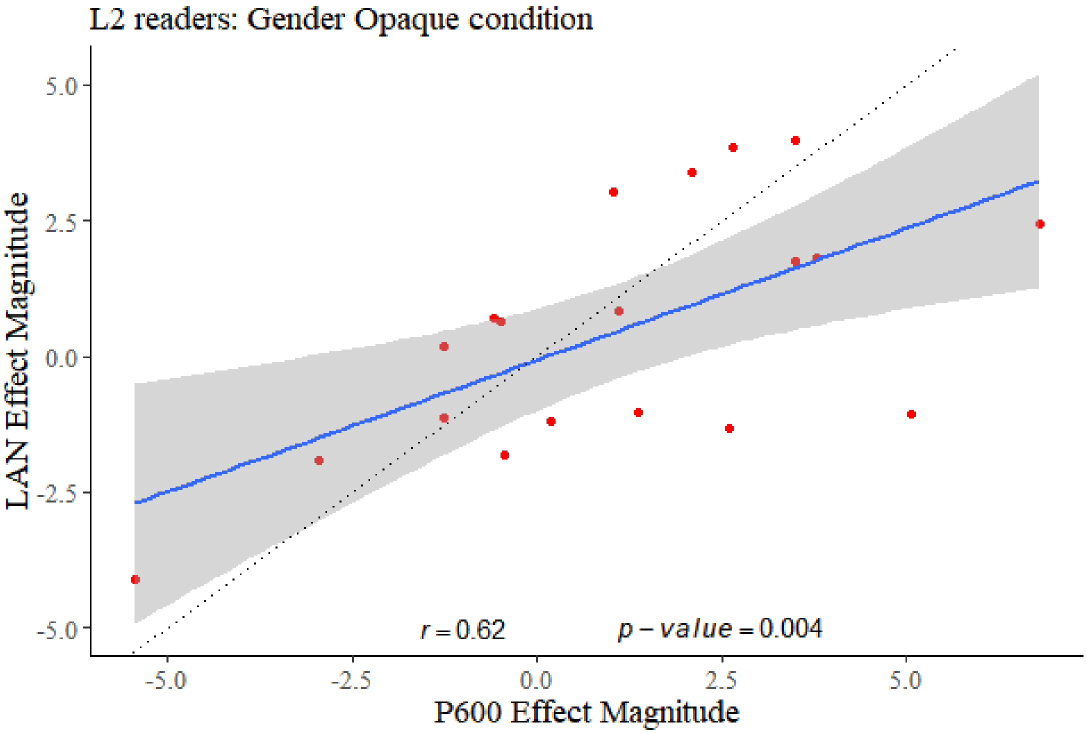


Figure 5.18. Scatterplots showing the relationship between LAN and P600 effect magnitudes in the L2 group for the Gender Opaque condition, averaged within a central-anterior ROI (F3, Fz, F4, CP1, CP2, C3, Cz, C4). The solid line indicates the best-fit line from the correlation analysis for this condition. The dashed lines represent equal LAN and P600 effect magnitudes: individuals below/to the right of the dashed line showed primarily a P600 effect, while individuals above/to the left of the dashed line showed mainly a LAN effect.

Since the grand mean result of ERP waveforms for the L2 group did not yield any significant results in an early time-window (see section 5.2.3) for the Gender Opaque condition, a visual inspection of the individual topographic maps was conducted to better understand the correlation pattern observed here: a negative correlation when a central-posterior ROI is used for the N400 and a positive correlation when central-anterior ROI is adopted instead. Figure 5.17 shows that Gender Opaque violated sentences elicited different types of negativities across subjects in the L2 group. It is possible that similar to what was found in the individual analysis conducted in chapter 4 (see section 4.2.5), these positive-negative correlations could be indicating that both type of biphasic responses (LAN/P600 or N400/P600) were present in the data, although not strong enough to be statistically significant. I will return to this in the discussion section.

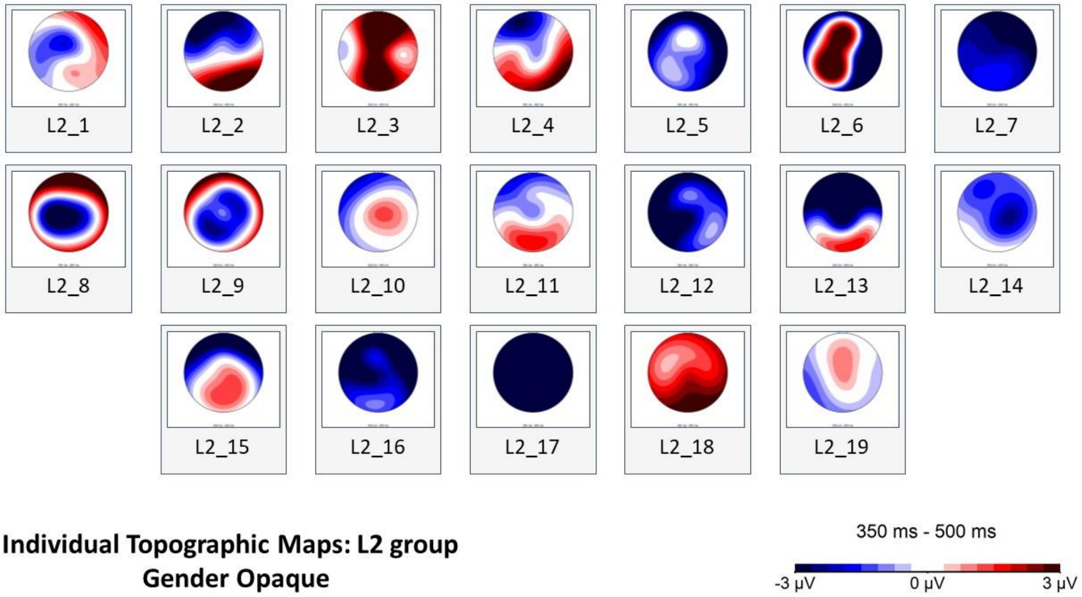


Figure 5.19. Individual topographical maps in the Gender Opaque condition for the L2 group showing that some subjects showed a N400-like response while others showed a LAN-like response. These negativities, however, were not robust enough to reach significance as statistical results did not show a Congruence effect for this group in an early time-window (350-500ms).

5.3.5.2 Correlations between ERP and behavioral measures

Following what was done in previous studies (see Mehravari et al., 2017) a correlation analyses between the reading comprehension task and ERP effects was performed. Generally, level of reading comprehension was significantly correlated with ERP effects only for the Number and Gender Transparent condition, but not for the Semantic and Gender Opaque condition. These results can be found in Table 5.6.

Moreover, since previous studies that investigated second-language learners have demonstrated that L2 learners' ability to detect agreement anomalies (i.e. d-prime scores for accuracy on the sentence acceptability task) increases linearly with their elicited P600 effect, which is not the case for native readers (Tanner et al., 2013), another correlation analysis between Sentence Acceptability task and ERP effects was also carried out to test if this was the case for our participants. These results are shown in table 5.7. Different to what was observed for hearing native and deaf participants, d-prime scores for the L2 group significantly correlated with the main ERP effects elicited in various conditions. These results indicated that the better their capacity to discern violations the bigger the ERP effects elicited, especially for the conditions in which orthographical cues were present (i.e. number and gender transparent).

Table 5.6.
Correlation coefficients (*r*) for the relationship between ERP effect magnitudes and Reading Comprehension scores for L2 learners.

	Reading Comprehension Task			
	Semantic	Number	Gender Transparent	Gender Opaque
LAN/N400 effect	0.1	-0.33	-0.35	0.08
P600 effect	-0.03	**0.57****	**0.49***	-0.01

(**$p < 0.01$. *****$p < 0.05$. •$p < 0.1$)

Table 5.7.
Correlation coefficients (*r*) for the relationship between ERP effect magnitudes and Sentence Acceptability Task (d-prime scores) for L2 learners.

	Sentence Acceptability Task			
	Semantic	Number	Gender Transparent	Gender Opaque
LAN/N400 effect	**0.44•**	-0.29	**-0.40•**	0.19
P600 effect	-0.11	**0.59****	**0.59****	**0.44•**

(**$p < 0.01$. *****$p < 0.05$. •$p < 0.1$)

A correlation matrix containing a summary of all correlation measures (i.e. behavioral measures, d-prime scores and ERP effects) is presented in the Appendix section for a more complete overview (see sections F to I).

5.4 Discussion and conclusions

As previously discussed in chapter 2, L2 learners are a valuable source of information to shed light on how the process of a second language representations evolve from beginners to advanced language users (see section 2.2.3 for further details). Understanding how L2 learners process language might also contribute to understanding how deaf people acquire and process a written language as many researchers consider deaf readers to be a type – albeit a special kind – of L2 learner: sign-print bilinguals (Hoffmeister & Caldwell-Harris, 2014; Piñar et al., 2011). Therefore, the present results contribute to the identification of possible similarities as well as differences between deaf readers and hearing L2 learners.

Our results showed that high-skilled deaf readers and English speakers who are proficient L2 learners of Spanish elicit a similar pattern of ERP when dealing with semantic errors, indicating they use similar brain mechanisms to processes semantic information, in line with our initial predictions. However, the groups presented different ERP patterns in response to morphosyntactic violations (i.e. number and gender), suggesting that deaf readers do not process grammatical information in the same way that high-proficient L2 learners of Spanish do. This provides new evidence showing that, generally, high-skilled deaf readers process reading in a native-like fashion, different from high-proficient L2 readers of Spanish.

5.4.1 Semantic condition

Results from the Semantic condition showed that both deaf and L2 readers elicited a N400 effect for incongruent sentences relative to congruent sentences. Semantic violations also elicited a significant P600 effect in both groups. This effect, however, was only significant in its second phase (i.e. 800-1000 ms). In line with this, sentence acceptability scores revealed that both groups showed similar behavioral performance as there was no difference in accuracy for the Semantic condition between the two.

Previous studies suggest that the processing of semantic information is assimilated faster and usually appears before the acquisition of grammatical information (McLaughlin et al., 2004, 2010; Osterhout et al., 2006). Novice L2 learners need little instruction to acquire basic semantic knowledge of a language as revealed by the presence of a N400 effect for lexical-semantic tasks after little instruction of a new language (Osterhout et al., 2006). Therefore, the present results confirmed our predictions that both deaf readers and L2 readers would elicit a N400 effect for semantically incongruent sentences. We hypothesized that L2 readers might show a delay on the onset of the N400 effect (Braunstein et al., 2012; Moreno & Kutas, 2005); this was not the case and confirms that the L2 sample had sufficient levels of proficiency since this delay is associated with low proficiency learners.

Furthermore, semantic violations also elicited a positivity that was significant only in the later 800-1000 ms time-window. Although the P600 effect is generally associated with morphosyntactic processing, it is also common to find a positive deflection following a N400 effect in both native (Guajardo & Wicha, 2014; Moreno & Kutas, 2005; Ojima et al., 2005; Van de Meerendonk et al., 2009) and L2 learners (Bowden et al., 2013; Moreno & Kutas, 2005; Newman et al., 2012). As explained in chapter 4, this positivity reflects mismatches between the expected and the encountered item and, therefore, trigger revision and reanalysis/repair processes (Molinaro et al., 2008; Sassenhagen et al., 2014; Van de Meerendonk et al., 2009; for a review see Molinaro et al., 2011). Furthermore, this biphasic pattern for semantic violations can also be explained by different factors such as individual differences, working memory, and contextual constraint (Kos, Van den Brink, & Hagoort, 2012).

Finally, individual analysis revealed that L2 readers' scores for the acceptability judgment task positively correlated with this N400 effect, suggesting that, for this group, the better they were at distinguishing semantic violated sentence from control sentences, the stronger the N400 effect. This correlation was not observed for deaf readers (see section 4.5.2.2); the difference may be due to greater variability in the L2 group, which made it possible for the correlation to emerge. This correlation pattern between d' scores and ERP effects has been previously reported for L2 readers, but not for native readers (see Tanner et al., 2013), demonstrading that L2 learners' ability to detect agreement anomalies positively increases with their elicited P600 effect, which is not the case for native readers. Conversely, no other behavioral measures predicted the N400 effect for L2 learners.

5.4.2 Number condition

The Number condition showed a different pattern of results between deaf and L2 readers. In the early time-window, the L2 group did not show a N400 effect for ungrammatical sentences, in contrast to the deaf group, who showed a significant negativity for violated sentences relative to correct sentences. Subsequently, both groups elicited a significant effect in the first and second phases of the P600 effect in response to number violations, although some differences between these effects were observed. In the P600a time-window (600-800 ms) both groups elicited a broadly distributed effect that was more robust in central-posterior areas of the scalp, but the effect was more robust for the deaf group in comparison to the L2 learners. Additionally, both groups showed a greater positivity for incorrect sentences in the 800-1000 ms time-window, but this effect was more robust effect in posterior areas for the deaf group, while the L2 readers presented a more broadly distributed P600b effect.

In the early time-window, no effect was found for the L2 group while a N400-like was elicited by deaf readers in response to number disagreement. As explained in chapter 4 (see section 4.4.2.1), both markedness (singular vs. plural) and semantic integration (as number has a semantic component that is interpretable) might explain the presence of a N400 during number violations for the deaf group. In contrast, the absence of a negativity in response to morphosyntactic violation has been previously reported in studies that investigated number disagreement in high-proficient L2 learners (Alemán Bañón et al., 2014; Alemán Bañón & Rothman, 2016; Gillon Dowens et al., 2010). For example, Gillon Dowens and colleagues (Gillon Dowens et al., 2010) showed that English speakers who are late and high-proficient users of Spanish elicit a native-like biphasic LAN-P600 in response to within-phrase number violations, but elicit only a P600 effect in response to across-phrase number violations. Processing local, within-phrase violations is much less costly since the determiner and the noun are proximate, making it easier to identify the incongruence. In contrast, across-phrase violations are more difficult to detect because the grammatical feature-checking involves a greater distance with an intervening element (the verb) in between. This makes such violations costly to process, even for native speakers (Gillon Dowens et al., 2010; see Deutsch & Bentin, 2001). Additionally, an absence of a LAN effect for number violation in Spanish was also reported for Chinese native speakers who were high-proficient late learners of Spanish (Gillon Dowens, Guo, Guo, Barber, & Carreiras, 2011). Similar to the case of English, number agreement between noun-adjective does not occur in Chinese, and the absence of a significant LAN for this condition might evidence their difficulty in detecting this type of error in a more automatic way. Mueller (2005) argues that even if an L2 speaker acquires native-like linguistic knowledge, it is possible that L2 parsing will be regulated by different neural mechanisms to those observed in L1 syntactic processing. Importantly, number agreement in English only exists in the verbal domain between the subject and the verb (and in a limited way in the nominal domain with some determiners), but never between noun and adjective as is the case of number agreement in Spanish. Due to the absence of this specific grammatical feature in their native language, English speakers who are L2 learners of Spanish might struggle with number agreement as they cannot use positive transfer to facilitate parsing processes and need to develop a new representation of these grammatical dependencies in the new language (Kotz, 2009). This does not mean that L2 learners cannot learn syntactic features that are not present in their L1. The full transfer and full access model (Schwartz & Sprouse, 1996) maintains that L2 learners are able to assimilate and accommodate new grammatical features in a second language, even when these rules are not present in their L1. However, these features are acquired slowly when compared to grammatical structures that are already present in the L1 (White, Valenzuela, Kozlowska-macgregor, & Leung, 2004). Therefore, the absence of a LAN response for our L2 participants suggests that although they were processing number agreement as evidenced by the presence of a P600 effect, the detection of the error was less automatic in comparison to the deaf group as there was no evidence of a negativity in an earlier time-window. Furthermore, even in the absence of a significant negativity for the L2 readers, individual analysis showed a negative correlation between the

N400 and P600, suggesting that any early negativity present in the L2 group was N400-like in nature and not evidence of a LAN. A similar pattern was also observed for the (combined) analysis for the deaf and hearing group (see section 4.2.5.1). Before looking at the individual analysis, I now turn to the results of later positivity.

A P600 effect was detected for both groups in both its phases. The distribution of the P600 was very similar in both groups in its first phase (600-800 ms), but a different pattern emerged in the later time-window for the deaf group: the L2 readers showed a widely distributed P600b effect, but the deaf group showed a more classical right-posterior P600 effect in this later time-window (see Figure 5.20).

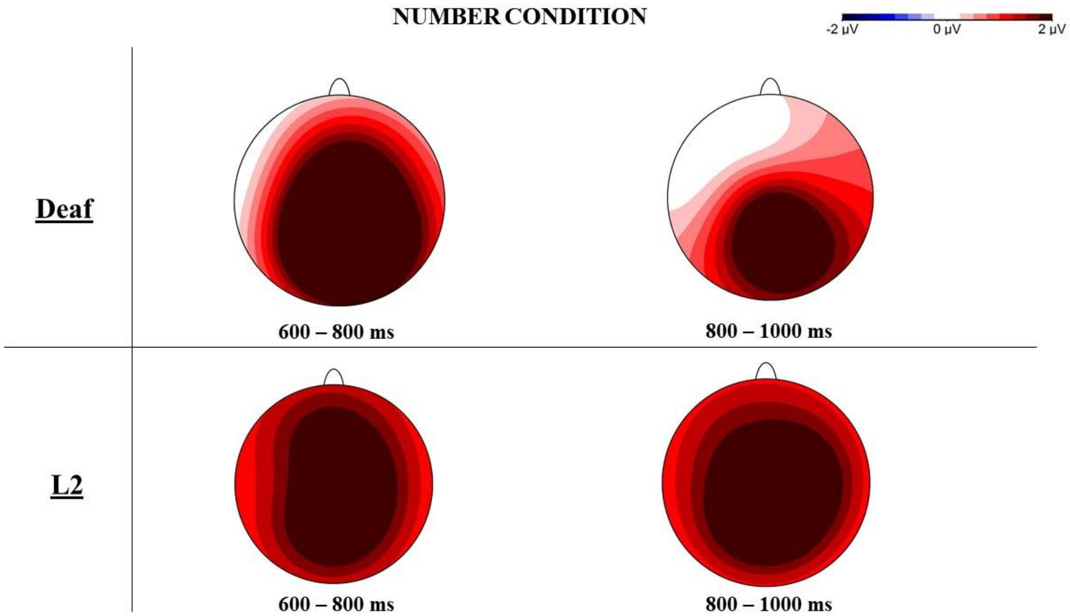


Figure 5.20. Comparison of the scalp distribution of the P600 effect for deaf and L2 readers in the Number condition.

The broadly distributed positivity that was observed for both groups in the P600a time-window could be indicating that they needed to use additional cognitive resources to perform integration processes. Specifically, previous studies have showed that non-natives tend to elicit a P600 effect that is larger and more spatially widespread compared to native speakers' response and that this broad distribution of the P600 may reflect recruitment of additional cognitive resources in order to compensate for reduced (or even absent) presence of those more automatic processes that are usually reflected by the presence of an early anterior negativity (Pakulak & Neville, 2011). The L2 group showed this same widespread P600 pattern in the reanalysis and repair phase (800-1000 ms), while deaf readers showed a more localized central-posterior effect, similar to the typical P600 response from native readers. Since noun-adjective number agreement is a feature that is not present in English, L2 readers might require greater cognitive effort to accommodate this agreement feature, although they are still able to perform integration (P600a) and reanalysis processes (P600b).

In the case of deaf readers, although they show a similar widespread P600a pattern, this need for extra cognitive resources during language processing seems to be attenuated in the P600b as they elicited a more focal P600b effect compared to the L2 group. It might be the case that because deaf readers have Spanish as their dominant language for reading, they show a mixed-pattern of response: in some epochs their processing is less native-like (i.e. P600a) and at other timepoints it is more native-like (i.e. P600b).

Finally, even though the L2 readers group did not show a significant negativity in an early time-window, an analysis of individual ERP responses was run to account for the variability of responses at the individual level. Results showed that for the L2 readers there was a strong negative correlation between a possible N400 effect[25] and the P600 response (see figure 5.4). This suggests that for L2 participants the more present one effect was, the

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[25] A possible effect in sense that there was no evidence of a N400 response for the L2 group in this condition at the group level.

less present the other. This finding is supported by two further results: the size of the P600 effect also correlated with scores for reading comprehension (see Table 5.6) and for the Sentence acceptability task (see Table 5.7). This provides converging evidence that the more proficient a L2 reader's command of the language (as reflected by reading comprehension and error detection), the more likely she will have a P600 response – and the less likely a N400 response – to violations in number agreement, in line with previous ERP work on morphosyntactic processing in L2 learners (Osterhout et al., 2006; Tanner et al., 2013).

Summary

Overall, deaf and L2 readers presented a different pattern of results for the Number condition. Specifically, L2 readers failed to elicit a negativity in an early time-window, while deaf readers showed a N400-like effect that could represent the use of form-based regularities to apply syntactic predictions or semantic integration processes as number carries a notable semantic component. In a later time-window, a widespread positivity was elicited by both groups; the L2 group showed a more widespread pattern of activation in the last phase of the P600 effect, possibly representing a need for more cognitive resources to perform reanalysis and repair processes to handle number agreement.

5.4.3 Gender Transparent condition

Results for the Gender Transparent condition revealed that the deaf group elicited a marginal N400-like effect in the 350-500 ms time-window without a clear topographical distribution (i.e. no interaction between Congruency and Topographical factors), while the L2 readers did not elicit any effect in this epoch. Moreover, the 600-800 ms time-window yielded a P600a effect for both groups that was mainly localized on the right side of central-posterior areas. Finally, in the 800-1000 ms time-window, the second phase of the P600 effect was significant only for the deaf group, as the L2 readers yielded only a marginal effect in posterior areas.

Gender processing in Spanish has been widely investigated in both native and L2 learners (Alemán Bañón et al., 2014; Gillon Dowens et al., 2011; Wicha et al., 2004). Across-phrase gender violations typically elicit a P600 effect for native readers and L2 learners that is sometimes preceded by a LAN effect, although this negativity is not always observed, especially among second-language learners (Alemán Bañón et al., 2014; Caffarra, Molinaro, et al., 2015; Gillon Dowens et al., 2011, 2010).

As explained in the discussion of the results of the Experiment 1 (see section 4.4), the pattern of responses by deaf readers suggests that while the grammatical feature of gender is well established in their mental lexicon (as indexed by a robust canonical P600 effect), they show a greater reliance on visual form-based cues to detect agreement for (transparent) gender since they show a (marginal) N400 rather than a LAN in the early time window. In chapter 6, I will address the fact that for this comparison (i.e. deaf vs. L2) the N400 effect for the deaf group revealed to be only marginal (see section 6.3).

The absence of an effect in an early time-window for the L2 learners might indicate that they do not engage automatic morphosyntactic processing that is indexed by the LAN effect typically observed among native readers (Molinaro et al., 2011). This difficulty in engaging automatic agreement computation could be a consequence of grammatical features present in the L2 but not in the L1, generating problems during the automatizing of mismatches of these new representations during parsing (Gillon Dowens et al., 2011).

Atypical processing was also observed in the later phase of the P600 effect for this group: although L2 readers showed a significant effect in the P600a time-window (i.e. 600-800ms), the later phase of this effect (i.e. 800-1000 ms) was found to be only marginal. Most of the available studies only report one time-window for the P600 effect, usually the early one, which makes it difficult to interpret the absence of a P600b for L2 learners. Given the functional interpretation of the different stages of the P600, this finding suggests that L2 readers were able to perform an analysis of what caused the error (integration phase), but had problems in the final repair phase, when they tried to carry out revisions (Kaan et al., 2000). Again, this is consistent with the fact that L2 features that are not present in the L1 are more difficult to process.

Even though the L2 readers showed no evidence of an effect in the early time window, the individual analysis revealed that there was a negative correlation between responses in the early and late time windows. This is in line with the proposal by Osterhout and colleagues that L2 learners evolve through a continuum during stages of second-language acquisition, in which N400 responses are elicited after little language instruction, passing through an intermediate stage of a N400-P600 response pattern, until they reach a final point in where only P600 responses are elicited (McLaughlin et al., 2004; Osterhout et al., 2006; Tanner et al., 2013). This indicates that our sample of L2 readers was distributed across this continuum, and is supported by the correlations between the effects and behavioral measures: individuals with a larger P600 effect had higher scores for reading comprehension and the sentence acceptability task; those with a larger N400 had lower scores for the sentence acceptability task. This is in line with previous studies with L2 learners reporting that the amplitude of the P600 positively correlates with the ability to detect grammatical anomalies (for a review see Caffarra et al., 2015). In contrast, the deaf group showed no correlation between the N400 and P600 effects or with any behavioral measures. This suggests that the deaf readers were not spread along the spectrum as the L2 readers were, and there may be a ceiling effect related to their earlier exposure to written Spanish (see Boudewyn, Luck, Farrens, & Kappenman, 2018).

Summary

For the Gender Transparent condition, we found that deaf readers elicited a marginal negativity without a clear topographical distribution, that resembled a N400 effect. Inter-individual variability in the use of different reading strategies could explain this marginal effect and the reliance by the deaf readers on the consistent visual cues when resolving agreement with transparent nouns could have modulated this negativity. Moreover, deaf readers elicited a P600 effect in its both phases that corresponded to the classical effect typically observed by native readers.

L2 readers showed a much more deficient response to gender violations (no early negativity and a marginal P600b effect) but did show sensitivity to this type of grammatical incongruence (P600a), confirming our initial predictions that L2 features that are not present in the L1 are more difficult to process. Additionally, the individual variability in both ERP and behavioral responses fits in with previous claims that, as L2 readers gain proficiency, they progress along a continuum from N400-dominant responses to P600-dominant responses. In contrast, the variability in the deaf group did not fit into this pattern.

5.4.4 Gender Opaque condition

In an earlier time-window (350-500 ms) the between-group analysis revealed no significant effect for either of the two groups. In contrast, the 600-800 ms time-window yielded a P600a effect which was localized in posterior areas of the scalp for both groups. Finally, in the 800-1000 ms time-window, although interactions were observed no P600b effect was observed for the deaf or L2 reader group.

As explained in the previous section, most of the evidence available shows that across-phrase gender violations elicit a P600 effect for native readers and L2 learners that is, sometimes, preceded by a LAN effect, although this negativity is not always observed, especially among second-language learners (Alemán Bañón et al., 2014; Caffarra, Molinaro, et al., 2015; Gillon Dowens et al., 2011, 2010). The predictions for the L2 and deaf group were that the Gender Opaque condition would be the most difficult condition to perform because opaque nouns do not offer any orthographic cues that could inform readers of the gender of the lexical item. Therefore, the expectation was that the L2 group would not elicit a LAN for this condition, although they would elicit a P600 as they are high-proficient readers. This was also the initial expectation for the deaf readers, although in chapter 4, I showed that they elicited a significant LAN effect that was indistinguishable from the one observed for the hearing group, as well as a P600 in its both phases. It is notable that the results for the deaf readers differ between the analysis with the hearing readers (presented in Ch. 4) and the analysis presented here with the L2 readers. I discuss this discrepancy in ch.6 and here concentrate on the results of the analysis of deaf and L2 readers.

The results corroborated these predictions: neither group showed an early negativity but there is evidence of sensitivity to gender opaque violations in the shape of a P600a effect. The only slight difference between the groups revealed by this analysis was the presence of a weak P600b effect in the deaf group. These findings fit min with the general pattern that both types of reader fail to show native-like sensitivity to morphosyntactic violations and have non-canonical processing for agreement of this type. However, the divergent results of the deaf group with respect to what was found in chapter 4 raise the need for caution, and I will return to this issue in chapter 6 when I attempt to reconcile both sets of results.

The individual analysis run afterwards revealed a very interesting correlation pattern between ERP responses for both L2 and deaf groups. For the deaf group, the analyses in chapter 4 already revealed a negative correlation between the P600 effect and early central-posterior negativity in the N400 time-window. However, when the early negativity was measured using a central-anterior region of interest, the correlation becomes positive (see section 4.3.5). The same pattern held for the L2 readers. The negative correlation suggests that the (central-posterior) N400 and the P600 are symmetrically opposed (i.e. the more you have of one, the less you have of the other), whereas the (central-anterior) LAN and the P600 are complementary (the more you have of one, the more you have of the other). This finding provides further evidence against the claim that the LAN effect is merely an artifact of averaging processes. Indeed, visual inspection of the topographic maps for the L2 group showed that, at the individual level, some participants showed a LAN response, while others showed a N400 response (see Figure 5.19).

Finally, individual analysis between behavioral measures and ERP effects for this condition showed that Sentence Acceptability task scores positively correlated with the P600 effect, suggesting that the better L2 readers were at discriminating between correct and incorrect sentences the bigger the P600 effect (see Table 5.7). Furthermore, correlation analysis showed that vocabulary also positively correlated with the size of the P600 effect, which I suggest relates to the peculiarities of agreement involving gender opaque nouns. That is, without the presence of orthographical cues to help the reader to retrieve gender information, vocabulary knowledge is necessary to correctly perform gender agreement in the presence of opaque nouns. For the deaf group, behavioral measures generally failed to correlate with ERP responses. Once more, this suggests that the for the L2 readers, their position on the continuum of proficiency is reflected in their processing mechanisms, whereas this does not hold for the deaf readers.

Summary

In the Gender Opaque condition, both groups showed defective processing characterized by a response limited to the P600a. This suggests that both deaf and L2 readers showed sensitivity to the violations, but there was no evidence of processing markers characteristic of morphosyntactic computations. For the L2 readers, this fits well with previous work (Molinaro et al., 2011) and our initial expectations. Additionally, the ERP results correlated with behavioral measures (such as vocabulary and IQ scores) in a way that characteristically reflects the relationship between proficiency and second language processing in this population. For the deaf readers, this result diverges from the findings of chapter 4 and needs to be examined more carefully; these issues will be revisited in chapter 6.

5.4.5 Overall Summary

Our findings in the Semantic condition confirmed our predictions that both L2 and deaf readers would elicit a similar pattern of response to semantically incongruent sentences: a classical N400 effect followed by a late P600. The P600 is more typically associated with syntactic violations but may also follow an early negativity. In the case of the deaf group, the relation between these two effects led us to speculate that variation in deaf individuals' education experience (especially with respect to how they learn to read) may give rise to variability in their ERP signature for this type of processing.

The predictions for the Number and Gender transparent conditions were similar and these were borne out in the results. We predicted that, L2 learners would elicit a P600 effect for these types of violation, but not the earlier LAN effect since number and gender agreement is not observed in English (at least between noun and predicative adjective).[26] This is exactly what we found: L2 readers only elicited a P600 effect (in both phases), showing that they could perform integration and repair processes, but failed to show earlier processing associated with morphosyntactic mechanisms. A negative correlation between the N400 and P600 suggested that individuals tended to have one type of response or the other, a pattern that has been widely attested for syntactic processing of a second language. Furthermore, various behavioral measures (reading comprehension and sentence acceptability judgment task) positively correlated with the P600 effect, confirming that

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[26] Previous findings of LAN effects in L2 learners have been limited to extremely high proficient L2 speakers detecting disagreement in short distance article-noun contexts (e.g. Gillon Dowens et al., 2010). Our study differed because the L2 learners were matched with the sample of Deaf readers on various measures of language and reading ability (see section 5.3.1) and the disagreement was between a noun and a predicative adjective.

proficiency strengthens the processing of number and gender transparent violations by L2 readers.

The deaf readers showed a P600 effect but also an early negativity for number and gender transparent violations. This negativity was a N400 effect (rather than a LAN), suggesting that this group relied on more general processing mechanisms (possibly reflecting semantic or form-based predictions) rather than grammatical processing. As such, these findings fully met our predictions for this group.

Our predictions for both deaf readers and L2 learners for the gender opaque condition was that due to the absence of gender features in their L1 dominant languages (English and LSE) and the opacity of the nouns used in the agreement (i.e. the absence of orthographical cues), the grammatical processing in this condition would be different from the classical pattern usually elicited by native participants (LAN and P600). The results of this analysis met these predictions. Specifically, we found that L2 and deaf readers elicited only a P600 effect for gender opaque violations and that this effect was only significant in its first phase (P600a). We interpreted this as evidence of no early processing of gender opaque violations (i.e. absence of LAN) although they were performing processing the agreement relation to some extent, as evidenced by the P600a. We also showed that for the L2 group – but not for the deaf group – the grammatical acceptability judgment task positively correlated with the P600 effect, as occurred with the number and gender transparent conditions for this group. Additionally, vocabulary was also correlated with the P600 effect in Gender Opaque, which I suggest relates to the peculiarities of agreement involving gender opaque nouns. Finally, the effects for the deaf group when compared with the L2 group diverge from what was found in the comparison with the hearing group in chapter 4 and this issue will be addressed in the next chapter (section 6.3.1).

Overall, evidence suggests that differences between deaf readers and L2 learners are more striking for morphosyntactic processing as no difference was observed for semantic processing. This is supported by previous evidence comparing native readers and L2 learners (e.g. Hahne, 2001; Hahne & Friederici, 2001). The results revealed three broad differences between deaf and L2 readers. Firstly, in grammatical violation conditions L2 readers failed to elicit an ERP effect in an early time-window (350-500 ms), while deaf readers generally elicited a negativity. Secondly, differences in the P600 effect were also found, with L2 readers showing less robust or shorter lived effects (that did not achieve significance in the P600b time-window), which I take as evidence that L2 readers had problems monitoring, checking and reprocessing the linguistic input (Caffarra et al., 2015) that is related to gender agreement. Thirdly, the L2 readers but not the deaf readers showed a correspondence between behavioral measures reflecting proficiency in some way (reading comprehension, sentence acceptability task) and the P600 effect.

In the next chapter I will discuss the results presented here in this chapter and in chapter 4 to try to accommodate both sets of findings, which at times give divergent results for the deaf group. I will address the question whether deaf readers should be considered L2 learners or native readers, or if they should be treated as a completely different and special kind of bilingual.

6. General discussion

The central goal of this study was to investigate the underlying neurophysiological mechanisms of sentence processing in high-skilled deaf readers. For this, I presented electrophysiological data that help to further understand how deaf individuals who are readers of a transparent language such as Spanish process written sentences. Specifically, I adopted the grammatical violation paradigm by means of a sentence acceptability judgement task (see section 2.1.4 for a comprehensive explanation of this paradigm). First, I compared deaf readers to a group of hearing native readers of Spanish to investigate the possible differences as well as the similarities between these two groups in the processing of semantic and syntactic information. After that, I compared the same group of deaf readers to a group of English speakers who were high-proficient L2 learners of Spanish, to see how reading processing in these two groups compares and to explore the possibility that deaf readers behave like high-proficient L2 learners, rather than native-like readers.

In the first comparison, our results (summarized in Table 6.1) showed that high-skilled deaf readers elicited a pattern of ERP responses that was very similar to native hearing readers of Spanish. This finding contradicts recent work proposing that deaf readers do not elicit the same ERP responses for grammatical violations as those observed for native readers (Mehravari et al., 2017), but is in line with other studies that demonstrated that deaf readers who are sign language users show an electrophysiological response similar to that of native peers (Skotara et al., 2011, 2012). Our findings also provide evidence that deaf readers do not always use semantic strategies to read as proposed in the past (e.g. Domínguez et al., 2016; Domínguez & Alegria, 2010; Domínguez et al., 2014; Hirshorn et al., 2014; Mehravari et al., 2017). Although deaf readers' electrophysiological responses for semantic and grammatical violations were broadly comparable to those observed for hearing peers, there were revealing differences in the three morphosyntactic conditions. Specifically, these differences suggest that high-skilled deaf readers might use orthographic cues to support parsing processes and, consequently, use distinct cognitive resources to process grammatical information in comparison to hearing readers. In section 6.1, I discuss these different reading strategies and how our results provide evidence for them.

Table 6.1. Summary of experiment 1: behavioral results for the sentence acceptability judgment task (%) and ERP effects for the two groups in the four conditions.

Condition	Hearing		Deaf	
	EEG task	ERPs	EEG task	ERPs
Semantic	91.8 (7.2)	N400 + P600ab	88.9 (16.2)	N400 + P600ab
Number	93.3 (6.1)	N400-like + P600ab	92.0 (12.3)	N400-like + P600ab
Gender Transparent	93.9 (6.5)	(L)AN + P600ab	92.5 (6.6)	N400-like + P600ab
Gender Opaque	93.1 (8.5)	LAN + P600ab	86.8 (11.8)	LAN + P600ab

The comparison between deaf and L2 learners (summarized in Table 6.2) showed a different pattern of ERP responses to violations for each group of readers for the morphosyntactic conditions. (The semantic violations elicited the same ERP effects for both groups, namely, a N400 followed by a late positivity.) For all three grammatical conditions, the L2 group only elicited the classical syntax-related P600 effect, and no effect in the earlier time-window, in contrast to the deaf readers, who did show early effects. This suggests that this group was able to process morphosyntactic information but lacked more automatic processes such as the early detection of errors indexed by the presence of a LAN effect.

Table 6.2. Summary of experiment 2: behavioral results for the sentence acceptability judgment task and ERP effects for the two groups in the four conditions.

Condition	L2		Deaf	
	EEG task	ERPs	EEG task	ERPs
Semantic	84.3 (15.7)	N400 + P600b	88.9 (16.2)	N400 + P600b
Number	82.0 (15.7)	P600ab	92.0 (12.3)	N400-like + P600ab
Gender Transparent	68.6 (20.7)	P600a	92.5 (6.6)	N400-like + P600ab
Gender Opaque	57.2 (20.7)	P600a	86.8 (11.8)	P600a

In this chapter, my goal is to discuss the overall results for both comparisons performed in chapters 4 and 5, and then integrate both sets of results to profile the electrophysiological signature for reading in high-skilled deaf readers. I focus on what this tells us about reading processing in this population and about reading processes more generally. I will also discuss the limitations of this study and directions for future research lines.

6.1 Deaf vs. hearing native readers of Spanish

The divergent results between deaf and hearing readers in the morphosyntactic conditions provide insightful evidence into how deaf readers might use different sources of information such as visual orthographic cues to support grammatical processing during reading. This evidence comes, first, from the behavioral results of the sentence acceptability judgment task: deaf readers performed the Number and Gender Transparent condition as accurately as their hearing peers but performed significantly poorer in the Gender Opaque condition (see section 4.2.2). Strikingly, although behaviorally there was a significant difference between the groups only for the Gender Opaque condition, ERP responses provided a distinct pattern of results: while ERP effects for Number and Gender Transparent conditions indicated the use of different cognitive processes by deaf readers relative to hearing readers, the Gender Opaque condition showed a similar pattern of response for both groups. The Gender Opaque condition did not offer any visual cues to support agreement, so we conclude that the presence of orthographic cues in Number and Gender Transparent served to support agreement computation for deaf readers. This gives rise to different ERP patterns that diverge from those of the hearing native readers but permits native-like performance on the explicit task (sentence acceptability judgment). Therefore, it seems that when orthographic cues are available deaf readers take advantage of them to better handle morphosyntactic information.

Our predictions for the Number condition were only partially confirmed: although deaf readers' electrophysiological response for the Number condition was qualitatively similar to the hearing group (i.e. a N400-P600 biphasic response), quantitative differences emerged. Specifically, this difference was evident only in a later time-window where deaf readers yielded a much more robust P600a effect in comparison to the hearing readers (see Figure 4.23). The presence of an N400 response for the deaf readers, who may be relying on semantic information, was somewhat expected, but this N400 response from the hearing readers was not predicted, since they typically show a LAN effect in this context (Barber & Carreiras, 2004; Gillon Dowens et al., 2010). In chapter 4, I argue that this result may be due to our experimental design, which included more orthographical cues for the Number condition that led to stronger effects of syntactic prediction and semantic integration, as reflected by the N400 (see section 4.4.2.1 for details).

The P600 effect elicited for number violations was quantitively different in its first phase for the deaf group relative to the hearing group. Specifically, we observed that the deaf group elicited a much more robust P600a effect in comparison to the hearing group. This larger effect found for the deaf group could be due to various factors. Firstly, it may be an indicator that deaf readers needed to use more cognitive resources to integrate number disagreement, illustrated by the widespread positivity over the scalp in contrast to the more localized effect for hearing readers (see Figure 4.23). Alternatively, it may be an effect of individual differences in working memory capacities since previous evidence suggests that individuals with larger working memory capacity elicit larger P600 effects (Kim et al., 2018). Finally, deaf readers may have had problems integrating the number violations at the discourse level, making greater use of predictions based on the regularity of number marking in Spanish. We cannot completely discard any of these alternatives and each of these factors may have modulated the P600a response to a certain degree; future studies should address these possibilities in order to tease them apart.

In contrast to the number condition, ERP responses for Gender Transparent violations were qualitatively different between the groups in the earlier time-window: deaf readers showed a N400 rather than a LAN effect. In our predictions, we suggested that gender agreement would be more difficult to process for the deaf group as there is no gender agreement in their dominant (sign) language, leading to a different ERP pattern of response in comparison to the hearing group. While hearing readers used more automatic processes to detect errors in gender agreement (illustrated by the presence of a (L)AN effect), deaf readers were using different cognitive processes (evidenced by the N400 response). Results from the post-EEG task demonstrated that all deaf participants knew the gender of the words used in the experiment, so we know that they were able to recognize and retrieve gender information. Because of the experimental design (participants were instructed to explicitly judge the correctness of the sentences and the all four conditions were mixed together), deaf readers might have found it less costly to rely on the available orthographical cues. Thus, in the gender transparent condition, as occurred in the number condition, this reliance on visual cues gave rise to a more domain-general (N400) response. The advantage of using these visual cues as a reading strategy might be especially useful for deaf readers as they generally have less experience with the spoken language and might pay more attention to visual regularities in the written form.

Finally, what can we learn from the results observed from the Gender Opaque condition in the light of the ERP pattern observed from the Number and Gender Transparent conditions for the deaf group? The Gender Opaque condition yielded exactly the same type of ERP response for deaf and hearing readers (i.e. a LAN and P600 effect), reinforcing our hypothesis that when orthographical features are available deaf and hearing show differences in the way they process grammatical information, but when these cues are not available, as in the case of Gender Opaque condition, deaf readers elicit the same type of ERP response as hearing peers. This suggests that both groups of readers were using the same cognitive processes to perform this type of agreement. Furthermore, it is striking that deaf readers can do canonical (i.e. native-like) agreement processing when no other option (i.e. orthographic cues) is available.

Overall, I have demonstrated that hearing and high-skilled deaf readers share many similitudes in the way they compute semantic and morphosyntactic information. Most revealing, however, is that the differences suggest that deaf readers engage in different type of processing when orthographical cues mark the agreement relation. Although we are not comparing the results across conditions (e.g. number vs. gender agreement) since our experiment was not designed for this purpose, we could speculate that since deaf readers elicited the same ERP pattern of responses for Number and Gender Transparent this could indicate that they were using similar cognitive mechanisms to process both these types of agreement, that is, the use of the orthographical cues to predict syntactic dependencies. In contrast, the pattern of ERP response elicited in the Gender Opaque condition indicates that in the absence of these visual orthographical cues, deaf readers process agreement more similarly to their hearing peers. Our experimental design cannot completely disentangle whether the N400 elicited by deaf readers in the Number and Gender Transparent condition represents underlying syntactic prediction processes. However, we argue that for the Number condition, the greater number of orthographical cues might have led readers (including hearing readers) to expect certain types of agreement dependencies as each word in the sentence before the target word was marked for number. When these cues were less evident, as in the case of Gender Transparent (only noun and adjectives were marking the gender), the hearing group *changed* the way they were processing the information to a more automatic detection of grammatical information while deaf readers continued to use visual cues to predict upcoming agreement. In the absence of orthographical cues, as in the case of Gender Opaque, a native-like processing emerged for deaf readers, and ERP responses were similar to those of the hearing group. Future studies should explore this possibility to understand *how* and *when* deaf readers make use of visual cues (i.e. orthographical information) to predict syntactic computations and, therefore, facilitate semantic integration, and to what extent the use of these cues to process sentences was modulated by the task. For example, would they take advantage of visual cues if the task was a comprehension task? In section 6.4 I will discuss the limitations of this study and offer directions for future studies.

I will turn to the second comparison: deaf and L2 readers.

6.2 Deaf vs. high-proficient L2 learners of Spanish

In this study, L2 readers showed sensitivity to morphosyntactic violations (evidenced by a P600 effect) but, in contrast to the deaf readers, failed to show early detection of this type of disagreement (no ERP response in the early time-window). This could have been due to interference arising from differences between the agreement features in L1 and L2: there is no number agreement between noun and adjective or any gender agreement in English. According to the *competition model*, this would influence the pace at which L2 readers achieve a native-like stage of processing.

The non-native type of processing was also evidenced in the P600 effect elicited in the Number condition: L2 readers did not show a native-like topographical pattern (namely, a significant positivity in posterior regions of the scalp; for a review see Molinaro et al., 2011). Instead, the P600 was characterized by a broadly distributed positivity in both its phases, suggesting that L2 readers needed more cognitive resources to process this type of violation. This pattern was also observed for the deaf group, although only during the first phase of the P600, which indicates that deaf readers might need more cognitive resources to integrate morphosyntactic errors, but not for reanalysis and repair processes. L2 readers' late time-window response was even more deficient for gender violations: they showed a weak/absent P600b effect. This suggests that L2 readers were able to perform integration analysis of gender violations, but reanalysis/repair processes were either very weak (gender transparent) or not engaged (gender opaque). This pattern could reflect an unstable representation of gender features that affected associated agreement processes. This is in line with our initial predictions where we argue that L2 features that are not present in the L1 are more difficult to acquire by L2 learners. Thus, gender agreement was processed more deficiently than number agreement, and this was also reflected in their scores in the sentence acceptability task. The accuracy level in the post-EEG task to identify word gender also revealed that the L2 readers did not have strong representations of this feature.

The individual variability in both ERP and behavioral responses fits in with previous claims that, as L2 readers gain proficiency, they progress along a continuum from N400-dominant responses to P600-dominant responses (Osterhout et al., 2006; Tanner et al., 2012). According to this account, the relationship between N400 and P600 correlates negatively, indicating that the bigger the N400 effect for a given subject the smaller the P600 effect. This seemed to be the case for Gender Transparent and Number conditions: both showed a negative correlation for the N400 and P600 effects. These findings reinforce the claim that L2 learners evolve through a continuum of language proficiency. In contrast, the variability in the deaf group did not fit into this N400-P600 continuum pattern and this may be due to several factors: the variability of the language background generally observed in deaf readers, especially in the way they have acquired reading, probably leading to the use of different reading strategies; their earlier exposure to L2 (although limited exposure through lipreading and later through the written form); or a ceiling effect (see Boudewyn et al., 2018).

Interestingly, for the individual analysis, in the Gender Opaque condition a different pattern emerged when we adopted a central-frontal ROI: we found a positive correlation between the early effect and the P600 for the both deaf and hearing groups. This contradicts previous proposals that the LAN is an artefact arising from averaging individual N400 and P600 responses (Tanner, 2015), and points towards the LAN as an autonomous effect that indexes early automatic processing of morphosyntactic features (see sections 4.3.5.1 and 5.3.5.1 for more details). In section 6.3.2, I discuss the methodological implications of ROI selection for individual analysis. The positive correlation between the LAN and the P600 for the Gender Opaque condition indicates that the bigger the P600, more robust the LAN effect. A visual inspection of individual topographical responses confirmed the presence of a frontal negativity for at least some of the L2 participants. These responses, however, were in a minority of L2 readers causing a null result in the grand mean on this time-window for this group.

Behavioral results from the sentence acceptability judgement task showed that deaf participants outperformed L2 learners in the sentence acceptability judgement task in all four conditions. In contrast, language comprehension scores for the L2 group were significantly better (see section 5.3.1). This raises an interesting question about whether L2 learners might transfer metalinguistic resources they have previously acquired through being native readers of another language, allowing them to apply language comprehension skills to read in the second language more efficiently, even if specific knowledge about L2 grammatical rules such as gender agreement are not completely internalized yet (Van

Gelderen et al., 2014). This is a relevant point to understanding reading comprehension in deaf readers and I will discuss it further in section 6.4.3.

6.3 Methodological considerations

6.3.1 Divergent results for the deaf group

As became apparent in chapter 5, the results for the deaf group in the comparison with L2 learners differed from those found in the comparison with the hearing controls in chapter 4, specifically with respect to the Gender Opaque condition. As can be seen in Table 6.3, the deaf vs. hearing comparison revealed a significant central-anterior negativity, or LAN effect, for both deaf and hearing groups (see section 4.3.3.4). The deaf vs. L2 comparison showed no significant effects for either group. To investigate why the LAN effect in deaf readers seems to disappear from one analysis to the next, a subsequent within-group analysis was run for the deaf group, which revealed no significant effect in the 350-500 ms time-window. At the same time, visual inspection of the wave forms as well as the topographic maps clearly showed that deaf group elicited an effect in this time-window (see, for example figures 4.10 and 4.11, in chapter 4).[27]

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[27] For the Gender Opaque condition, there was also a slight discrepancy for the P600b effect. I focus on the earlier (350-500ms) time-window since the interpretation of the effect is more critical to the findings. Equally, the explanation for the discrepancy in the early time window could be applied to this later window.

Table 6.3. Differences found for the deaf group in the Gender Opaque condition in both deaf vs. hearing readers contrast and deaf vs. L2 readers contrast.

Gender Opaque

Type of Analysis	**Results**	
	Deaf vs. Hearing	**Deaf vs. L2**
Between-group ANOVA	Significant LAN effect for both groups in *central-anterior* areas	No significant N400/LAN effects for either of the groups
Within-group ANOVA	Deaf: No significant LAN effect	
	Hearing: marginal LAN effect	L2: no significant LAN effect

One plausible explanation is that the deaf group elicited a small LAN effect: when the analysis was performed together with the hearing group, who also showed a LAN effect, the statistical power was sufficient to garner a significant effect. In contrast, when the deaf group alone is analyzed or when this comparison is done with a group who did not show any effect in this time-window (i.e. L2 readers), the effect fails to reach significance.

To confirm this hypothesis, we also ran a within-group analysis on the hearing group in the Gender Opaque condition to see if the LAN effect was actually significant for the hearing group alone. Contrary to expectations, there was only a marginal interaction[28] and the follow-up post-hoc analysis failed to show evidence of a (L)AN effect. This finding could suggest that both groups (hearing and deaf) elicited a small LAN effect for the Gender Opaque condition: when both groups were analyzed together statistical power increased and a significant effect emerged. The inter-subject variability in ERP responses may also have influenced this result. In chapter 4, I presented the individual topographical maps of ERP responses for the Gender Opaque condition indicating the presence of a mixed pattern of

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[28] Results from the within-group analysis for the hearing showed a marginal interaction between Congruence x Anteriority ($F(2,36) = 2.90$, $p = .09$), but post hoc analysis failed to show any significant effect (anterior: $t(18) = 1.78$, $p = .27$; central $t(18) = 1.47$, $p = .31$; posterior: $t(18) = .37$, $p = .71$).

N400 and (L)AN responses for both hearing and deaf groups, with some subjects that elicited a broadly distributed negativity rather than a negativity at central-anterior sites (see Figure 4.22).

Our main conclusion for this apparent discrepancy of results between the two comparisons (i.e. deaf vs. hearing and deaf vs. L2) is that the early effects for both gender conditions (and the P600b effect for the Gender Opaque condition; see fn. 3) were overall weak and only reached significance when hearing and deaf groups were analyzed together because both groups elicited the same trend of effects. This was not the case when deaf readers were compared to L2 readers as this group elicited a distinct pattern of ERP results. These weak effects for the deaf may reflect inter-subject variability (see section 4.2.5.1 for further details on individual analysis), which might result in less-robust significance values at the group level as has been pointed out in previous studies (Corina et al., 2013). This also points to the difficulty of conducting studies of this nature with populations where sample sizes are limited.

6.3.2 Individual differences analysis and the use of different ROIs

As discussed in chapters 4 and 5, previous studies have suggested that a biphasic pattern of ERP responses may serve as an indicator of individual differences for both native and L2 learners (e.g. Tanner et al., 2014, 2013; Tanner & Van Hell, 2014). Therefore, we analyzed individual ERP responses by checking the correlation between the LAN/N400 and the P600 effect in order to understand the nature of the relationship between these two ERP effects. In previous work, the analysis of these biphasic patterns is done by considering only a central-posterior region of interest, where the N400 and the P600 effects are typically stronger (e.g. Tanner et al., 2014; Tanner & Van Hell, 2014). The motivation for adopting only central-posterior ROIs is that individual waveforms reveal that this effect tends to appear in central-posterior areas, even though in the grand mean results the effect appears to be in central-anterior areas (Tanner et al., 2014). In our study, visual inspection of individual waveforms indicated a mixed pattern of results: some subjects showed a central-posterior negativity while others had a central-anterior effect. Consequently, we questioned whether the pattern of correlations would change if we adopted a central-anterior ROI to index the earlier negativity (while maintaining a central-posterior ROI for the later positivity).

With a central-posterior ROI, a negative correlation is found between the early and late effects and is taken to indicate individual variability: readers' ERP responses vary on a continuum between N400-like responses and P600-like responses. According to this view, the LAN effect does not exist and is merely appears in the grand mean analysis due to individual (Tanner, 2015). By adopting a central-anterior ROI (see section 5.3.5.1 for full details of this analysis), we found a very different pattern of results for the Gender Opaque condition: for all three groups of participants (native, deaf and L2), the correlation between early and late effects was positive. With the central-posterior ROI, the correlation continued to be negative, supporting the idea of a continuum: the more one effect dominates an individual's processing, the less present the other effect is. The positive correlation between the (anterior-central) early effect and the later effect suggests that there are two temporally and topographically distinct effects that index processing. The magnitude of later effect, the P600, indexes language proficiency (Osterhout et al., 2006); the positive correlation between the early effect and the P600, suggests that the former is also modulated by proficiency. This finding provides support for the claim that the earlier anterior effect, the LAN, is an independent ERP effect, and not just an artefact of averaging processes.

Furthermore, the LAN is associated with morphosyntactic processing (Molinaro et al, 2011), so it is congruent that we find evidence for this effect specifically in the Gender Opaque condition, in which the only way to process the agreement relationship is by accessing abstract grammatical features that are not marked on the form of the noun.

In addition to weighing in on the debate about the LAN effect, the finding highlights two methodological issues. Firstly, the change in the correlation depending on the ROI used points to the impact of methodological choices when carrying out analyses of this type. Secondly, the finding confirms that individual difference analysis is very important to understanding how different readers might process the same stimuli by using different cognitive mechanisms. Future studies should adopt the use of different ROIs to follow up on this finding and to better understand the impact of individual differences in the grand mean of ERP responses.

6.4 The profile of high-skilled Deaf readers revisited

In this section, I would like to offer new insights into the reading profile of high-skilled deaf readers. The main goal of this dissertation was to investigate deaf readers' neurophysiological signature for semantic and grammatical processing to shed light on the underlying processes and mechanisms that support efficient reading in deaf individuals. Previous studies have tried to understand how deaf readers can achieve excellent reading skills by comparing deaf readers with their hearing peers (Mehravari et al., 2017; Skotara et al., 2011) as well as with L2 learners (Hoffmeister & Caldwell-Harris, 2014; Piñar et al., 2011; Skotara et al., 2012). Overall, these studies contributed the following to our current understanding on how deaf readers process reading: (a) high-skilled deaf readers have a solid first language, either spoken or signed (Mayberry et al., 2011); (b) they do not necessarily use phonological information to read (Bélanger et al., 2012; Fariña et al., 2017), although this information can be available to them (Gutierrez-Sigut et al., 2017); (c) skilled deaf readers have a wider perceptual span in comparison to their hearing peers (Bélanger et al., 2013); (d) they are more efficient than hearing readers at processing words (Bélanger et al., 2012). Even though these studies filled an important gap in the scientific literature, the available evidence provided by ERP studies on literacy attainment in deaf readers has not offered a clear picture of the neurophysiological signature underlying reading in this population. Furthermore, only few studies have looked at the brain mechanisms that support reading in deaf readers at the sentence level (Mehravari et al., 2017; Skotara et al., 2011, 2012), and none of these studies was conducted in a transparent and morphologically rich language such as Spanish. Therefore, the motivation of this work is to fill this gap, adding new evidence to create a revisited profile of high-skilled deaf readers.

As I show throughout this dissertation, even though deaf readers showed a native-like electrophysiological response to semantic and syntactic violations, they also showed some important differences with their hearing peers. These differences seem to be mainly related to the fact that high-skilled deaf readers make greater use of orthographical cues, when they are available, to support agreement computation. Orthographical regularities present in transparent languages like Spanish might offer extra support for deaf readers during lexical retrieval processes or an alternative strategy for predicting syntactic dependencies.

Difficulties related to grammatical processing of written texts among deaf readers might come from the lack of exposure to the primary (spoken) form of the language in early childhood (Hoffmeister & Caldwell-Harris, 2014). Because there is great variability in the way deaf readers learn to read it is difficult to disentangle the impact that prior language experience, educational background, and other confound variables might have on language processing. Nevertheless, understanding the underlying mechanisms that allow some deaf readers (such as the participants in this study) to reach an excellent reading level has important practical implications for the creation of new educational interventions and teaching methodologies. Reading proficiency depends not only on reading skills but also on context, that is, the nature and goals of a given reading task.[29] I will now discuss the characteristics of high-skilled deaf readers based on the results this study.

6.4.1 Semantic and orthographical cues: support for morphosyntactic processing

Early language experience shapes the way the brain processes linguistic information (Arshavsky, 2009). For deaf readers, the lack of access to auditory input during the first years of life and the low frequency of exposure to the spoken language and written texts during school life (Tomasuolo et al., 2018) might lead to a less consolidated representation of the language: the representation of each lexical item (what the features are) and certain grammatical mechanisms such as the agreement system itself (how the features work). If language representations are weaker, alternative strategies might arise, and visual input such as orthographical information might become more important for deaf readers. For instance, a recent study suggests that deaf readers who are signers rely more heavily on orthography and direct orthographic-to-semantic connections as a reading strategy (Lee, Meade,

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[29] Afflerbach and colleagues make a distinction between reading skills and reading strategies: while the first is related to more automatic and crystalized reading abilities, the latter is more intentional, deliberate, and it relates to the use of metacognitive skills (Afflerbach, Pearson, & Paris, 2008).

Midgley, Holcomb, & Emmorey, 2019). Other studies have also showed that orthographical information has more weight for deaf readers than for hearing readers (Fariña et al., 2017; Gutierrez-Sigut, Vergara-Martínez, & Perea, 2019). Although these studies were limited to investigating word-level reading, I propose here that these findings might extend to the sentence level.

Regularities of orthographical cues could help deaf readers to assimilate linguistic information such as grammatical rules. In the case of gender agreement, visual cues might help the memory system to retrieve gender features. Non-native hearing readers certainly appear to take advantage of visual cues during reading, making more use of cue-based parsing to guide memory retrieval (Cunnings, 2017). How the memory system works in retrieving lexical and grammatical information may vary according to language experience and background, such as whether readers are L1 or L2 learners and how they learned the language (Ullman, 2001, 2016). As such, proficiency and language experience may also shape how deaf readers retrieve linguistic information: differences in language acquisition in deaf children affect the way they organize orthographic, phonological, and semantic information in their lexicon (Lee et al., 2019). Thus, deaf individuals rely more on orthographical information to read.

The results of this study support the proposal that, in comparison to hearing readers (native and L2 readers), deaf readers (especially deaf signers) make greater use of visual orthographic cues to facilitate grammatical processing. We saw that for deaf readers ERP responses when orthographic cues were available (number and gender transparent conditions) reflected processing mechanisms that diverged from those of native hearing readers. This possibly indicates that for deaf readers these visual cues play a more relevant role during language processing, especially in the case of morphosyntactic processing. One limitation of this interpretation is the use of an explicit task to judge the correctness of the sentences, which may have induced deaf readers to pay more attention to sentence details such as orthographical cues. Because they are less experienced than their hearing peers in the language they are reading, deaf readers may have used a visual strategy to be more accurate during the task. This could be tested by conducting a follow-up study using a comprehension task: future studies should address more specifically how deaf readers weigh these orthographic cues during reading, and the role of the reading task.

6.4.2 Semantic and syntactic prediction

Our brain is constantly looking for regularities in the environment in order to effectively predict future outcomes and this ability to predict extends to the processing of language information (Van Petten & Luka, 2012). In the case of reading, native readers (monolinguals and native bilinguals) make predictions during both semantic (DeLong et al., 2005; Ito, Corley, Pickering, Martin, & Nieuwland, 2016; Szewczyk & Schriefers, 2018) and syntactic processing (Martin, Monahan, & Samuel, 2017; Molinaro et al., 2017), while L2 readers' capacity to predict seems to depend on the readers' ability to regulate the native language (Zirnstein, Van Hell, & Kroll, 2018) as well as their level of proficiency (Martin et al., 2013). Although it was not the aim of this thesis to investigate prediction processes in reading comprehension, based on the data reported here, we propose that deaf readers might take advantage of orthographical cues (i.e. gender marking) to generate expectations about upcoming forms, thus facilitating agreement processing.

The use of orthographical cues to boost agreement processes has been previously proposed for hearing readers (Hagoort, 2003) and it is supported by evidence that the N400 effect indexes the prediction of specific words (DeLong et al., 2005; Federmeier, 2007; Federmeier & Kutas, 1999; Kutas & Federmeier, 2000, 2011), including their morphosyntactic features (Otten & Van Berkum, 2008; Van Berkum et al., 2005; Wicha et al., 2004). As already mentioned, the available evidence on reading in the deaf population suggests that orthographical information has more weight for deaf readers than for hearing readers (Fariña et al., 2017; Gutierrez-Sigut et al., 2019), and that skilled deaf readers are "more efficient" than hearing readers at processing words as they retain more low-level visual information and have an enhanced perceptual span during text reading (Bélanger et al., 2018). Consequently, the way orthographical information is computed, and these previously reported visual advantages, could affect the way deaf readers anticipate morphosyntactic information. For example, there may be an impact on their (visual) statistical learning processes, especially in the case of a transparent language such as Spanish, which contains so many regularities.

There is an established link between statistical learning ability and language/reading skills in children (Kidd & Arciuli, 2016; Misyak, Christiansen, & Tomblin, 2010) and adults (Arciuli & Simpson, 2012). However, for deaf readers, this relation is not so clear: Giustolisi and Emmorey (2018) found that reading comprehension scores were a significant predictor of accuracy in a visual non-verbal statistical learning task in hearing readers, but not in deaf readers. However, when reading comprehension scores were considered (i.e. matching hearing and deaf in reading comprehension) no difference in statistical learning skills was found between the groups. The authors discuss the possibility that deaf people with high statistical learning abilities might be more likely to become proficient readers. Therefore, it is possible that deaf readers with better statistical learning skills might be better at computing grammatical dependencies, which might help them to become better readers but would not imply that they will perform as well as their hearing peers in reading comprehension tasks since comprehension requires additional higher-order and inferential skills. This was exactly what we observed in our study: while deaf readers were processing grammatical information in a similar fashion to the hearing group, levels of reading comprehension were not the same: both hearing groups (native and L2) outperformed deaf readers.

Native-like prediction processes and good statistical learning abilities might help to explain how some deaf readers become excellent readers. The possibility that high-skilled deaf readers use abilities – such as predictions based on visual cues – to be more efficient at processing grammatical dependencies would help to fill an important gap in the literature by explaining how some deaf readers become so good at reading while others do not. Future studies should address this more carefully to confirm or discard this hypothesis (see section 6.6 for a further discussion on future directions).

6.5 Limitations of the study

In this study our main goal was to understand how deaf readers process semantic and syntactic information by comparing them with a group of hearing native (experiment 1) and L2 learners (experiment 2). During the execution of this work many questions arose and although we were able to answer most of them, other questions remained without a clear explanation. Here, I would like to address these issues. We hope that futures studies are able to further consider them so we can better understand semantic and syntactic processing of written language in the deaf population. The next section identifies other outstanding issues that should be addressed in future work on reading in deaf individuals.

6.5.1 Small sample size

The first limitation is our sample size. As explained in chapters 4 and 5, a sample of 19 deaf readers was used even though data was collected from 36 deaf participants. The final analysis was conducted using a smaller sample because of the difficulty in matching deaf and hearing participants (especially with native speakers) in the behavioral tasks (see section 4.1). We also had to exclude deaf participants for low performance in the sentence acceptability judgment task as they were performing at chance. We understand that significant findings based on small samples can lead to erroneous statistical inferences and make difficult future replications in ERP studies (Clayson, Carbine, Baldwin, & Larson, 2019). Small sample sizes can also be problematic for correlation analyses because data points with extreme values may introduce a false sense of relationship (Goodwin & Leech, 2006; Schönbrodt & Perugini, 2013). However, this is an inherent problem with working with special populations which limits the number of available participants who fit a certain profile (i.e. signing high-skilled deaf readers or hearing readers with reading skills within a certain range). We acknowledge this limitation and have tried to adopt measures in our analyses (such as excluding outliers in correlation analyses) to ensure that our results are as robust as possible. Clearly, future work on this topic will be able to confirm or refute these findings.

6.5.2 Specificity of the sample: high skilled deaf readers

This study used a sample of high-skilled deaf readers because of our research goal, which was to understand semantic and syntactic processing in deaf readers who have successfully acquired reading skills. There might be important differences with less skilled readers and we need to be cautious about whether our results can be applied to other types of deaf readers. The fact that most of our participants were signers also limits the extrapolation of these results to other deaf reader profiles such as oralized deaf readers. Future studies could compare different groups of deaf readers (e.g. oralized vs. signers) to investigate how differences in language acquisition could impact language comprehension in high-skilled readers.

6.5.3 Individual differences: Working memory, cognitive control and statistical learning differences

Many studies have addressed the role of non-linguistic skills such as working memory and cognitive control in language processing. For example, ERP effects such as the LAN have been linked to verbal working memory (Kluender and Kutas, 1993) and cognitive control mechanisms play a role in language comprehension (Ye & Zhou, 2008; Zirnstein et al., 2018). Statistical learning skills have also been associated with reading skills (as discussed in section 6.4.2). In our study, we had to limit the behavioral battery to tests that involved language skills in order to make data collection feasible. Nevertheless, we understand that controlling for non-linguistic cognitive skills would provide insight into the role of these factors in reading and leave it to future studies to explore these dimensions.

6.5.4 The type of the task

As addressed in our previous discussion (see section 4.4.2.2), it is possible that the type of task used in our experiment modulated the results reported here. The type of task used (sentence acceptability judgments task vs. reading comprehension task) can modulate ERP responses (Kuperberg, 2007). Since we used a sentence acceptability judgment task (Alemán Bañón et al, 2012; Caffarra & Barber, 2015), participants were explicitly asked to judge whether the sentences were correct or not. This might have motivated deaf readers to pay more attention to the available orthographical cues in order to spot morphosyntactic anomalies. In future studies, it would be interesting to use a different task, such as comprehension questions, so that agreement computation is performed in a more natural manner, reflecting what occurs when people read for comprehension.

6.6 Future directions

Typically, individuals acquire a (spoken) language first implicitly, such that their knowledge of grammar is naturally built (Seidenberg, 1997), and later learn to read by associating the (auditory) linguistic forms already acquired with the corresponding written system. Second-language learners carry the linguistic representation of a solid L1, and this helps them to learn the rules of the L2 linguistic code through language transfer (see section 2.2.3 for further information on theories of language transfer). Deaf readers, however, are a very different case. This section addresses issues that arise from the findings of this study and can inform future work into reading in deaf individuals. I consider various particularities of deaf readers that require further attention and suggest how the field can pursue these lines of research.

The most striking difficulty for deaf readers is that they do not have direct access to the underlying phonological information. This has two consequences. Firstly, deaf readers do not have a clear auditory or phonological representation to associate the written form with. More generally, the representation of the language system is underspecified and weak, and reading is not supported by a consolidated framework of linguistic rules. This is the Gordian knot for deaf readers; reading relies on underlying knowledge of the language but knowledge of the language comes through reading.

In this closing section, I wish to draw attention to two other characteristics of deaf readers. Firstly, since there is no written system in sign language, learning to read as a deaf signer means that this is their first written language. Secondly, if they are sign language users, reading implies managing with two languages that differ in modality and, more importantly, in linguistic properties. I address each of these issues in turn.

6.6.1 Lack of a written form for the dominant (sign) language

Sign language does not have a written representation, so deaf (signing) readers come to reading with a linguistic knowledge but without literacy. Having only one representation of the written language might actually benefit deaf readers: they may be less prone to linguistic interference during reading. Hearing bilingual children whose languages have different writing systems show less between-language transfer that those whose languages use the same writing system (Bialystok, Luk & Kwan, 2005). Therefore, having only one written system might be beneficial for proficient deaf readers as they would suffer fewer intrusions from the sign language, which has no written form, during reading. Conversely, during the reading acquisition process, already having a well-established written system might be beneficial, offering support to L2 learners by providing a pre-existing framework and transferrable skills, such as higher-level inference skills that are important to abstract meaning from the text. This study included a measure of reading comprehension skills and deaf readers' performance in this task was significantly worse in comparison to both native hearings (see Table 4.3) and L2 learners (see Table 5.2). Although we expected the group of native hearing readers to show better reading comprehension skills, it was striking that L2 readers performed better on the comprehension task in contrast to the deaf group, but *not* on the grammatical judgement task. That is, L2 readers performed quite well when they were asked to extract meaning from a text but performed much worse when they were asked to judge the grammatical acceptability of sentences. We suggest that this was due to higher order inference skills previously acquired during L1 reading acquisition that enabled them to compensate for relatively inefficient processing of L2 grammatical system (Van Gelderen et al., 2004).

The relatively poor comprehension skills of deaf readers highlight an important aspect of reading: processing semantic and grammatical information is not the same as comprehending a text. Deaf readers' ability to process semantic and grammatical information in Spanish was more similar to that of their native hearing peers, and they outperformed L2 readers in all the three morphosyntactic conditions (see section 5.3.2). Reading comprehension difficulties in deaf readers might be due to poorly developed higher order skills that come with learning to read. Having a well-established L1 does not seem to be sufficient for acquiring the skills required for reading comprehension: it is the specific experience of literacy that provides the framework for acquiring (and subsequently transferring) these skills. Future studies could investigate this further by testing L2 learners with no literacy in (spoken) L1.

6.6.2 Intra-modal vs. cross-modal language transfer

Models of language transfer generally assume that the grammar of the L1 is the foundation on which grammatical rules from the L2 will be learnt (for more information of these models see section 2.2.3). In the case of deaf readers who are signers, the sign language is usually considered the dominant language, but, as pointed out above, the written system of the spoken language is also the first/dominant *written* language. One interesting question is how the two language systems of deaf readers interact during reading and to what extent there is interference between the two. There is growing evidence that bimodal bilinguals activate lexical items of both languages in the brain regardless of which of the two is being used in a given moment (Shook & Marian, 2012; Villameriel, Dias, Costello, & Carreiras, 2016), including for signs and written words in deaf individuals (Lee et al, 2019; Morford, Kroll, Piñar & Wilkinson, 2014; Meade et al., 2017; Ormel, Hermans, Knoors, Verhoeven, 2011). Although this evidence is limited to the lexical level, we suggest here that this parallel activation might also occur at the sentence level, giving rise to between-language transfer. Such cross-language transfer depends on the similarity between the two languages in question; in this case, it is not clear how to measure the linguistic distance between languages across modalities. For example, sign languages express agreement through the use of signing space (Costello, 2016), a resource that has no parallel in spoken language grammars.

The present study cannot clearly distinguish if deaf readers suffered interference from sign language during the reading task. We specifically included a grammatical condition (gender agreement) that is absent in the sign language to see if deaf readers would have a less stable representation of a feature that they had to assimilate directly from print.

What we found was that, so long as there were no visual cues that could facilitate an alternative strategy (transparent gender), deaf readers were able to process this feature in a similar way to the hearing group (opaque gender). This suggests that deaf readers are able to overcome interference from their first language (i.e. the lack of a grammatical feature) and acquire native-like processing in a way that hearing L2 readers cannot. The role of modality in between-language transfer is a matter for future research.

7. Conclusions

The aim of the present work was to investigate the neurophysiological signature for reading comprehension in high-skilled deaf adults. Understanding how some deaf readers are able to achieve a high level of reading skills despite their lack of access to the spoken language has been a topic of high interest in the scientific community. Firstly, this is an important issue because most prelocutive deaf individuals struggle to learn to read and only achieve a basic reading level (Mayberry et al., 2010; Musselman, 2000). Therefore, identifying the brain processes in those deaf readers who do achieve good reading skills could shed light on the variability of literacy levels among deaf individuals. Secondly, looking at reading in deaf individuals may provide greater insight into the mechanisms of reading in general. So far, most of the available evidence has focused on understanding how deaf readers process reading at the word level, and little research has looked at sentence-level processing in this population. Any such work has not offered a clear picture of how deaf readers process sentences: one study has showed that deaf readers process morphosyntactic information differently from their hearing peers (Mehravari et al., 2017), but the other two studies claimed that native-like ERP responses for grammatical violations are only observed for deaf readers who are native signers (Skotara et al., 2011), and that oralized-deaf readers process morphosyntactic information more like L2 learners (Skotara et al., 2012). Furthermore, these studies were limited to Germanic languages (i.e. English and German), and the samples used were either very small (n=8; Skotara et al., 2011; 2012) or very heterogeneous in respect to deaf participants' reading skills (Mehravari et al., 2017).

The goal of this study was to fill this gap in the literature by showing how high-skilled deaf readers of a language with a transparent orthography like Spanish process semantic and syntactic information during a sentence reading task. For this, I compared a group of high-skilled deaf readers to a group of hearing native readers (Experiment 1) and to a group of English speakers who were proficient L2 learners of Spanish (Experiment 2). Generally, our results provide new evidence supporting the claim that high-skilled deaf readers of Spanish process morphosyntactic information in a native-like manner rather than as a L2. Importantly, deaf readers showed native-like processing even for linguistic features, such as grammatical gender, that do not exist in their L1. This contrasted with what we found for L2 readers, who failed to show native-like processing for morphosyntactic features that either were absent in their L1 (gender agreement) or work differently (number agreement). At the same time, even though deaf readers processed morphosyntactic information more similarly to their native peers than to the L2 group, the data show that deaf readers do not fit completely into a hearing-reader profile and suggest that deaf readers make use of alternative strategies for processing grammatical dependencies. Whenever relevant information (e.g. gender) is explicitly marked, deaf readers seem to take advantage of these orthographical cues to support the processing of grammatical relations during reading. One way in which high-skilled deaf readers use this orthographical information to resolve agreement dependencies may be through prediction mechanisms that anticipate upcoming input, thus facilitating overall integration processes. In other words, skilled deaf readers might use certain reading strategies that involve a greater reliance on visual cues (i.e. orthographical information) and favor prediction processes. While hearing readers (native and L2 readers) acquire a strong representation of the spoken language before learning to read, which will inform how they process the written form of that language, deaf people come to reading without this linguistic baggage (they may have learnt a signed language, or have merely had degraded input of the spoken language), leading them to give greater weight to orthographical information. More studies are needed to look at how deaf readers use these cues and the role of prediction in resolving agreement dependencies.

The results of this study add valuable information towards a more complete reading profile of skilled deaf readers, but various notes of caution are necessary as far as the impact and application of these findings is concerned. Firstly, this study focused on a specific type of deaf reader: only a small proportion of the deaf population can be considered high-skilled readers. Furthermore, understanding how skilled deaf readers process language does not fully explain how they actually become good readers. Another important take-away message from this study is that the processing of semantic and syntactic information is part of but by no means the whole story behind successful reading and achieving comprehension. Deaf readers in this study were matched with their hearing peers on several measures of reading skills, but their reading comprehension was lower than both the native and the L2 readers. As noted above, deaf readers can show native-like processing of certain language features during reading, yet there seems to be a missing piece when it comes to functional reading ability. Future work should look into this issue and explore the role of literacy in a consolidated language in furnishing readers with higher order skills, such as inference and evaluation, that lead to successful reading.

Finally, understanding how deaf readers are able to achieve native-like levels of literacy challenges what we know about reading. Almost everything we know about how the brain processes written language comes from studies with the hearing population. Certainly, it is very useful to have a typical reference population that serves as a baseline: we can use these previous findings as a starting point to understand how deaf people read. However, as the results of this study show, deaf readers are not hearing readers. To comprehend how deaf people become skilled readers we need to pay attention to the alternative mechanisms that these readers use, and to how those processes help or hinder the attainment of functional literacy. Future studies should link the available experimental evidence with relevant factors, such as the role of sign language or educational experience; these individual differences may shed light on the path to becoming a good reader. I hope this work will contribute to and inform our understanding of reading in the context of deafness.

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Appendices

Appendix A: Questionnaire used for the selection of participants.

Appendix B: List of stimuli for the Semantic condition.

Appendix C: List of stimuli for the Number condition.

Appendix D: List of stimuli for the Gender Transparent condition.

Appendix E: List of stimuli for the Gender Opaque condition.

Appendix F: Correlations between behavioral measures and ERP effects for the Semantic condition.

Appendix G: Correlations between behavioral measures and ERP effects for the Number condition.

Appendix H: Correlations between behavioral measures and ERP effects for the Gender Transparent condition.

Appendix I: Correlations between behavioral measures and ERP effects for the Semantic condition.

Appendix J: Number of correct trials per condition in the End-of-Sentence Acceptability Judgment Task.

APPENDIX A: Questionnaire used for the selection of participants

Nombre y apellidos [Nombre y Apellidos]
Fecha de nacimiento
Provincia de residencia
Datos de contacto
¿A través de qué medio prefieres que nos pongamos en contacto contigo-
Sexo
Dominancia manual
¿Cuál es tu ocupación actual (puesto de trabajo, estudiante, en paro, etc.)-
¿A qué edad comenzó la sordera?
¿Cuál es el grado de pérdida de tu oído derecho SIN audífono?
¿Cuál es el grado de pérdida de tu oído izquierdo SIN audífonos?
¿Sabes la causa de tu sordera?
¿Usas audífonos?
¿Tienes implante coclear?
¿Entiendes y usas la Lengua de Signos Española (LSE)?
Si sabes LSE, ¿dónde la aprendiste?
Si sabes LSE, ¿a qué edad comenzaste a usarla?
En una escala de 1 al 5, ¿cómo de buena crees que es tu LSE? (siendo 1 "no muy buena" y 5 "excelente")
¿Entiendes y usas español (castellano)?
¿Dónde aprendiste castellano?
¿A qué edad comenzaste a usar castellano?
En una escala del 1 al 5, ¿cómo de buena crees que es tu castellano? (siendo 1 "no muy buena" y 5 "excelente")
¿Qué lengua oral es la que mejor dominas?
¿Cuál es tu lengua nativa?
¿Cuál es la lengua que usas actualmente para tu comunicación diaria?
Aparte de LSE o castellano, ¿conoces alguna otra lengua (oral o signada)?
¿Cuál es el nivel académico más alto que tienes?
De los 5 a los 11 años, ¿qué idioma usaste EN las clases?
De los 12 a los 16 años, ¿qué idioma usaste EN las clases?
¿En qué tipo de centros has estudiado (ordinario, preferente, residencia, instituto, universidad, etc.)?
¿Tu madre es/era sorda u oyente?
¿Tu padre es/era sordo u oyente?
Cuando eras niño/a, ¿cuál era el principal sistema de comunicación que utilizabas con tu madre?
Cuando eras niño/a, ¿cuál era el principal sistema de comunicación que utilizabas con tu padre?
En caso de tener pareja actualmente, ¿cuál es el principal sistema de comunicación que utilizas con él/ella?
¿La mayoría de tus amigos son sordos, oyentes o por igual?
¿Alguno/as de tus hermanos/as (en caso de tenerlos) es sordo/a o sordociego/a?
¿Tienes algún otro pariente sordo o sordociego en tu familia?
¿Te gusta leer?
¿A qué edad aprendiste a leer?
Cuando eras pequeño... [¿alguien de tu familia te leía libros o cuentos?]
Cuando eras pequeño... [¿alguien de tu familia te compraba libros o cuentos?]
Cuando eras pequeño... [¿alguien de tu familia te preguntaba por lo que leías?]
Actualmente, en tu trabajo o estudios, ¿utilizas la lectura?
¿Cuántas horas AL DÍA dedicas a la lectura? [Por cuestiones de trabajo o estudios]
¿Cuántas horas AL DÍA dedicas a la lectura? [Libros (novelas, poemas, acción, suspense, etc.)]
¿Cuántas horas AL DÍA dedicas a la lectura? [Periódicos, revistas y artículos]
¿Cuántas horas AL DÍA dedicas a la lectura? [Correos electrónicos, internet, mensajería móvil]
Aproximadamente, ¿cuántos libros tienes en casa?
¿Cuántos libros te has leído en el último año (libros físicos o electrónicos)?
¿Con qué frecuencia utilizas el subtitulado para ver la televisión?
Si quieres añadir algún comentario, puedes hacerlo aquí.

APPENDIX B: List of stimuli for the Semantic condition

Correct sentences	Incorrect sentences
Sus dedos parecían finos en la foto.	Tus pantalones están condenados en el dobladillo.
Tus castigos son crueles y perversos.	Mis objetivos eran solares pero los conseguí.
Sus créditos serán aceptados por la universidad.	Sus tornillos eran valientes y de metal.
Tus productos eran exclusivos y muy peculiares.	Tus trapos estaban asustados después de la limpieza.
Sus consejos eran prácticos y realistas.	Mis teléfonos están brutos en la agenda.
Mis hábitos eran sanos según el médico.	Sus documentos son fritos para este juicio.
Sus tesoros estaban enterrados en la playa.	Tus derechos fueron cocinados durante la dictadura.
Sus cursos son gratuitos durante el invierno.	Sus partidos serán ingenuos para ganar la liga.
Tus bolígrafos están puestos en la mesilla.	Mis platos son mutantes y de porcelana.
Tus archivos fueron borrados del ordenador.	Tus perros están divorciados con el nuevo juguete.
Mi cuerpo estaba cambiado después de la cirugía.	Tu sueño será morado si no lo intentas.
Mi estudio era prioritario para el centro.	Su micrófono era optimista y bastante potente.
Mi pronóstico era razonable según el especialista.	Mi sótano está enfadado desde la semana pasada.
Tu cuadro estará incluido en la exposición.	Tu marido es estatal de engañarte.
Su gato es cariñoso y muy juguetón.	Su salario era calvo para una vida de lujo.
Su vestido era sensual para su corte.	Tu piano fue pacificado por el técnico del taller.
Mi verano fue maravilloso y memorable.	Su camino estaba sudado de hierba reseca.
Su argumento fue ofensivo para la profesora.	Mi primo es vertical con sus amigos.
Mi futuro será feliz y próspero.	Tu negocio parecía emocionado para este mercado.
Su empleo es indefinido con un buen sueldo.	Su destino era grasiento e inevitable.
Tus ruedas estarán arregladas en dos horas.	Mis corbatas son silvestres como mis trajes.
Sus cuerdas estaban enrolladas dentro del saco.	Mis manzanas están despedidas y llenas de moho.
Sus manoplas eran cálidas para usar en la nieve.	Sus plantas eran afeitadas y exóticas.
Sus gafas eran graduadas debido a su miopía.	Tus raquetas son cocinadas para jugar al tenis.
Tus galletas eran dulces dentro de la cesta.	Sus servilletas son dramáticas y de papel suave.
Mis zapatillas eran deportivas y muy informales.	Mis copas eran rabiosas y de diferentes tamaños.
Sus perchas estaban colocadas en el mueble.	Sus bragas eran celosas y muy monas.
Tus sábanas son ideales para mi cama.	Tus revistas son perezosas y difíciles de entender.
Mis lámparas estaban tiradas en el suelo.	Sus blusas son jugosas y le favorecen.
Sus naranjas eran ácidas porque estaban verdes.	Mis hojas estaban embarazadas dentro del archivo.
Su novia era pobre y honrada.	Mi baraja es íntima de la normal.
Tu furgoneta es económica porque consume poco.	Tu barba era turística y muy estilosa.
Su cartera estaba desaparecida esta mañana.	Su cara parecía electrónica cuando sonreía.
Su rutina era intensa porque curraba mucho.	Mi familia es hinchable en sus valores.
Mi huerta está ubicada detrás del cementerio.	Mi gorra fue castigada con mi nombre.
Su cocina estaba caótica todas las mañanas.	Tu medicina era educada y muy eficaz.
Su maleta era estrecha y muy simple.	Su tortuga era cantante y vivía en un acuario.
Tu sopa estaba picante por el pimentón.	Mi lengua estaba rencorosa por el café caliente.
Mi empresa estaba arruinada después del suceso.	Su crema era cuadrada para eliminar arrugas.

Su nómina fue entregada al principio del mes.	Tu hermana es anual pero borde.

APPENDIX C: List of stimuli for the Number condition

Correct sentences	Incorrect sentences
Mis huesos estaban fracturados en muchas partes.	Sus pendientes eran plateado y con piedras preciosas.
Mis zapatos estaban desgastados después de años de uso.	Tus pedales estaban defectuoso y no funcionaban bien.
Sus músculos están fuertes por la práctica del deporte.	Mis botines eran elegante y de cuero marrón.
Mis puños estaban lesionados por el entrenamiento.	Sus balancines fueron retirado del parque.
Sus tejidos eran coloridos y muy alegres.	Tus sillines fueron elaborado con material impermeable.
Mis calcetines estaban mojados en el tendedero.	Mis brazos estaban tatuado con letras chinas.
Tus guantes fueron cosidos por la costurera.	Tus ojos eran atractivo y muy seductores.
Mis cables fueron conectados por el técnico.	Sus datos fueron copiado en el ordenador.
Sus árboles estaban magníficos y llenos de frutos.	Mis cascos estaban barato en las rebajas.
Sus sobres fueron sellados por seguridad.	Sus rasgos eran parecido a los de su madre.
Su evento fue autorizado por toda la junta.	Mi perfil fue creados la semana pasada.
Su vicio era nocivo para sus pulmones.	Su tren era eléctricos y muy moderno.
Su juego parecía entretenido para su familia.	Mi pez era dorados y comía mucho.
Su baño estaba limpio e higienizado.	Su resumen está guardados en un fichero.
Mi barco era espléndido y muy sofisticado.	Su cofre estaba blindados y bien protegido.
Su tomate era fresco y de caserío.	Su miedo era intensos y muy paralizante.
Tu informe fue útil para la empresa.	Tu pulso estaba flojos y no se apreciaba.
Su test era sencillo y muy previsible.	Su libro fue seleccionados por el jurado.
Mi aceite era importado y muy especial.	Mi texto fue escritos con mucha prisa. .
Su póster fue presentado en la conferencia.	Su pedido fue enviados por email ayer.
Sus monedas estaban sueltas dentro del bolso.	Tus frases son tonta y poco inteligentes.
Sus tapas eran famosas en todo el país.	Sus canciones eran apreciada y muy célebres.
Sus camisetas fueron estampadas en diferentes colores.	Tus actividades eran amena y muy joviales.
Mis recetas eran apetitosas y simple de cocinar.	Mis aves fueron donada al jardín zoológico.
Sus huellas fueron identificadas por la policía nacional.	Sus razones estaban justificada por la situación.
Sus intenciones son claras desde el principio.	Sus camas estaban hecha de madera maciza.
Mis virtudes son valoradas por todos mis amigos.	Tus deudas están cubierta desde el año pasado.
Tus acciones eran ilógicas y difíciles de entender.	Mis toallas son perfumada y muy suaves.
Sus leyes eran importantes para todo el pueblo.	Sus piernas estaban cargada después de la carrera.
Mis cuestiones fueron discutidas en el grupo de estudio.	Mis mantas estaban asquerosa en el salón.
Su bebida fue servida por el camarero.	Su comunidad será elegidas la mejor de la región.
Mi cita fue anulada por mi asistente.	Mi calvicie estaba avanzadas en los últimos meses.
Su melena estaba teñida de color rubio.	Su torre era altas y con mucha visibilidad.
Mi alarma fue utilizada durante la emergencia.	Tu calle está cortadas por obras.
Tu prenda era igual a la mía.	Su pose parecía fingidas y artificial.

Mi aeronave estaba aparcada en el aeropuerto.
Su clave era fácil de descifrar.
Mi conexión era buena para acceder a internet.
Mi reunión será confirmada por mi jefe mañana.
Su canción era horrible y de mal gusto.

Mi excusa fue mencionadas en la reunión.
Su droga fue encontradas ayer por la policía.
Mi oferta fue rechazadas por su cliente.
Mi navaja era afiladas y muy peligrosa.
Su broma fue irónicas y sin gracia.

APPENDIX D: List of stimuli for the Gender Transparent condition

Correct sentences
Su bolsillo estaba rematado con hilo grueso.
Tu pañuelo era discreto y de seda italiana.
Mi peinado era exagerado para la ocasión.
Tu ejercicio parecía complejo para los estudiantes.
Tu esfuerzo fue escaso en la competición.
Su colegio era público y con gran profesorado.
Tu abanico estaba roto dentro de la basura.
Mi arbusto creció hermoso en muy poco tiempo.
Tu trabajo es lento y con pocos resultados.
Su vaso estaba sucio de café esta mañana.
Tu sombrero era idéntico al de mi hermana.
Su terreno está iluminado y cerca del río.
Su piso fue abandonado tras el incendio.
Mi contrato fue firmado por la tarde.
Mi candado era seguro para la bici.
Su palacio fue construido en el siglo pasado.
Su asiento era pequeño para personas mayores.
Tu despacho está alejado del centro.
Mi martillo era pesado y molesto de manejar.
Tu pelo es oscuro y muy brillante.
Tu bicicleta va rápida en carretera.
Su pregunta fue positiva para el debate.
Tu tarta era casera y recién horneada.
Su carta era confusa y difícil de leer.
Su comida estaba salada para mi gusto.
Su factura parecía cara para la familia.
Su fiesta fue aburrida e interminable.
Tu casa está organizada todos los días.
Su falda estaba lavada desde antes de ayer.
Mi carpeta está llena de impresos.
Mi hucha está vacía por la crisis.
Su chimenea estaba húmeda y no encendía.
Su nota es baja pero suficiente.
Su miseria era penosa e irreparable.
Tu pintura es bonita pero poco novedosa.
Mi pantalla es nueva y con tecnología de punta.
Su aventura fue divertida y sorprendente.
Tu lavadora era antigua pero funcionaba bien.
Su ensalada estaba rica y bien aliñada.

Incorrect Sentences
Mi disco fue grabada en un estudio ayer.
Su casino es conocida por todos en la ciudad.
Su mechero es peligrosa porque pierde gas.
Tu artículo fue publicada en una revista.
Su carro era ligera y fácil de desplazar.
Mi chaleco era auténtica y muy llamativo.
Tu teclado era negra y con teclas numéricas.
Su helicóptero estaba lista para despegar.
Mi armario era amplia y con muchas baldas.
Tu anuncio es graciosa pero muy machista.
Su bocadillo era exquisita y enorme.
Mi abrigo estaba empapada y olía mal.
Su ejemplo fue obvia pero explicaba el problema.
Tu folio estaba dibujada con acuarela.
Su queso estaba deliciosa con la mermelada.
Su anuario era clásica y en blanco y negro.
Su rebaño estaba perdida en los montes.
Su edificio fue proyectada por un arquitecto alemán.
Tu cigarrillo fue apagada por el viento.
Tu velero fue usada durante las vacaciones.
Su villa fue renovado el mes pasado.
Tu oficina fue decorado por un profesional.
Mi tinaja fue pintado de verde claro.
Mi cerveza estaba congelado en el frigorífico.
Tu botella fue reciclado en la fábrica.
Su silla era cómodo y también ergonómica.
Mi pizarra es blanco y también digital.
Tu camisa era bello y muy femenina.
Su mochila era adecuado para hacer senderismo.
Mi chaqueta era sobrio pero de buen gusto.
Tu pistola era automático y fácil de usar.
Su alegría fue pasajero pero inolvidable.
Su arcilla era apropiado para fabricar tiestos.
Su impresora estuvo encendido todo el fin de semana.
Tu persiana estaba abierto esta mañana.
Su boda fue modesto pero muy romántica.
Mi margarita creció precioso en mi terraza.
Tu guitarra era viejo pero muy original.
Mi zanahoria estaba crudo cuando la comí.

Mi mesa era redonda y con detalles azules.	Su ventana estuvo cerrado toda la noche.

APPENDIX E: List of stimuli for the Gender Opaque condition

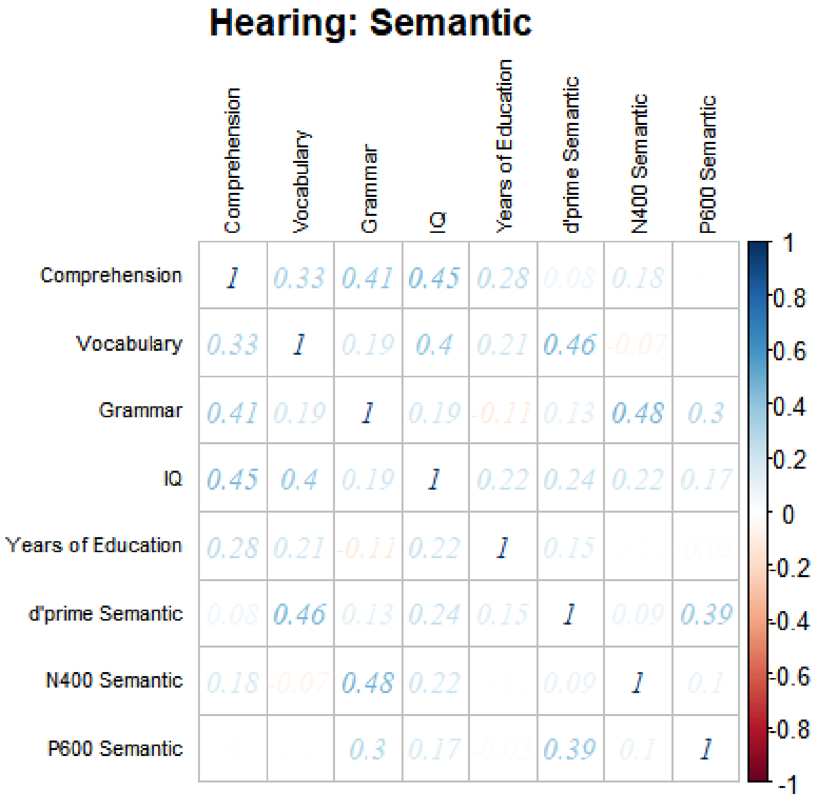
Correct sentences
Mi cristal fue rayado antes de ayer.
Mi diente fue extraído por el dentista.
Su delantal era ajustado y muy corto.
Su coche estaba registrado en España.
Mi talismán fue regalado por mi madre.
Mi examen fue arduo y muy exigente.
Tu jardín era florido y encantador.
Su detalle era perfecto para la ocasión.
Mi mensaje fue extenso y muy impersonal.
Mi peine fue fabricado en China.
Mi violín fue costoso cuando lo compré.
Su cadáver parecía asombroso en la tumba.
Mi aguacate estaba maduro y muy tierno.
Tu restaurante es lujoso para mi gusto.
Su chicle era rojo con sabor a fresa.
Tu billete fue vendido por poco precio.
Su carácter era misterioso y un poco sombrío.
Mi pie estaba dolorido por el entrenamiento.
Mi té estaba frío y poco apetecible.
Mi paquete fue olvidado en el maletero.
Su cicatriz era fea y permanente.
Mi miel estaba caducada en la nevera.
Mi coliflor estaba sabrosa con el jamón.
Tu mente es complicada de entender.
Su piel estaba seca por el invierno.
Su ciudad es ruidosa durante el día.
Mi tele parecía averiada cuando la encendí.
Su sangre era viscosa y bastante espesa.
Mi clase era tranquila y con pocos estudiantes.
Su libertad fue concedida por el juez.
Mi noche fue animada en la discoteca.
Tu amistad parecía falsa y muy desleal.
Su tarde fue inesperada y muy alegre.
Tu luz estaba fundida hacía semanas.
Mi imagen resultó perjudicada por la entrevista.
Tu tos era crónica por la neumonía.
Su voz parecía aguda en la radio ayer.

Incorrect sentences
Mi papel estaba arrugada en la bolsa.
Tu machete estaba escondida en mi trastero.
Su plan parecía arriesgada para la investigación.
Su viaje fue cancelada debido al mal tiempo.
Mi maletín fue dejada en el aeropuerto.
Su implante era metálica y de mucha calidad.
Tu fax estaba encendida durante todo el día.
Su móvil fue hurtada de su bolso.
Mi champú fue rebajada de precio.
Su mocasín estaba cubierta de barro y suciedad.
Mi cojín estaba rellena de plumas de ganso.
Su diamante era pura e incoloro.
Su hospital está saturada de pacientes.
Tu broche era valiosa para tu familia.
Su arroz estaba pegada y sin sabor.
Tu manual era didáctica para los estudiantes.
Su reloj fue diseñada por un artista.
Su bar estaba próxima a la universidad.
Mi pan fue horneada en la panadería.
Tu chocolate es amarga y sin azúcares.
Mi llave está colgado en la entrada.
Su habitación estaba recogido esta mañana.
Su higiene era obsesivo hasta el extremo.
Tu gripe parecía serio y preocupante.
Su suerte era fantástico en las apuestas.
Su nave estaba ocupado por muchos pasajeros.
Su opinión era atrevido para alguien inexperto.
Mi actitud fue respetado por sus amigos.
Tu serpiente estaba preso en la trampa.
Su gratitud era sincero y admirable.
Su cumbre es ancho y pedregosa.
Tu flor es amarillo como el sol.
Su salud era delicado en ese momento.
Mi sien estaba hinchado después del golpe.
Su muerte fue doloroso y muy trágica.
Tu calle estaba bloqueado por la procesión.
Su vejez parecía sosegado en los últimos años.

Mi serie fue basada en una historia real.
Su raíz era larga para este tiesto.
Tu costumbre es mala para tu familia.

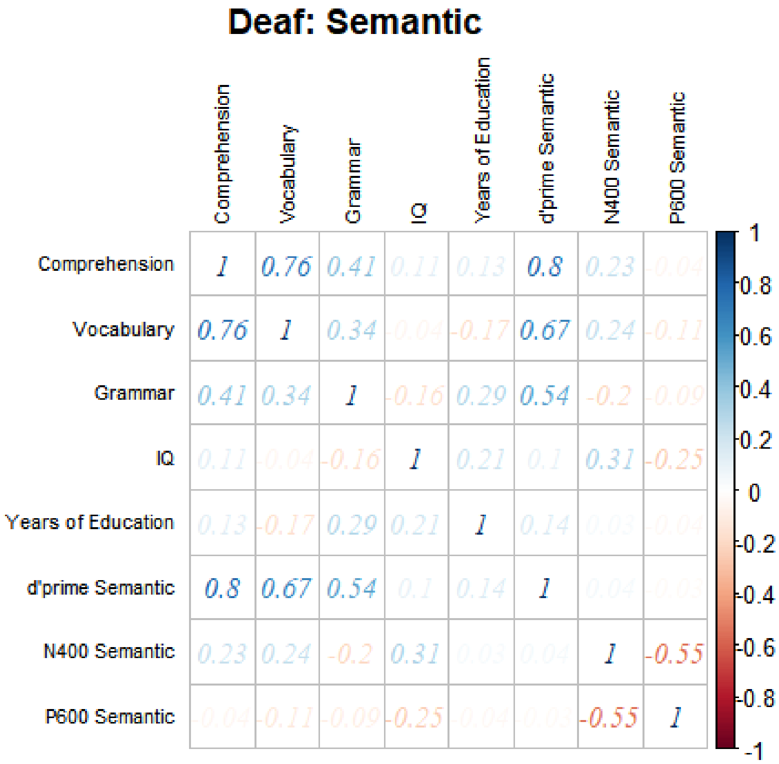
Tu religión era estricto y muy intolerante.
Su juventud era tedioso en aquel pueblo.
Su pared fue derribado por el aparejador.

APPENDIX F: Correlations between behavioral measures and ERP effects for the Semantic condition



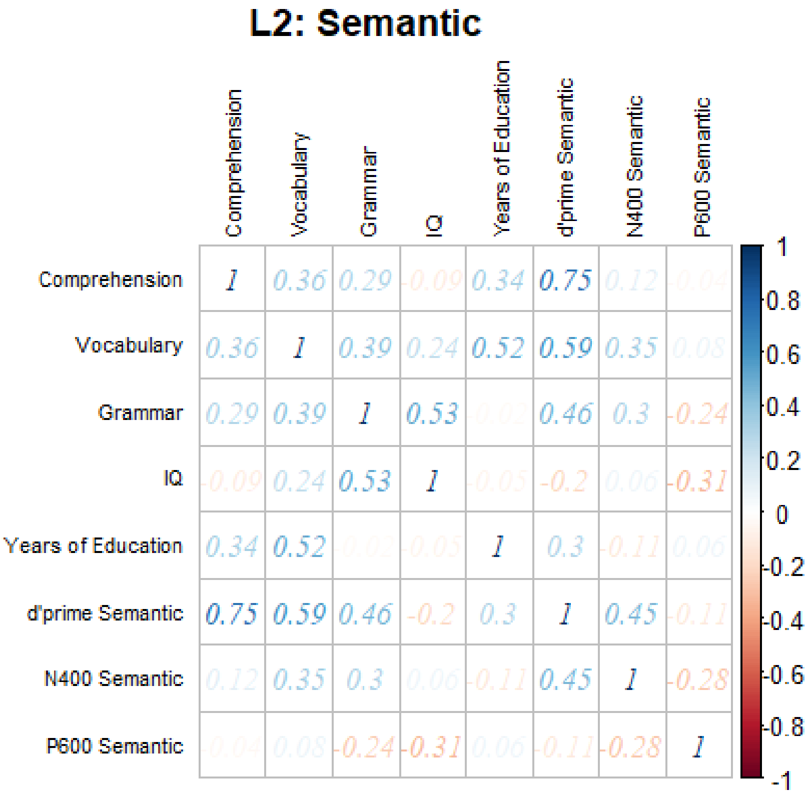
Hearing: Semantic

	Comprehension	Vocabulary	Grammar	IQ	Years of Education	d'prime Semantic	N400 Semantic	P600 Semantic
Comprehension	1	0.33	0.41	0.45	0.28	0.08	0.18	0
Vocabulary	0.33	1	0.19	0.4	0.21	0.46	-0.07	-0.01
Grammar	0.41	0.19	1	0.19	-0.11	0.13	0.48	0.3
IQ	0.45	0.4	0.19	1	0.22	0.24	0.22	0.17
Years of Education	0.28	0.21	-0.11	0.22	1	0.15	-0.01	-0.03
d'prime Semantic	0.08	0.46	0.13	0.24	0.15	1	0.09	0.39
N400 Semantic	0.18	-0.07	0.48	0.22	-0.01	0.09	1	0.1
P600 Semantic	0	-0.01	0.3	0.17	-0.03	0.39	0.1	1



Deaf: Semantic

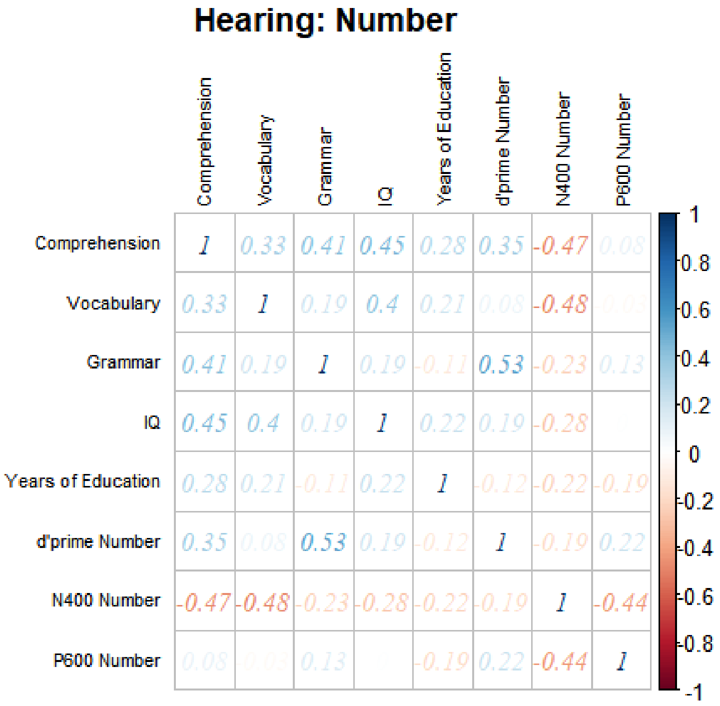
	Comprehension	Vocabulary	Grammar	IQ	Years of Education	d'prime Semantic	N400 Semantic	P600 Semantic
Comprehension	1	0.76	0.41	0.11	0.13	0.8	0.23	-0.04
Vocabulary	0.76	1	0.34	-0.04	-0.17	0.67	0.24	-0.11
Grammar	0.41	0.34	1	-0.16	0.29	0.54	-0.2	-0.09
IQ	0.11	-0.04	-0.16	1	0.21	0.1	0.31	-0.25
Years of Education	0.13	-0.17	0.29	0.21	1	0.14	0.03	-0.04
d'prime Semantic	0.8	0.67	0.54	0.1	0.14	1	0.04	-0.03
N400 Semantic	0.23	0.24	-0.2	0.31	0.03	0.04	1	-0.55
P600 Semantic	-0.04	-0.11	-0.09	-0.25	-0.04	-0.03	-0.55	1



L2: Semantic

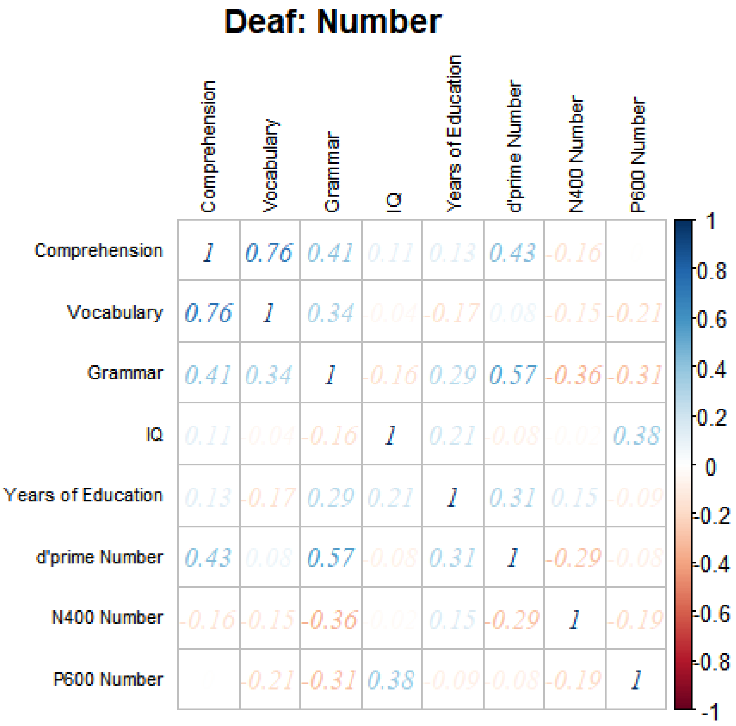
	Comprehension	Vocabulary	Grammar	IQ	Years of Education	d'prime Semantic	N400 Semantic	P600 Semantic
Comprehension	1	0.36	0.29	-0.09	0.34	0.75	0.12	-0.04
Vocabulary	0.36	1	0.39	0.24	0.52	0.59	0.35	0.08
Grammar	0.29	0.39	1	0.53	-0.02	0.46	0.3	-0.24
IQ	-0.09	0.24	0.53	1	-0.05	-0.2	0.06	-0.31
Years of Education	0.34	0.52	-0.02	-0.05	1	0.3	-0.11	0.06
d'prime Semantic	0.75	0.59	0.46	-0.2	0.3	1	0.45	-0.11
N400 Semantic	0.12	0.35	0.3	0.06	-0.11	0.45	1	-0.28
P600 Semantic	-0.04	0.08	-0.24	-0.31	0.06	-0.11	-0.28	1

APPENDIX G: Correlations between behavioral measures and ERP effects for the Number condition.



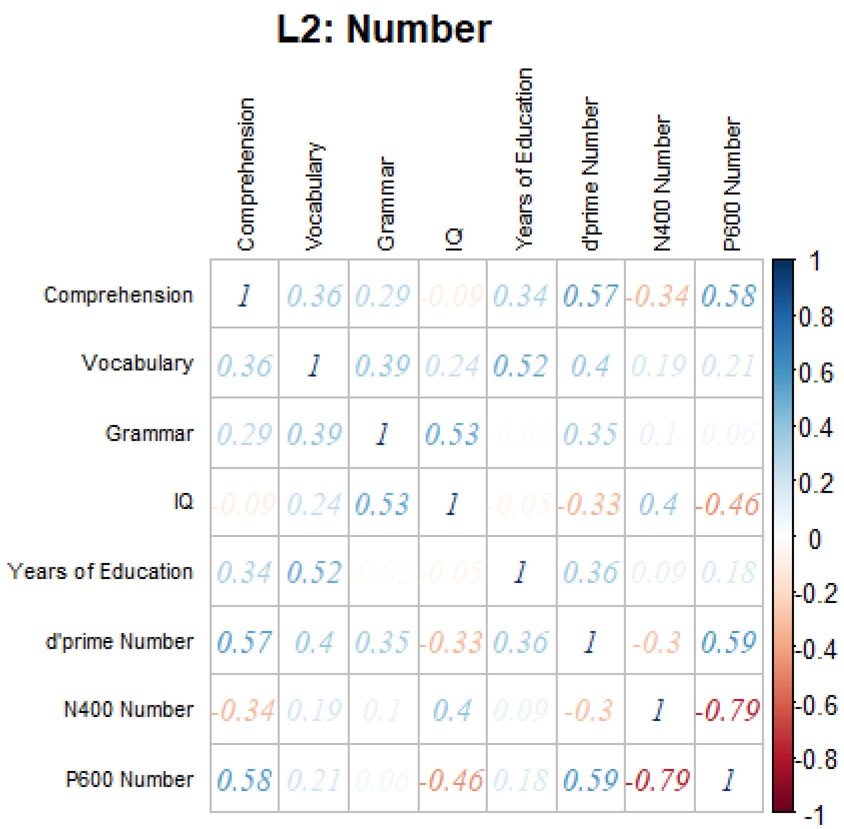
Hearing: Number

	Comprehension	Vocabulary	Grammar	IQ	Years of Education	d'prime Number	N400 Number	P600 Number
Comprehension	1	0.33	0.41	0.45	0.28	0.35	-0.47	0.08
Vocabulary	0.33	1	0.19	0.4	0.21	0.08	-0.48	-0.03
Grammar	0.41	0.19	1	0.19	-0.11	0.53	-0.23	0.13
IQ	0.45	0.4	0.19	1	0.22	0.19	-0.28	
Years of Education	0.28	0.21	-0.11	0.22	1	-0.12	-0.22	-0.19
d'prime Number	0.35	0.08	0.53	0.19	-0.12	1	-0.19	0.22
N400 Number	-0.47	-0.48	-0.23	-0.28	-0.22	-0.19	1	-0.44
P600 Number	0.08	-0.03	0.13		-0.19	0.22	-0.44	1



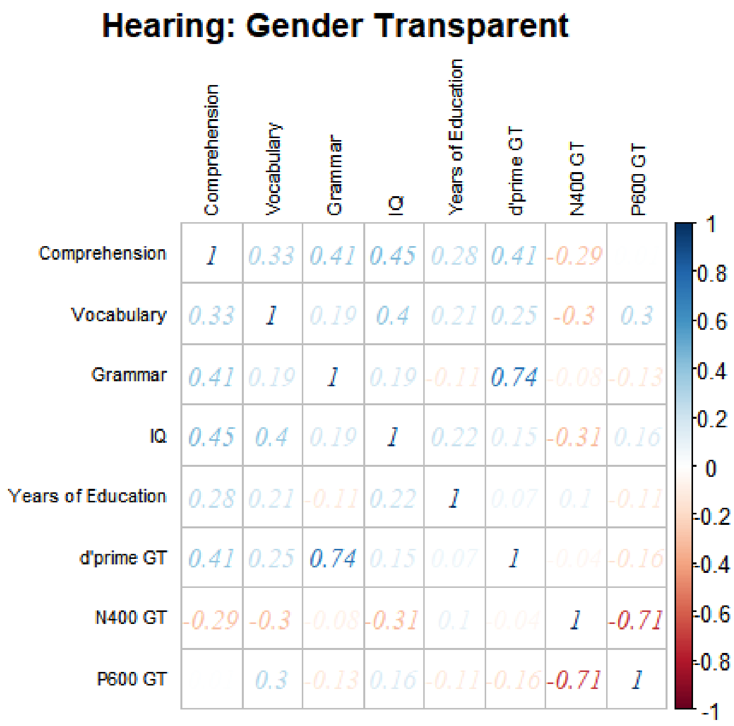
Deaf: Number

	Comprehension	Vocabulary	Grammar	IQ	Years of Education	d'prime Number	N400 Number	P600 Number
Comprehension	1	0.76	0.41	0.11	0.13	0.43	-0.16	
Vocabulary	0.76	1	0.34	-0.04	-0.17	0.08	-0.15	-0.21
Grammar	0.41	0.34	1	-0.16	0.29	0.57	-0.36	-0.31
IQ	0.11	-0.04	-0.16	1	0.21	-0.08	-0.02	0.38
Years of Education	0.13	-0.17	0.29	0.21	1	0.31	0.15	-0.09
d'prime Number	0.43	0.08	0.57	-0.08	0.31	1	-0.29	-0.08
N400 Number	-0.16	-0.15	-0.36	-0.02	0.15	-0.29	1	-0.19
P600 Number		-0.21	-0.31	0.38	-0.09	-0.08	-0.19	1



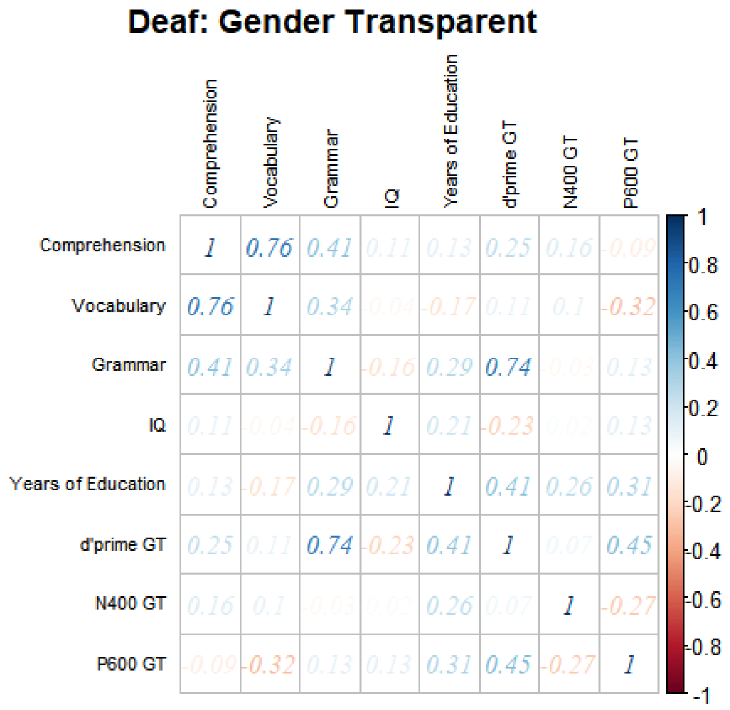
	Comprehension	Vocabulary	Grammar	IQ	Years of Education	d'prime Number	N400 Number	P600 Number
Comprehension	1	0.36	0.29	-0.09	0.34	0.57	-0.34	0.58
Vocabulary	0.36	1	0.39	0.24	0.52	0.4	0.19	0.21
Grammar	0.29	0.39	1	0.53	-0.02	0.35	0.1	0.06
IQ	-0.09	0.24	0.53	1	-0.05	-0.33	0.4	-0.46
Years of Education	0.34	0.52	-0.02	-0.05	1	0.36	0.09	0.18
d'prime Number	0.57	0.4	0.35	-0.33	0.36	1	-0.3	0.59
N400 Number	-0.34	0.19	0.1	0.4	0.09	-0.3	1	-0.79
P600 Number	0.58	0.21	0.06	-0.46	0.18	0.59	-0.79	1

APPENDIX H: Correlations between behavioral measures and ERP effects for the Gender Transparent condition.



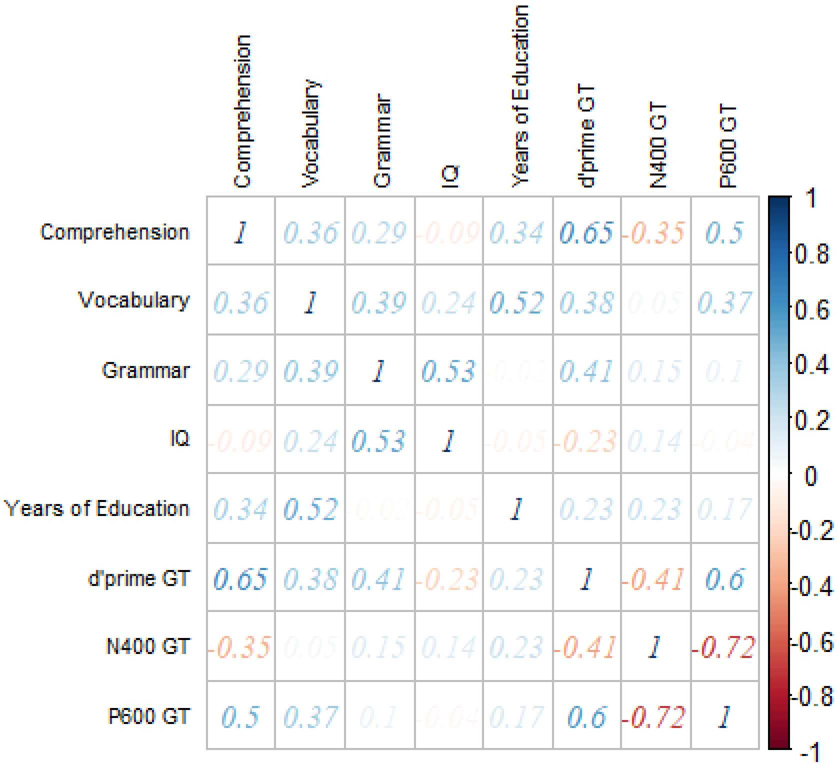
Hearing: Gender Transparent

	Comprehension	Vocabulary	Grammar	IQ	Years of Education	d'prime GT	N400 GT	P600 GT
Comprehension	1	0.33	0.41	0.45	0.28	0.41	-0.29	[illegible]
Vocabulary	0.33	1	0.19	0.4	0.21	0.25	-0.3	0.3
Grammar	0.41	0.19	1	0.19	-0.11	0.74	-0.08	-0.13
IQ	0.45	0.4	0.19	1	0.22	0.15	-0.31	0.16
Years of Education	0.28	0.21	-0.11	0.22	1	0.07	0.1	-0.11
d'prime GT	0.41	0.25	0.74	0.15	0.07	1	-0.04	-0.16
N400 GT	-0.29	-0.3	-0.08	-0.31	0.1	-0.04	1	-0.71
P600 GT	[illegible]	0.3	-0.13	0.16	-0.11	-0.16	-0.71	1



Deaf: Gender Transparent

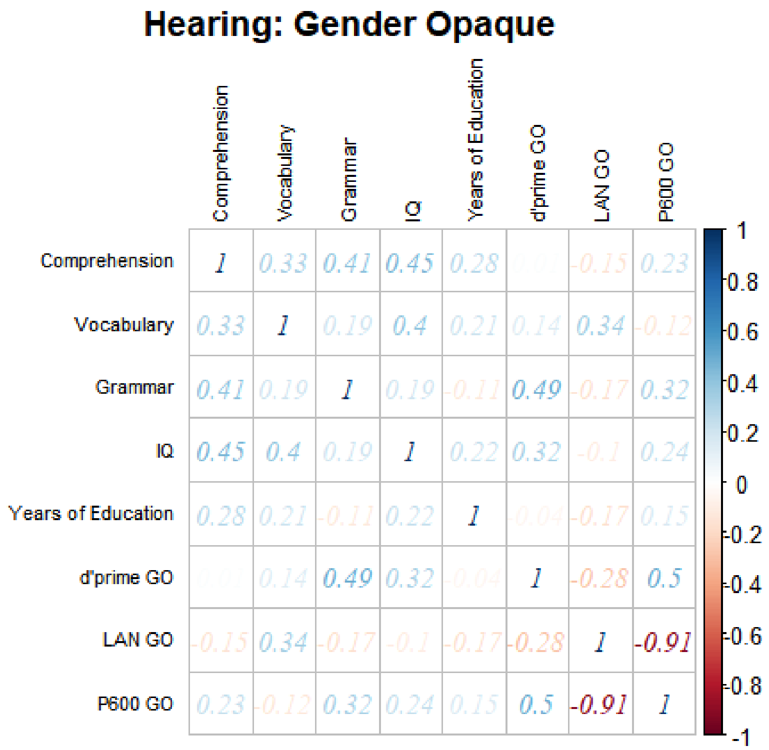
	Comprehension	Vocabulary	Grammar	IQ	Years of Education	d'prime GT	N400 GT	P600 GT
Comprehension	1	0.76	0.41	0.11	0.13	0.25	0.16	-0.09
Vocabulary	0.76	1	0.34	-0.04	-0.17	0.11	0.1	-0.32
Grammar	0.41	0.34	1	-0.16	0.29	0.74	-0.03	0.13
IQ	0.11	-0.04	-0.16	1	0.21	-0.23	0.02	0.13
Years of Education	0.13	-0.17	0.29	0.21	1	0.41	0.26	0.31
d'prime GT	0.25	0.11	0.74	-0.23	0.41	1	0.07	0.45
N400 GT	0.16	0.1	-0.03	0.02	0.26	0.07	1	-0.27
P600 GT	-0.09	-0.32	0.13	0.13	0.31	0.45	-0.27	1



L2: Gender Transparent

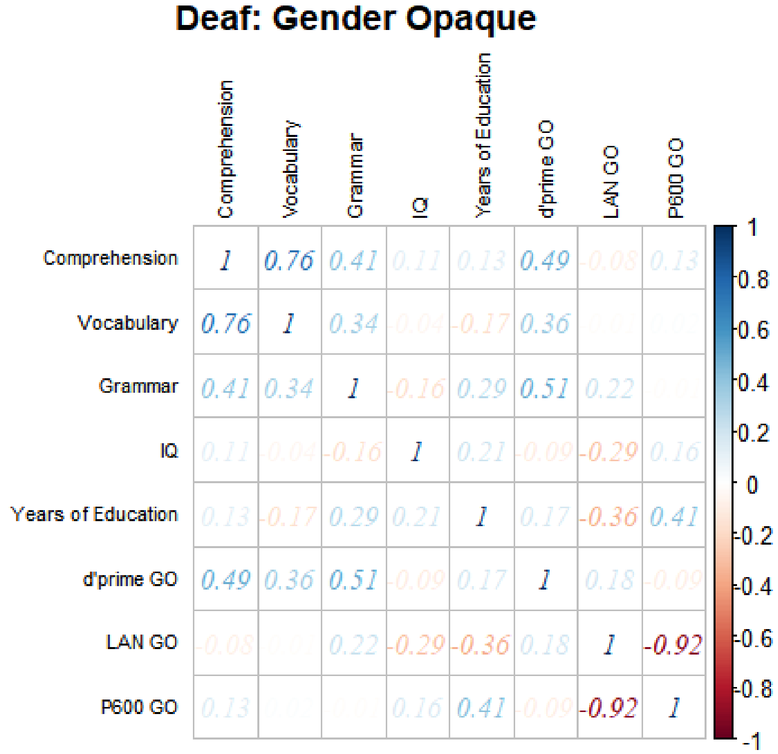
	Comprehension	Vocabulary	Grammar	IQ	Years of Education	d'prime GT	N400 GT	P600 GT
Comprehension	1	0.36	0.29	-0.09	0.34	0.65	-0.35	0.5
Vocabulary	0.36	1	0.39	0.24	0.52	0.38	0.05	0.37
Grammar	0.29	0.39	1	0.53	-0.02	0.41	0.15	0.1
IQ	-0.09	0.24	0.53	1	-0.05	-0.23	0.14	-0.04
Years of Education	0.34	0.52	-0.02	-0.05	1	0.23	0.23	0.17
d'prime GT	0.65	0.38	0.41	-0.23	0.23	1	-0.41	0.6
N400 GT	-0.35	0.05	0.15	0.14	0.23	-0.41	1	-0.72
P600 GT	0.5	0.37	0.1	-0.04	0.17	0.6	-0.72	1

APPENDIX I: Correlations between behavioral measures and ERP effects for the Gender Opaque condition.



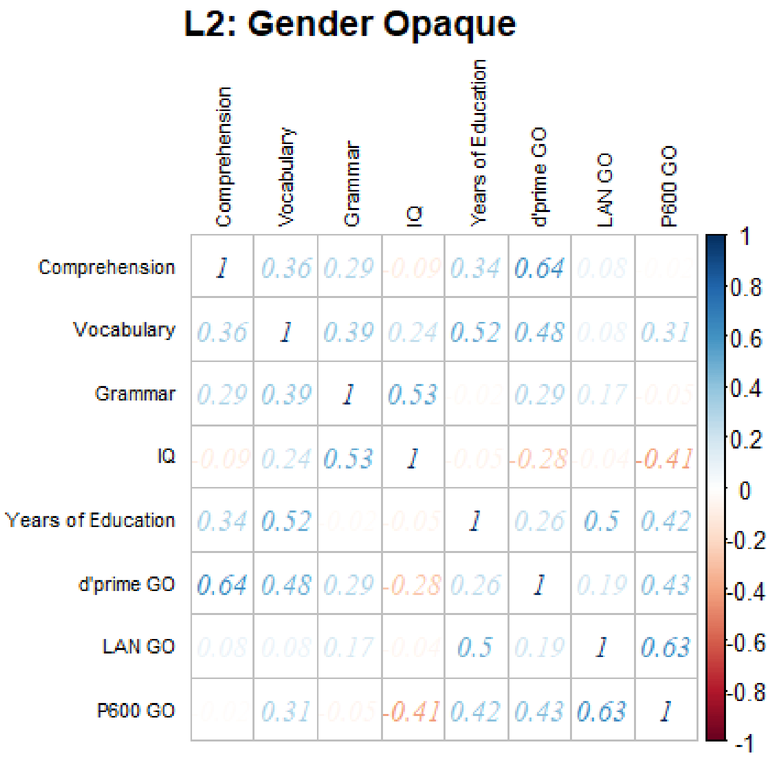
Hearing: Gender Opaque

	Comprehension	Vocabulary	Grammar	IQ	Years of Education	d'prime GO	LAN GO	P600 GO
Comprehension	1	0.33	0.41	0.45	0.28	0.01	-0.15	0.23
Vocabulary	0.33	1	0.19	0.4	0.21	0.14	0.34	-0.12
Grammar	0.41	0.19	1	0.19	-0.11	0.49	-0.17	0.32
IQ	0.45	0.4	0.19	1	0.22	0.32	-0.1	0.24
Years of Education	0.28	0.21	-0.11	0.22	1	-0.04	-0.17	0.15
d'prime GO	0.01	0.14	0.49	0.32	-0.04	1	-0.28	0.5
LAN GO	-0.15	0.34	-0.17	-0.1	-0.17	-0.28	1	-0.91
P600 GO	0.23	-0.12	0.32	0.24	0.15	0.5	-0.91	1



Deaf: Gender Opaque

	Comprehension	Vocabulary	Grammar	IQ	Years of Education	d'prime GO	LAN GO	P600 GO
Comprehension	1	0.76	0.41	0.11	0.13	0.49	-0.08	0.13
Vocabulary	0.76	1	0.34	-0.04	-0.17	0.36	-0.01	0.02
Grammar	0.41	0.34	1	-0.16	0.29	0.51	0.22	-0.01
IQ	0.11	-0.04	-0.16	1	0.21	-0.09	-0.29	0.16
Years of Education	0.13	-0.17	0.29	0.21	1	0.17	-0.36	0.41
d'prime GO	0.49	0.36	0.51	-0.09	0.17	1	0.18	-0.09
LAN GO	-0.08	-0.01	0.22	-0.29	-0.36	0.18	1	-0.92
P600 GO	0.13	0.02	-0.01	0.16	0.41	-0.09	-0.92	1



L2: Gender Opaque

	Comprehension	Vocabulary	Grammar	IQ	Years of Education	d'prime GO	LAN GO	P600 GO
Comprehension	1	0.36	0.29	-0.09	0.34	0.64	0.08	-0.02
Vocabulary	0.36	1	0.39	0.24	0.52	0.48	0.08	0.31
Grammar	0.29	0.39	1	0.53	-0.02	0.29	0.17	-0.05
IQ	-0.09	0.24	0.53	1	-0.05	-0.28	-0.04	-0.41
Years of Education	0.34	0.52	-0.02	-0.05	1	0.26	0.5	0.42
d'prime GO	0.64	0.48	0.29	-0.28	0.26	1	0.19	0.43
LAN GO	0.08	0.08	0.17	-0.04	0.5	0.19	1	0.63
P600 GO	-0.02	0.31	-0.05	-0.41	0.42	0.43	0.63	1

APPENDIX J: Number of correct trials per condition in the End-of-Sentence Acceptability Judgment Task.

	Conditions								
Hearing Group	**Semantic Control**	**Semantic Violation**	**Number Control**	**Number Violation**	**GenTr Control**	**GenTr Violation**	**GenOp Control**	**GenOp Violation**	**Total Trials**
Participant_1	39	39	37	37	38	39	38	39	306
Participant_2	31	30	33	29	33	33	34	30	253
Participant_3	38	39	38	39	36	40	39	39	308
Participant_4	31	33	32	34	28	29	29	33	249
Participant_5	37	36	34	34	34	31	37	28	271
Participant_6	34	29	32	33	34	29	33	26	250
Participant_7	26	24	23	22	23	25	26	20	189
Participant_8	38	39	37	36	37	39	36	38	300
Participant_9	39	34	39	39	36	33	38	38	296
Participant_10	39	34	36	36	38	37	37	38	295
Participant_11	34	36	33	30	30	37	35	32	267
Participant_12	38	36	38	36	35	38	33	38	292
Participant_13	36	35	35	34	34	33	34	38	279
Participant_14	35	30	40	37	37	38	36	38	291
Participant_15	40	40	39	40	37	40	38	39	313
Participant_16	37	39	38	40	37	39	39	40	309
Participant_17	37	36	35	36	39	34	37	34	288
Participant_18	38	36	38	34	37	35	39	34	291
Participant_19	34	37	34	35	33	36	37	33	279

Note: The maximum of correct trials for each condition is 40.

Deaf Group	**Conditions**								
	Semantic Control	**Semantic Violation**	**Number Control**	**Number Violation**	**GenTr Control**	**GenTr Violation**	**GenOp Control**	**GenOp Violation**	**Total Trials**
Participant_1	40	38	38	38	40	38	39	39	310
Participant_2	40	37	37	38	38	38	38	39	305
Participant_3	38	28	34	39	35	39	35	31	279
Participant_4	40	38	39	37	37	38	39	39	307
Participant_5	40	26	39	40	40	39	40	37	301
Participant_6	30	28	28	27	23	32	29	31	228
Participant_7	30	22	34	28	28	34	32	28	236
Participant_8	36	37	32	32	36	35	33	33	274
Participant_9	36	29	34	37	33	34	31	30	264
Participant_10	37	24	38	38	37	35	38	24	271
Participant_11	32	38	36	40	32	39	28	37	282
Participant_12	29	25	29	27	23	27	26	25	211
Participant_13	23	36	18	19	20	26	19	22	183
Participant_14	39	18	34	38	40	37	35	30	271
Participant_15	38	22	35	33	38	37	37	36	276
Participant_16	39	39	36	39	36	33	34	31	287
Participant_17	36	30	37	35	35	33	38	34	278
Participant_18	39	39	37	39	40	40	40	40	314
Participant_19	39	38	38	39	40	38	39	40	311

Note: The maximum of correct trials for each condition is 40.

L2 Group	**Conditions**								
	Semantic Control	**Semantic Violation**	**Number Control**	**Number Violation**	**GenTr Control**	**GenTr Violation**	**GenOp Control**	**GenOp Violation**	**Total Trials**
Participant_1	38	36	38	39	39	37	38	31	296
Participant_2	37	30	30	30	38	27	29	22	243
Participant_3	27	29	27	29	26	24	27	23	212
Participant_4	37	37	34	38	32	36	34	32	280
Participant_5	36	36	34	34	33	33	31	27	264
Participant_6	27	35	25	28	21	25	27	16	204
Participant_7	29	21	32	20	27	14	34	11	188
Participant_8	35	28	33	33	35	23	34	17	238
Participant_9	26	31	29	19	24	19	30	15	193
Participant_10	38	35	35	38	37	33	37	24	277
Participant_11	32	30	32	35	35	35	31	33	263
Participant_12	32	34	30	32	26	33	24	25	236
Participant_13	36	17	37	34	36	25	29	16	230
Participant_14	34	30	27	28	28	11	28	14	200
Participant_15	36	33	29	31	34	25	27	25	240
Participant_16	29	34	30	24	32	23	31	16	219
Participant_17	29	38	36	31	28	16	33	10	221
Participant_18	38	39	37	37	39	35	37	35	297
Participant_19	35	33	33	36	36	27	35	27	262

Note: The maximum of correct trials for each condition is 40.