UNIVERSIDAD COMPLUTENSE DE MADRID
FACULTAD DE PSICOLOGÍA

TESIS DOCTORAL

Mecanismos neurales implicados en la generación de inferencias

Neural mechanisms underlying inference generation

MEMORIA PARA OPTAR AL GRADO DE DOCTOR

PRESENTADA POR

Pablo Rodríguez Gómez

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“Ahora podemos entender mejor el abismo que separaba a Sabina de Franz: él escuchaba con avidez la historia de su vida y ella lo escuchaba a él con la misma avidez. Comprendían con precisión el significado lógico de las palabras que se decían, pero no oían en cambio el murmullo del río semántico que fluía por aquellas palabras”

Milan Kundera
La insoportable levedad del ser
Maxi Tusquets Editores, 18º Edición, 2017, p. 94

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SUMMARY

Introduction

Many psycholinguistics models have been proposed to study reading comprehension. All of these models agree that inference generation is a fundamental tool to achieve good comprehension levels. Generally, inference generation is assumed to be divided in two processes: activation and integration, and they are obtained combining the information included in the text and our own previous information and world knowledge. Nevertheless, there is still much to know about inferences and their characterization. The amount of models and theoretical proposals make it hard to reach a quorum about inferences classification. Especially, two models attempted to describe the conditions that encourage inference generation and which elements are helpful for it: the constructionist model and the minimalist model. The first takes the reader as an active agent who is always searching for meaning by creating a mental representation. This model takes into account the importance of extra linguistic aspects, such as the reader intentionality. On the other hand, the minimalist model defends that the main goal when reading is to establish local coherence. Since inference generation is mainly made during reading, the Event Related Potentials technique is perfect to study this process due to its high temporal resolution.

Objectives

The main objective of this thesis is to study the activation and integration processes involved in inference generation by exploring two typical ERPs components in language studies (N400 y P600). Another aim is to investigate neural differences of some types of inferences, depending on the information that is activated to generate each of them. In addition, we do not know much about what happens when the information included in the text and our world knowledge are conflicting, so we will try to shed some light to which source of information is preferred by readers in case of competition. Besides, we will consider the effect of extra linguistic aspects such as mood in inferences generation. Finally, our data will be useful to prove which model (constructionist versus minimalist) is more suitable to inference generation processes.

Results

The N400 component is a useful marker to study anticipation and integration in inference generation processes by combining the information included in the text and our own world experience. When the information in the text is not enough or the connection between the ideas is difficult to achieve, the inference is difficult to anticipate (and therefore to activate), and this elicits an increase in the N400 amplitude. Once the inference is generated, its integration can be monitored in the N400 amplitude. If the inference is violated, the amplitude of this component will increase. The P600 component and other late positivities such as the pN400FP are related to revision processes, reanalysis, conflict monitoring and formation of memory traces. If the inference can be integrated in previous context, the increase in the amplitude of the P600 component can be linked to the formation of memory traces in order to update the mental representation supported by the constructionist model. However, if the inference cannot be integrated, inhibition of strong predictions (pN400FP) or revision and reanalysis processes (P600) may occur. All of these neural mechanisms take place in function of the type of inference that is being violated. In case of competition between the information in the text and our own world knowledge, readers tend to rely on their experience. Finally, under a negative mood, readers tend to operate in a more analytical and logical way.

Conclusions

The N400 component is linked to activation and integration processes in inference generation, whereas the P600 component is related to revision and conflict monitoring processes when an inference is violated and the new information cannot be integrated. The constructionist model fits better our results, since it defends a mental representation and takes into account reader's intentionality. Nevertheless, it forgets to mention the importance of extra linguistic aspects such as mood in reading comprehension. Our results indicate that inferences can be classified regarding the information that is activated, since different neural mechanisms take part depending on the type of inference.

RESUMEN

Introducción

Se han propuesto numerosos modelos psicolingüísticos para el estudio de la comprensión lectora. Todos ellos coinciden en la importancia de la generación de inferencias en la misma. De manera general, se divide la generación de inferencias en dos procesos: activación e integración, y se asume que las inferencias se obtienen mediante una combinación de la información contenida en el texto junto con nuestro conocimiento del mundo y experiencia previa. Sin embargo, el debate sobre la caracterización de las mismas aún sigue vigente. La variabilidad de modelos y propuestas teóricas dificulta alcanzar un consenso sobre la clasificación de inferencias. Principalmente dos modelos se encargan de intentar explicar bajo qué condiciones se elaboran estas inferencias y de qué elementos nos servimos para ello: el modelo construccionista y el modelo minimalista. El primero defiende un papel activo del lector en busca de significado. Esta búsqueda de significado la lleva a cabo mediante inferencias estratégicas con las que va creando una representación mental. Este modelo es el único que tiene en cuenta la influencia de aspectos extralingüísticos en la comprensión lectora, como la intencionalidad del lector. Por el contrario, el modelo minimalista establece que el principal objetivo del lector es establecer coherencia local y apunta a niveles de representación mínimos. La generación de inferencias se lleva a cabo principalmente durante la lectura; por este motivo, la técnica de los Potenciales Evento-Relacionados (ERPs) es idónea para su estudio debido a su alta resolución temporal.

Objetivos

El principal objetivo de esta tesis doctoral consiste en explorar la posible relación de dos componentes típicos de ERPs en estudios de lenguaje (N400 y P600) con los procesos de activación e integración de las inferencias. Asimismo, estudiaremos las diferencias a nivel neural de varios tipos de inferencia en función del conocimiento del mundo que se activa para cada una de ellas, para intentar establecer una taxonomía de manera objetiva. Por otro lado, intentaremos dilucidar el papel que juegan la información presente en el texto y nuestro conocimiento del mundo en la elaboración de inferencias, así como a cuál de las dos se le otorga más peso en caso de competición. Además, consideraremos el efecto de aspectos extralingüísticos como el estado de ánimo. Los datos arrojados por los cuatro estudios de esta tesis doctoral, además, servirán para comprobar qué modelo (minimalista *versus* construccionista) se ajusta más a los procesos de generación de inferencias.

Resultados

El componente N400 sirve como marcador tanto de la anticipación como de la integración de las inferencias generadas a partir de la información contenida en el texto y nuestra propia experiencia. Cuando la información que se aporta es insuficiente, o la conexión entre las ideas de un texto es difícil de realizar, la inferencia es difícil de anticipar (y por tanto activar), y esto se traduce en un aumento de la amplitud del N400. Una vez generada la inferencia, su integración en el texto también se ve reflejada en los cambios de amplitud del mismo componente. Si una inferencia es violada, la amplitud del N400 también va a incrementarse. El P600 y otras positividades tardías, por su lado, están relacionados con procesos más tardíos de revisión, reanálisis, monitorización y creación de huellas de memoria. Si la inferencia generada puede ser integrada, el incremento de amplitud de la P600 se relaciona probablemente con la creación de huellas de memoria con el objetivo de actualizar la representación mental que presupone el modelo construccionista. En cambio, si una inferencia no puede ser integrada, se incurren en procesos de inhibición de predicciones fuertes, reflejada por la aparición de una pN400FP, o en procesos de revisión y reanálisis relacionadas con el P600. Estos diferentes mecanismos neurales entran en juego en función el tipo de inferencia que se está violando. En caso de competición entre la información del texto y nuestro conocimiento del mundo, tendemos a otorgar más peso y confiar más en nuestra propia experiencia. Por último, bajo un estado de ánimo negativo tendemos a operar de manera analítica y anticipar más fácilmente estímulos lógicos.

Conclusiones

De manera general, el N400 está relacionado con los procesos de activación e integración de las inferencias, mientras que el P600 interviene en procesos de revisión y reparación del conflicto cuando tiene lugar la violación de una inferencia y se dificulta su integración. El modelo construccionista es el que más se ajusta a nuestros resultados, por la asunción de la representación mental que se crea y por la importancia que le da a la intencionalidad del lector. Sin embargo, no tiene en cuenta la influencia de aspectos extralingüísticos como el estado de ánimo. En caso de competición entre las fuentes requeridas para la generación de inferencias, prima nuestro conocimiento del mundo. Por último, tiene sentido clasificar las inferencias en función del contexto y la experiencia que se activa, al intervenir diferentes mecanismos neurales en la generación de cada una de ellas.

Capítulo 2

Introducción

La comprensión lectora constituye una de las habilidades humanas más complejas. Desde los inicios de la psicolingüística experimental, la manera de comprender un texto o un discurso ha estado sujeta a controversia (Kintsch, 1980; Schank, 1986; Weizenbaum, 1976; Winograd, 1986). La mayoría de los debates teóricos se centran en determinar si los procesos implicados en la comprensión son modulares (Fodor, 1983) o interactivos (Marslen-Wilson & Tyler, 1987), así como en esclarecer si la comprensión está basada en procesos *bottom-up*, que ocurren cuando el procesamiento y el control atencional se ejecutan automáticamente, dirigidos por las propiedades del estímulo, *top-down*, que tienen lugar cuando el control atencional es dirigido por una meta y se procesa la información atendiendo a estímulos relevantes para sus propósitos, o una mezcla de ambos (Albrecht, O'Brien, Mason, & Myers, 1995; Graesser, Singer, & Trabasso, 1994; Magliano & Radvansky, 2001; McKoon & Ratcliff, 1998; Myers & O'Brien, 1998). De manera general, existe un consenso a la hora de aceptar que la comprensión lectora consiste en la construcción de una representación mental a varios niveles: *literal*, donde se reconoce la estructura base del texto, *inferencial*, que permite al lector leer entre líneas, presuponer y deducir lo implícito, y *crítico*, que permite al lector emitir juicios sobre el texto leído. La complejidad que conlleva esta tarea necesita de un modelo teórico capaz de reunir y explicar los diversos procesos cognitivos y lingüísticos implicados. Algunos de los modelos que intentan abordar esta problemática son: el modelo de construcción-integración (*the construction-integration model)* (Kintsch & Vandijk, 1978), el modelo de panorama (*the landscape model)* (Tzeng, Van Den Broek, Kendeou, & Lee, 2005), el modelo de construcción de estructuras (*the structure building model)* (Gernsbacher, Varner, & Faust, 1990), el modelo de resonancia (*the resonance model)* (Myers & O'Brien, 1998), el modelo de señalización de eventos (*the event-indexing model)* (Zwaan, Langston, & Graesser, 1995), el modelo de red causal (*the causal network model)* (Trabasso, Vandenbroek, & Suh, 1989), y el modelo construccionista (*the *constructionist model*) (Graesser et al., 1994). McNamara y Magliano (2009) ofrecen una revisión detallada de estos modelos.

A la hora de abordar la comprensión, habitualmente se ha establecido una dicotomía entre procesos de bajo y alto nivel, siendo crucial la interacción entre ambos. Por un lado, los procesos de bajo nivel se encargan de decodificar estímulos para combinar sus significados y formar frases, oraciones y textos de una manera lineal (Gough, 1972). Para ello, juegan un papel importante procesos como el acceso al léxico (Ehri, 2005; Perfetti, 2007; Stafura & Perfetti, 2014), y características del sujeto como la fluidez (Laberge & Samuels, 1974) o su conocimiento de vocabulario (Beck, Perfetti, & Mckeown, 1982; Nagy, Herman, & Anderson, 1985; Stanovich, 1986; Tannenbaum, Torgesen, & Wagner, 2006). Por otro lado, los procesos de alto nivel se encargan de generar representaciones mentales del texto y de integrar las ideas de dicho texto con el conocimiento global del lector, es decir, con el conocimiento que se encuentra almacenado en su memoria a largo plazo. En este apartado se incluyen aspectos tales como la generación de inferencias (Cain & Oakhill, 1999; Graesser et al., 1994; Kintsch, 1998), la monitorización de la comprensión (Oakhill, Hartt, & Samols, 2005) o la memoria de trabajo (Baddeley, 2003; Cowan, 2010; Swanson & O'Connor, 2009). Los distintos modelos teóricos están de acuerdo en que la capacidad de generar inferencias juega un papel muy importante en la comprensión lectora, constituyendo uno de los principales predictores de la calidad y el éxito de la misma (Cain, Oakhill, Barnes, & Bryant, 2001; Cromley & Azevedo, 2007; Hannon & Daneman, 1998; Kendeou, Bohn-Gettler, White, & van den Broek, 2008; Kendeou, White, van den Broek, & Lynch, 2009; Oakhill & Cain, 2012). A lo largo de la presente tesis doctoral nos centraremos en la generación de inferencias y en su contribución a la comprensión lectora.

La generación de inferencias: una habilidad necesaria para la comprensión lectora

Las representaciones mentales generadas a partir de la comprensión de un texto consisten en la suma de la información contenida de forma explícita en el texto, la información relacionada con el texto y las diferentes inferencias que se han generado a partir del mismo. Sin ellas, el lector no puede conectar información previa con la que va apareciendo durante la lectura.

Una inferencia es una representación basada en información que se recupera o se genera durante la lectura y que se puede deducir de forma implícita a partir de la información que aparece en un texto (Elbro & Buch-Iversen, 2013; Kintsch, 1998; McNamara & Magliano, 2009; Oakhill, 1984). Sin realizar inferencias no habría posibilidad de lograr coherencia local (donde tienen un papel predominante las inferencias basadas en antecedentes causales), global (donde las inferencias basadas en objetivos superordinados adquieren relevancia), ni de resolver problemas anafóricos. Con carácter más o menos general, se asume que el proceso de generación de una inferencia consta de dos etapas: activación e integración. En primer lugar, la lectura del texto provoca la activación de información previamente disponible, ya sea en fragmentos anteriores del texto o recuperada de la memoria a largo plazo. En segundo lugar, esta información necesita integrarse con la nueva información que va aportando el texto para que se produzca la comprensión (McKoon & Ratcliff, 1992). La activación de la información puede ocurrir independientemente de su integración con el texto, y el hecho de que se produzca la activación o anticipación de información no garantiza su posterior integración (Blanc, Kendeou, van den Broek, & Brouillet, 2008; Cook, Halleran, & O'Brien, 1998; Kendeou, Smith, & O'Brien, 2013; Long & Chong, 2001; O'Brien, Cook, & Guerand, 2010; O'Brien, Cook, & Peracchi, 2004). Se ha propuesto que la activación y la integración se perciben como un continuo que pueden solaparse (Kintsch, 1998). Myers y O'Brien (1998) defienden que la activación es un proceso que tiene lugar de forma pasiva, y que por lo tanto, escapa del control del lector. Por el contrario, la integración puede estar monitorizada por procesos estratégicos y/o atencionales. En esta etapa son importantes los estándares de coherencia de cada lector, que son criterios explícitos subjetivos de comprensión (Van den Broek, Bohn-Gettler, Kendeou, Carlson, & White, 2011; Van den Broek, Lorch, Linderholm, & Gustafson, 2001; Van den Broek, Risden, & Husebye-Hartmann, 1995). La capacidad de la memoria de trabajo y/o el conocimiento del contexto de los lectores van a influir directamente sobre el proceso de comprensión. Además, las características y demandas del texto, como el tipo de contenido y el orden en el que se presenta, también va a modular la comprensión, y por tanto, la generación de inferencias.

Ciertos aspectos relacionados con la generación de inferencias han suscitado un enorme debate en la comunidad científica, como discernir en qué momento se realizan las predicciones (durante o después de la lectura) y establecer los niveles de representación que se pueden alcanzar. Principalmente dos modelos se han encargado de abordarlo: el modelo construccionista (Graesser et al., 1994) y el modelo minimalista (McKoon & Ratcliff, 1992).

El modelo construccionista (Graesser et al., 1994) enfatiza el papel de procesos *top-down* durante la comprensión lectora, asumiendo pese a ello el carácter automático o "inevitable" de algunas inferencias. Según este modelo, los niveles de representación mental de un texto son tres: estructura superficial (reconocimiento de palabras y relaciones semánticas y sintácticas entre ellas), texto base (significado de las frases), y modelo de situación (representaciones análogas a las que construimos en nuestra experiencia directa con el mundo que incluye parámetros temporales, espaciales, causales e interpersonales) (Van Dijk & Kintsch, 1983). En este modelo es fundamental el concepto "*search for meaning*", con el que se alude al hecho de que la comprensión y el entendimiento sólo se consiguen a través de procesos activos y de construcción. Este concepto parte de tres supuestos: 1) supuesto de coherencia, que determina que el lector construye representaciones de significado que sean congruentes tanto a nivel local como global; 2) supuesto de objetivo del lector, que establece que el lector genera inferencias orientadas a sus propias metas; 3) supuesto de explicación, que especifica que los individuos buscamos una explicación para los eventos que experimentamos, por lo que constantemente ponemos en marcha procesos de evaluación valiéndonos de nuestras inferencias y predicciones (Trabasso et al., 1989). Esta teoría, por tanto, defiende un punto de vista activo del lector. Se presupone al lector como un individuo motivado que de manera constante pone en funcionamiento procesos costosos de comprensión lectora.

Esta teoría se opone a la hipótesis minimalista propuesta por McKoon & Ratcliff (1992), que sostiene que las inferencias que se pueden realizar durante la lectura son mínimas. Estas se producen automáticamente durante la lectura, están basadas en información fácilmente disponible y proporcionan una representación básica de información textual. Esta teoría defiende que la principal meta del lector es alcanzar coherencia local entre las distintas partes del texto. Este modelo defiende únicamente la generación de inferencias automáticas, sin la intervención de procesos estratégicos y la mediación de conciencia. Los autores de esta teoría incluyen en inferencias automáticas las inferencias puente y las inferencias causales antecedentes (profundizaremos en la taxonomía de las inferencias a continuación). Mientras que el modelo construccionista se dirige a un nivel de representación profundo, no sólo textual (modelo de situación), la teoría minimalista apunta a niveles de representación mínimos (sintácticos, léxicos y locales).

La presente tesis pretende estudiar, mediante la técnica de los Potenciales Evento Relacionados (ERPs), los procesos de activación e integración relativos a la generación de inferencias, así como comprobar qué modelo (construccionista versus minimalista) se ajusta más a nivel electrofisiológico a los procesos de generación de inferencias. Antes de explicar en qué consiste esta técnica, detallaremos en la siguiente sección los diferentes tipos y clasificaciones de inferencias que propone la literatura.

Taxonomía de las inferencias

El objetivo de esta sección es delimitar y ofrecer una taxonomía completa y actualizada de los diversos tipos de inferencias que se pueden realizar durante procesos de comprensión lectora. La segmentación de las inferencias en dos procesos independientes, activación e integración, puede ayudarnos a la hora de explicar y entender algunos de los muchos tipos de inferencias que se han propuesto en la literatura. En relación a la fuente de la información que se activa para la generación de la inferencia, encontramos inferencias que dependen exclusivamente de la información del texto e inferencias que dependen tanto de la información presentada en el texto como de nuestro conocimiento general del mundo. Las inferencias del primer tipo se conocen como *conectoras* (Graesser et al., 1994; Kintsch & Kintsch, 2005), *interfrase* (Cain & Oakhill, 1999), *frase-frase* (Cromley & Azevedo, 2007), *puente* (Singer & Ritchot, 1996) o *de coherencia* (Bowyer-Crane & Snowling, 2005). Estas inferencias mantienen la cohesión al conectar las ideas del texto, relacionan expresiones con elementos del discurso y establecen relaciones causa efecto. En cambio, las inferencias del segundo tipo a menudo se conocen como *basadas en el conocimiento* o *extratextuales* (Graesser et al., 1994; Kintsch & Kintsch, 2005), *elaborativas* (Bowyer-Crane & Snowling, 2005; Kintsch, 1998), o *gap-filling* (Cain & Oakhill, 1999). Este tipo de inferencias, por su parte, enriquecen la representación que se forma del texto o ayudan a crear una representación coherente aportando información sobre el tema, la moraleja o el mensaje general del texto.

Otra distinción consiste en clasificar las inferencias en locales y globales (Albrecht & O'Brien, 1993; Graesser et al., 1994). La conexión entre el texto que se está leyendo con el texto precedente (cuya información se encuentra disponible en la memoria de trabajo) es lo que se conoce como inferencia local. Por el contrario, la conexión entre el texto que se está leyendo con información que se ha presentado previamente pero que ya no está disponible en la memoria de trabajo (presumiblemente se encuentra en la memoria a largo plazo) es lo que se denomina inferencia global. Las inferencias locales engloban las de *coherencia* y *las inferencias puente* mientras que dentro de las inferencias globales podemos encontrar inferencias sobre el tema y el tono del texto.

Algunos autores distinguen entre inferencias *online* e inferencias *offline* (Graesser et al., 1994; Long, Oppy, & Seely, 1994) basándose en el momento en el que se elaboran las inferencias. Las inferencias *online* se generan durante el proceso de lectura, mientras que las *offline* son las que se producen una vez el proceso de lectura ha finalizado. Desde una perspectiva minimalista únicamente se generan inferencias *online.* Por el contrario, el modelo construccionista sostiene que aunque la mayoría de inferencias se generan durante el proceso de lectura, las inferencias *offline* también juegan un papel importante.

Las inferencias también pueden ser clasificadas en función de su probabilidad de ser generadas (Gernsbacher, Goldsmith, & Robertson, 1992; Gernsbacher, Hallada, & Robertson, 1998; Morishima, 2015). Así, por ejemplo, podemos encontrar inferencias de causalidad o basadas en emociones. Las unas se van a diferenciar de las otras en función de la manera en que está organizada la información en nuestra memoria, de forma que las inferencias de causalidad, al generarse de manera rutinaria (Griffiths & Tenenbaum, 2009), tendrán más probabilidad de construirse que otro tipo de inferencias.

Atendiendo al esfuerzo cognitivo realizado a partir de la lógica y del razonamiento en la comprensión lectora, las inferencias también se pueden clasificar en inductivas y deductivas (Singer & Lea, 2012). Las inferencias inductivas son aquellas que provienen de nuestro conocimiento y entendimiento del mundo y son de naturaleza probabilística, mientras que las inferencias deductivas son aquellas que son ciertas cuando parten de premisas verdaderas. De esta manera, las inferencias inductivas engloban a la mayoría de inferencias que hemos descrito previamente, mientras que las inferencias deductivas sólo incluyen aquellas que se generan siguiendo las reglas de la lógica (Lea, 1998).

Este breve resumen pone de manifiesto la variabilidad y la complejidad de los diferentes tipos de clasificaciones de inferencias en la literatura (Tabla 1). A lo largo de la presente tesis doctoral, exploraremos algunos de estos tipos de inferencias, estableciendo diferencias empíricas entre las mismas en función de los mecanismos neurales que intervienen en la generación de cada una de ellas. Para ello, nos valdremos de la técnica de los Potenciales Evento-Relacionados (ERPs), que explicaremos a continuación.

Clasificación	Tipos	Definición
En función de la fuente de información	Conectoras, interfrase…	Dependen únicamente de la información contenida en el texto
	Elaborativas, extratextuales…	Dependen de nuestro conocimiento general del mundo
En función de la dimensión de la inferencia	Locales	Mantienen la cohesión del texto
	Globales	Crean una representación coherente del texto
En función del momento en el que se realiza la inferencia	*Offline*	Inferencias realizadas una vez ha terminado la lectura
	Online	Inferencias realizadas durante la lectura
En función del conocimiento del mundo	Causalidad, emocionales…	
En función del razonamiento	Deductivas	Inferencias que siguen la regla de la lógica
	Inductivas	Son de naturaleza probabilística (mayoría de inferencias)

Tabla 1. Diferentes clasificaciones de las inferencias.

La técnica de los Potenciales Evento-Relacionados (ERPs)

Como se ha mencionado, la generación de inferencias es una habilidad necesaria para la comprensión lectora y ocurre de manera natural durante el proceso de lectura. La técnica de los Potenciales Evento Relacionados se deriva de la electroencefalografía (EEG) y es idónea para el estudio de la generación de inferencias, por su alta resolución temporal (del orden de milisegundos) y por no precisar de una respuesta abierta (motora o verbal) para estudiar el proceso que subyace. El EEG es una técnica no invasiva que consiste en el registro de la actividad eléctrica cerebral a lo largo del tiempo mediante electrodos colocados en la superficie del cuero cabelludo (Beres, 2017). Los potenciales de acción, al ser tan rápidos y breves, no pueden ser detectados por los electrodos. La señal EEG proviene fundamentalmente de potenciales post sinápticos de neuronas piramidales de la corteza, que suponen un cambio eléctrico fuera de la membrana de las neuronas que puede durar hasta 200 ms. La alineación de las neuronas piramidales permite que la suma alcance la superficie del cuero cabelludo. El registro de EEG mide la diferencia de potencial eléctrico entre dos electrodos (los electrodos activos y el electrodo de referencia). Se deben colocar electrodos alrededor de los ojos para detectar parpadeos y movimientos oculares, cuya señal se introduce en electrodos cefálicos en un gradiente de proximidad a la fuente: es decir, más en electrodos frontales que en posteriores. Su registro permite eliminar los artefactos oculares que contaminan el registro de la señal en electrodos cefálicos, mediante el uso de algoritmos matemáticos (Luck, 2005).

Sin embargo, la interpretación de la señal registrada por EEG y su posible relación con ciertos procesos cognitivos es difícil, puesto que dicha señal contiene ritmos u oscilaciones que dependen del estado de alerta. La base teórica de esta técnica es simple: la actividad eléctrica registrada es producida como respuesta a la presentación de una serie de estímulos (sonidos, palabras, imágenes, etc.). Gracias a esta técnica, se puede saber con certeza en qué preciso momento se presentaron los estímulos, analizándose el patrón cerebral que aparece tras ellos.

El continuo de EEG se trocea en segmentos denominados épocas, que se corresponde con la actividad cerebral producida por la repetición de la presentación de los estímulos. Estas épocas se filtran y se promedian y las fluctuaciones espontáneas del EEG se anulan, obteniéndose la típica onda de ERP (Figura 1). Esta onda suele tener una serie de picos negativos y positivos y son los denominados componentes (Figura 2).

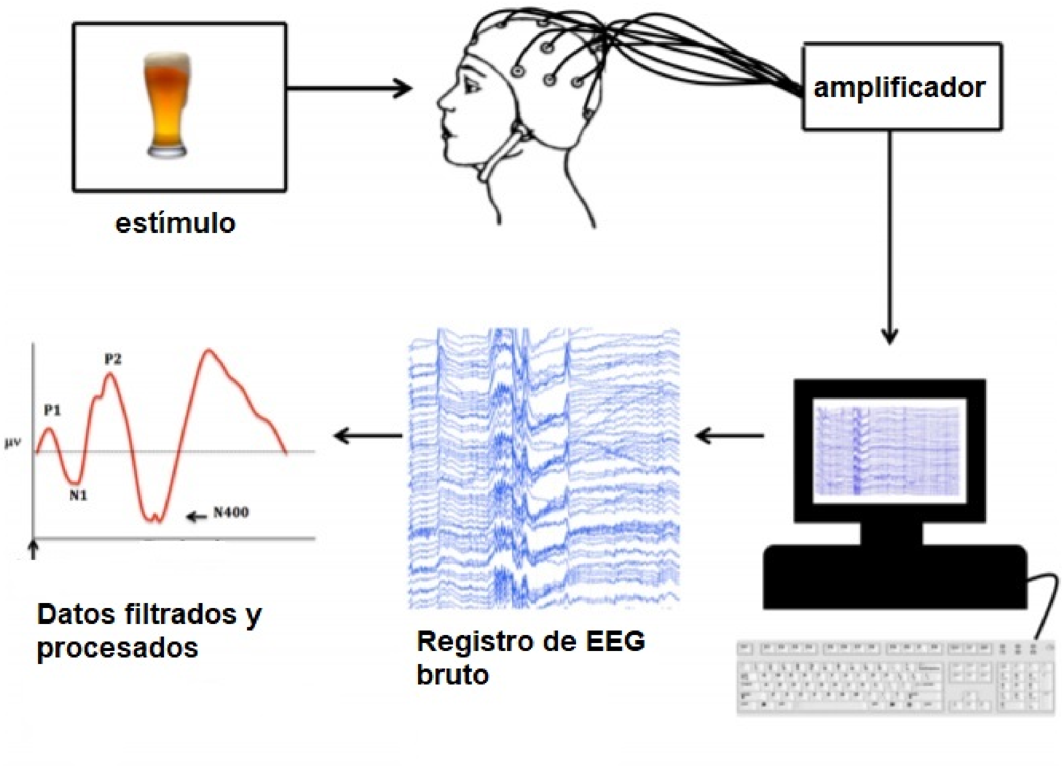

Figura 1. Figura adaptada de Beres (2017). La técnica de los ERPs recoge la señal cerebral producida ante la presentación de una serie de estímulos. Posteriormente, esta señal es procesada y analizada.

El principal aliciente de esta técnica es su increíble resolución temporal, lo que la convierte en una técnica idónea para el estudio del procesamiento del lenguaje. Como ya hemos mencionado anteriormente, la generación de inferencias es necesaria para la comprensión lectora, y ésta ocurre en gran medida de manera simultánea a la lectura, por lo que esta técnica nos permitiría explorar los mecanismos neurales subyacentes a este proceso y su discurso temporal.

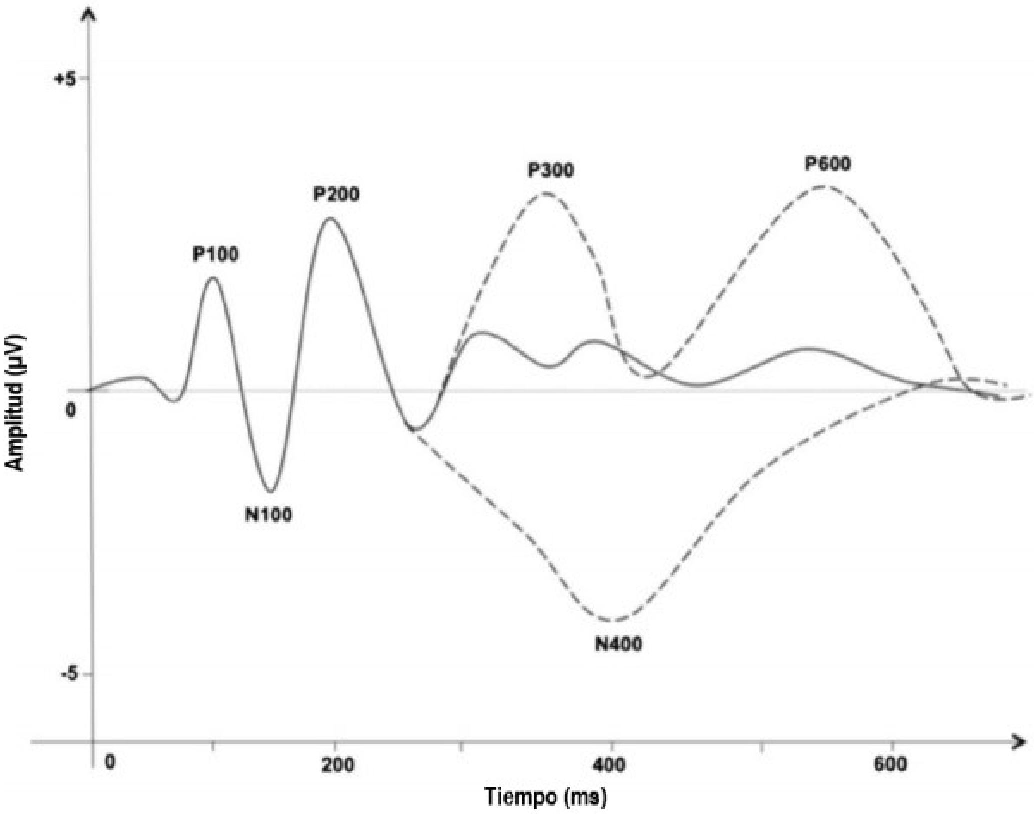

Figura 2. Figura adaptada de Beres (2017). Algunos de los componentes más explorados en estudios de lenguaje.

Componentes del ERP relacionados con la generación de inferencias

A continuación se describen dos componentes básicos que se analizan de manera habitual en estudios de lenguaje: el N400 y el P600. Asimismo, se describirá el componente denominado postN400FP (positividad frontal post N400), que esperamos encontrar en algunos estudios de la presente tesis doctoral en función del diseño experimental.

N400

Este componente fue descrito por primera vez por Kutas y Hillyard (1980). Estos autores utilizaron un paradigma en el que presentaban una serie de frases palabra por palabra. El 25% de estas frases terminaban con palabras semánticamente improbables ("Él plantó guisantes en su *coche*") o de forma anómala ("Me tomo mi café con nata y *perro*"). Las medidas cerebrales registradas revelaron una negatividad parietal ante estas dos últimas condiciones en comparación con el 75% de frases restantes, que eran frases semánticamente correctas. Denominaron a este componente N400 y concluyeron que se trataba de un indicador de dificultad para realizar la integración semántica de una palabra con el contexto oracional previo. El N400 es por tanto un componente negativo que habitualmente empieza a incrementar su amplitud alrededor de los 200 msegs tras la presentación del estímulo hasta los 600 msegs aproximadamente. Su distribución en la superficie del cuero cabelludo suele ser centro parietal, desplazada ligeramente hacia el hemisferio derecho.

Estudios posteriores pretendieron explorar bajo qué condiciones aparecía este componente y a qué manipulaciones experimentales era sensible (ver la revisión de Kutas & Van Petten, 1990). El componente N400 presentaba sensibilidad a la probabilidad de cierre de una palabra en una frase. La probabilidad de cierre es una medida offline que refleja el porcentaje de ocasiones en las que una serie de participantes elige una determinada palabra como continuación o terminación de un fragmento oracional. Las palabras con una probabilidad de cierre alto suelen presentar una disminución en la amplitud de este componente frente a las palabras con una probabilidad de cierre bajo. Por tanto, este componente está directamente relacionado con la plausibilidad semántica. Asimismo, se demostró que la amplitud del N400 se ve afectada por factores léxicos como la frecuencia de uso de palabras, el número de vecinos ortográficos (Laszlo & Federmeier, 2011), los diferentes tipos de relaciones semánticas, la repetición o la posición de una palabra dentro de una oración (Kutas & Federmeier, 2011).

Además, varios estudios han demostrado la similitud temporal y cualitativa de este componente en tareas de *priming* de palabras y en tareas que utilizan frases más largas y complejas y exploran el procesamiento del discurso (Kutas, 1993). Por lo tanto, la amplitud de este componente depende tanto de procesos de bajo nivel como de alto nivel.

Por otro lado, Hagoort et al. (2004) demostraron que este componente también era sensible a la propia experiencia del lector y su conocimiento del mundo. En frases como "Los trenes holandeses son ___ y muy concurridos", las diferencias de amplitud del N400 no eran significativas cuando la palabra en el hueco era "amargos" (violación semántica) y cuando la palabra era "blancos" (violación del conocimiento del mundo). Además, Van Berkum et al. (2008) demostraron asimismo que las inferencias de edad, género y estatus social acerca de una persona afectaban a la amplitud de este componente. Ésta era mayor cuando la frase *"¡Quiero mi oso de peluche!"* era pronunciada por una persona adulta que por un niño pequeño, donde se produce una violación de aspectos pragmáticos del lenguaje.

Además, algunos estudios parecen confirmar que, al menos para lectores adultos, la información presentada en el contexto local de la oración sirve para preactivar características de las siguientes palabras de un discurso o texto (DeLong, Urbach, & Kutas, 2005; Van Berkum, Brown, Zwitserlood, Kooijman, & Hagoort, 2005; Wicha, Moreno, & Kutas, 2004). En el estudio de DeLong et al. (2005), los autores midieron la respuesta cerebral a los artículos que precedían las palabras target (por ejemplo, "*On windy days, the boy liked to go outside and fly a/an (kite)/*En días con viento, al chico le gustaba ir afuera y volar su (cometa)*")*. El hecho de que reportaran un N400 de mayor amplitud para el artículo *an vs. a* (en este ejemplo) era indicativo de que la palabra "kite/cometa" de algún modo había sido preactivada o anticipada, indicando que los individuos habrían tenido un papel activo en la realización de una predicción previa al momento de procesamiento del target "kite/cometa". Por otra parte, se ha comprobado que este componente aparece incluso en respuesta a pseudopalabras (cadenas de letras que cumplen las reglas de gramática y fonología pero que carecen de significado, ej. tuléminos) (Bentin, McCarthy, & Wood, 1985).

En definitiva, la amplitud de este componente refleja la actividad producida por un estímulo lingüístico en una red neural multimodal que depende de la experiencia a corto y largo plazo de la persona (conocimiento del mundo, estímulos lingüísticos y no lingüísticos recientes, estados atencionales, etc.). (Kutas & Federmeier, 2011).

P600

Los primeros estudios sugerían que el incremento de amplitud de este componente estaba directamente relacionado con el procesamiento de estímulos sintácticamente incorrectos (*the spoilt child throw(s) the toys on the floor*, el niño mimado tiró los juguetes al suelo; donde existe una violación gramatical de la persona del verbo en inglés) y con la continuación gramaticalmente correcta pero no preferida de oraciones (*the girls looks with great satisfaction at the ironed clothes*, la niña mira con gran satisfacción la ropa planchada) (Hagoort, Brown, & Groothusen, 1993; Osterhout & Holcomb, 1992). En estos estudios se describió el P600 como un componente de amplitud positiva con una distribución parietal que suele aparecer en torno a los 500 msegs tras la presentación del estímulo. Con posterioridad se encontró que el procesamiento de oraciones *garden-path*, gramaticalmente correctas pero temporalmente ambiguas (ej., Mientras la joven montaba el potro fue robado de las caballerizas), producían un incremento en la amplitud del P600, al igual que ocurría con frases correctas con una estructura gramatical compleja comparadas con frases simples (Kaan, 2007), como las frases en las que se requiere una evaluación para establecer un nuevo referente. Todos estos estudios parecían indicar que este componente estaba relacionado con algún tipo de procesamiento sintáctico, puesto que siempre aparecía ante dificultades sintácticas (Kaan, 2000). Sin embargo, el componente P600 también se describió ante diferentes tipos de anomalías semánticas (los ojos consisten, entre otras cosas, en pupila, iris y *pegatina*), (Kim & Osterhout, 2005; van de Meerendonk, Kolk, Vissers, & Chwilla, 2010). De manera general, el P600 suele relacionarse con procesos de revisión y reparación (Kaan & Swaab, 2003). Se han propuesto varios modelos para intentar explicar los procesos cognitivos que subyacen a la P600. En este sentido, Friedirici (2002) distingue varias etapas en un procesamiento serial de oraciones: 1) la construcción de la estructura de la frase; 2) comprobación de la congruencia de la frase y otros procesos relacionados con el chequeo de la estructura; 3) integración temática y procesos de revisión. Según este modelo, el P600 estaría reflejando estos últimos procesos de revisión no automáticos. Por el contrario, Hagoort (2003) defiende un procesamiento en paralelo de oraciones, donde todas las fuentes de información están disponibles y se usan a la vez. La unificación de esta información y la competición por la selección del análisis a llevar a cabo en la oración sería la responsable del incremento de amplitud en este componente.

PostN400FP

Este componente positivo, en comparación con el P600, suele tener una distribución frontal y aparece como respuesta a violaciones de palabras en contextos muy constreñidos (DeLong, Urbach, Groppe, & Kutas, 2011; Federmeier, Wlotko, De Ochoa-Dewald, & Kutas, 2007; Moreno, Federmeier, & Kutas, 2002). Los procesos cognitivos que subyacen a esta onda no están del todo claros. En primer lugar se ha relacionado con el coste necesario para inhibir un ítem léxico preactivado (Federmeier et al., 2007). Asimismo, algunos investigadores sugieren que este componente pone de manifiesto la anticipación de elementos léxicos en comparación con el N400, que estaría reflejando una anticipación de elementos conceptuales de las palabras (Thornhill & Van Petten, 2012). Xu et al. (2015) probaron que cuando una asunción causal no se ve satisfecha, aparece el N400 seguido de esta positividad frontal. Además Kutas et al. (2011) relacionaron este componente con procesos generales de control cognitivo y monitorización del conflicto. Para finalizar, Davenport y Coulson (2011) concluyeron que este componente aparece cuando el estímulo que encontramos "desafía las expectativas codificadas en el modelo situacional del lector".

Generación de inferencias y ERPs

Existen una serie de estudios de ERPs que exploran la generación de inferencias durante la lectura. Sin embargo, debido a los distintos modelos teóricos que intentan explicar este fenómeno, la amplia taxonomía de las inferencias y la disparidad de resultados, continúa vigente el debate sobre bajo qué circunstancias se realizan las predicciones y cómo de robustas pueden llegar a ser (Ito, Corley, Pickering, Martin, & Nieuwland, 2016).

Uno de los estudios pioneros en abordar la generación de inferencias mediante la técnica de los ERPs es el de St George et al. (1997). Estos autores obtuvieron una modulación de la amplitud del componente N400 como prueba de que los participantes eran capaces de generar inferencias de tipo causal online durante la lectura. Para ello, utilizaron historias breves como estímulos. Cuando la frase final correspondía a una inferencia que los participantes podían hacer a lo largo de la historia, la amplitud del componente N400 se reducía. Kuperberg et al. (2011) demostraron que las relaciones de causalidad en diferentes escenarios provocaban una reducción en la amplitud de este componente en comparación con escenarios en los que no se encontraba esta relación de causalidad. Para ello, usaron tres tipos de escenarios de tres frases cada uno: altamente causal (*Jill tenía la piel muy sensible. Olvidó ponerse crema solar. Al día siguiente tenía quemaduras*), medianamente causal (*Jill tenía la piel muy sensible. Normalmente se acuerda de ponerse crema solar. Al día siguiente tenía quemaduras*) y no causal (*Jill siempre* *tiene la piel bronceada. Siempre se pone crema solar. Al día siguiente tenía quemaduras*). Steele et al. (2013) presentaron a sus participantes una serie de escenarios de dos frases que les podía resultar familiar, poco familiar o neutral (familiar: *el estudiante tenía examen mañana y se puso a estudiar. Después de tres horas, estaba seguro de que se sabía todo el tema de memoria*; poco familiar: *el agente de la CIA cogió la fotografía del sospechoso. Después de unos minutos, sabía que podría identificarlo si lo veía por la calle;* neutral: *los niños llegaron el primer día a clase con ropa nueva. Estaban muy emocionados por conocer a sus nuevos profesores, reencontrarse con los amigos y jugar en el patio*). Tras la lectura de estas frases, realizaban una tarea de decisión léxica con palabras que podían haber inferido o palabras nuevas no relacionadas con los escenarios. La presentación del primer tipo de palabras provocó una reducción en el componente N400, así como una positividad tardía que se relacionó con el P600 y que se describió como un marcador de inferencias de coherencia causal. Asimismo, en un estudio realizado por Burkhardt (2007), la necesidad de establecer una coherencia causal entre las frases que forman un escenario se puso de manifiesto en función de la amplitud del componente P600 como respuesta a una palabra que aportaba información necesaria para completar una frase anterior. Por ejemplo, los participantes de este experimento primero veían una frase del tipo: "Un estudiante ha sido (a) encontrado muerto (b) asesinado (c) disparado". A continuación, la historia se cerraba con la siguiente frase: "la prensa ha asegurado que la *pistola* con la que lo mataron…". La amplitud del P600 para la palabra *pistola* era menor cuando la frase inicial terminaba con el final (c), reflejando la rapidez en la generación de una inferencia del tipo de herramienta (pistola) cuando el contexto local y el conocimiento del mundo lo favorecen. Todos los estudios descritos anteriormente han contribuido al conocimiento acerca de la generación de inferencias utilizando como estímulos contextos, historias y palabras. Sin embargo, la necesidad de realizar una inferencia se vuelve imperiosa cuando no conocemos el significado de una palabra que se nos presenta en una historia o contexto determinado. Por tanto, el uso de pseudopalabras supone un buen comienzo para abordar el estudio de la generación de inferencias.

Pseudopalabras: cuando las inferencias son necesarias para la comprensión

Algunos estudios trataron de establecer las diferencias que tenían lugar a nivel cerebral cuando las inferencias estaban basadas en contextos con significado y sin él. En estos estudios, las palabras *target* eran pseudopalabras, y los autores registraban la respuesta cerebral producida por la aparición de estas pseudopalabras a lo largo de presentaciones sucesivas de la misma. La lógica que subyace a estos estudios es que la variación en el patrón de actividad eléctrica a lo largo de las diferentes presentaciones estaría reflejando la realización de inferencias sobre el significado de las pseudopalabras.

El primero de estos estudios fue realizado por Mestres-Misse et al. (2007). En él se utilizaron tripletes de oraciones en los que el estímulo final podía ser una palabra (A ella le gustan las personas con los *dientes* limpios y bonitos. En una pelea, María se rompió dos *dientes*. Después de una comida, siempre debes lavarte los *dientes*) o una pseudopalabra (Mario siempre olvida donde deja su *suerpa*. Era muy caro reparar su *suerpa*. Se le había pinchado la rueda de su *suerpa*). El significado de las pseudopalabras podía inferirse gracias al contexto a medida que se presentaban las oraciones. Tras las tres presentaciones, se produjo un decremento en la amplitud del N400 de similar magnitud en respuesta tanto a palabras como a pseudopalabras, lo que indicaba la adquisición del significado de las pseudopalabras por parte de los participantes.

El segundo estudio lo llevaron a cabo Batterink y Neville (2011) y contaba con tres condiciones experimentales: contextos narrativos con palabras, contextos narrativos con pseudopalabras que permitían hacer inferencias y contextos narrativos con pseudopalabras que no permitían generar inferencias puesto que dichos contextos narrativos estaban formados también por pseudopalabras. Después de diez presentaciones consecutivas, los participantes fueron capaces de otorgar un significado a estas pseudopalabras en los contextos narrativos que permitían la elaboración de inferencias, como indicaba la reducción en la amplitud del componente N400 en comparación con la condición en las que el contexto no permitía generar inferencias sobre las pseudopalabras. Sin embargo, este estudio tiene algunas limitaciones. En primer lugar, sólo se utilizaron cuatro historias como estímulos. En estas historias, se combinaban multitud de pseudopalabras, lo que podía complicar el proceso de generación de inferencias. Además, las pseudopalabras aparecían hasta diez veces a lo largo de las historias, por lo que la repetición de las mismas puede haber contribuido al efecto de reducción de la N400 (Bentin et al., 1985).

El primer estudio de esta tesis doctoral (capítulo 4) pretende profundizar en la generación de inferencias mediante la atribución de significado a pseudopalabras. Por un lado, nos permitirá comprobar si los lectores llevan a cabo estas inferencias de manera automática en aras de alcanzar la comprensión, y por otro lado, nos permitirá estudiar la cohesión a nivel local como primer paso, donde todavía no es necesaria la representación de un modelo situacional por parte del lector. Este estudio permite explorar por primera vez la generación de inferencias en presencia de pseudopalabras como referentes.

Diferentes tipos de inferencia, diferentes mecanismos neurales

El modelo construccionista de Graesser et al. (1994) establece la creación por parte del lector de una representación mental de la situación a la que alude el texto. En esta representación mental se incluyen todas aquellas inferencias que el lector construye mientras lee (planes, metas y objetivos que motivan las acciones de los personajes; escenarios y objetos; creencias y estados mentales de los personajes…). Para la generación de estas inferencias, la información que se activa e integra puede provenir de fragmentos anteriores del texto o de nuestro conocimiento del mundo. Por tanto, en función de la información que vayamos a aportar al modelo situacional, estaríamos activando un tipo de información diferente, y por consiguiente, generando un tipo de inferencia u otro. El siguiente estudio de la presente tesis doctoral trata de investigar si la generación de diferentes tipos de inferencias incurre en diferentes mecanismos neurales. Para ello, distinguimos tres tipos de inferencias en nuestro estudio: inferencias causales (acerca de los planes y objetivos de los personajes), inferencias emocionales (acerca de los estados mentales de los personajes), e inferencias de lugar (acerca de los escenarios y los objetos en ellos). No hemos encontrado ningún estudio en la literatura que haga esta distinción y se plantee ahondar en esta cuestión, por lo que no contamos con hipótesis firmes acerca de los resultados. Griffiths y Tenenbaum (2009) sostienen que las inferencias causales son las que generamos de manera más cotidiana, y en consecuencia, son las que tienen más probabilidad de ser generadas. Habitualmente, este tipo de inferencia se describe como espontánea, automática o no intencional (Hassin, Bargh, & Uleman, 2002). Por otro lado, hay más o menos consenso a la hora de indicar que los humanos tenemos una habilidad automática de inferir el estado emocional de otras personas (Gernsbacher et al., 1992; Gernsbacher et al., 1998; Morishima, 2015). No obstante, los estudios realizados con el objetivo de abordar las representaciones de los contenidos emocionales no son muy abundantes. Una de las principales razones es que los textos y contextos narrativos empleados en estas investigaciones son escuetos, en aras de satisfacer restricciones de contrabalanceo y control de variables, alejándose de toda complejidad emocional. Este estudio forma parte del capítulo 5.

Diferencias neurales entre inferencias válidas e inválidas a partir de premisas verdaderas y falsas

Como ya se ha ido mencionando a lo largo de la introducción, el lector se sirve tanto de la información contenida en el texto como de su conocimiento del mundo para elaborar inferencias. Los diversos modelos propuestos para intentar explicar los procesos implicados en la comprensión coinciden en que esas dos son las fuentes de donde proviene la información que se activa y posteriormente se integra. Se asume que ambas fuentes poseen información *complementaria* y no entran en competición. Algunas teorías, como el modelo mental de razonamiento propuesto por Johnson-Laird (1975) intentan arrojar algo de luz en el caso de que exista dicha competición. Este modelo defiende que se tiende a rechazar inferencias para las cuales se pueden encontrar contraejemplos. Sin embargo, no hay estudios que utilicen la técnica de los ERPs para encontrar soporte neural e intentar clarificar qué ocurre en aquellas situaciones en las que las dos fuentes de información son contradictorias entre sí y el lector debe decantarse por una de ellas. Por tanto, el tercer estudio que conforma esta tesis doctoral (capítulo 6) pretende explorar los mecanismos neurales que entrarían en juego en esta situación de contradicción entre el conocimiento del mundo y la información contenida en el texto.

Como se ha comentado con anterioridad, una de las clasificaciones propuestas para distinguir entre inferencias defiende su división en inductivas y deductivas. Las inferencias deductivas se alcanzan gracias a la información contenida en una serie de argumentos: una premisa mayor (Todos los hombres son mortales) y una premisa menor (Juan es un hombre) que inducen una conclusión (Juan es mortal). Este tipo de inferencias depende de la veracidad de las premisas y siguen las reglas de la lógica (Lea, 1998). Existen varios estudios de ERPs que han tratado de explorar nuestra capacidad de generar inferencias de manera deductiva. La mayoría de estos trabajos se han centrado en el razonamiento condicional: *si p entonces q, p, entonces q*

(Blanchette & El-Deredy, 2014; Bonnefond & Henst, 2013; Bonnefond, Kaliuzhna, Van der Henst, & De Neys, 2014; Bonnefond & Van der Henst, 2009; Qiu et al., 2007)

En el experimento de Qiu et al. (2007) se utilizaron ochenta argumentos del tipo: (1) Si una figura es un cuadrado entonces es rojo. (2) La figura es un cuadrado. (3) Entonces es rojo/no es rojo (condición de inferencia deductiva válida vs condición de inferencia inválida). Además, se incluyeron ochenta argumentos adicionales como condición de línea base en los que la premisa menor no guardaba ninguna relación con la premisa mayor, lo que impedía la realización de inferencias. El análisis de los ERPs correspondientes a la premisa menor mostró que las inferencias cuya conclusión resultó ser válida producían una amplitud más negativa que aquellas en las que la conclusión era inválida en dos ventanas temporales (500-700 msegs y 1700-2000 msegs). Los autores atribuyeron los efectos entre los 500 y los 700 msegs a la aplicación de las reglas de lógica, mientras que los efectos entre los 1700 y los 2000 msegs reflejarían el esfuerzo cognitivo necesario para verificar si las conclusiones extraídas eran correctas.

En un estudio posterior realizado por Bonnefond et al. (2014) se emplearon argumentos con un contenido semántico de carácter cotidiano: (1) Si la mantequilla se calienta se derrite. (2) La mantequilla se calienta. (3) La mantequilla se derrite. Además, los autores consideraron que bajo algunas condiciones la premisa mayor no tenía que cumplirse obligatoriamente. Teniendo en cuenta el siguiente ejemplo: “Si Juan estudia mucho, aprobará el examen”, existen diversas circunstancias por las que aunque Juan estudie mucho, no tiene por qué aprobar necesariamente. Puede que Juan no pueda llegar al examen por un accidente en la carretera o que el examen sea especialmente difícil. Así pues, el estudio incluía dos condiciones experimentales: argumentos con muchas circunstancias que lo pueden volver inválido (CIs, *circunstancias invalidantes*) y argumentos con pocos CIs. Los análisis de los ERPs en respuesta a las conclusiones revelaron una reducción en la amplitud de los componentes N2 frontal y P3b parietal para los argumentos con muchos CIs en comparación con los condicionales con pocos CIs. Estos efectos se interpretaron como un reflejo del mayor esfuerzo que es necesario para procesar las conclusiones de los argumentos con muchos CIs.

Por último, en un estudio llevado a cabo por Blanchette y El-Deredy (2014) se encontraron resultados que contradecían la literatura previa. Se llevaron a cabo dos experimentos en los que se usaron nuevamente argumentos condicionales. En el primero de estos trabajos las premisas estaban completas [(1) Si un país está en guerra, muere gente; (2) Gran Bretaña está en guerra; (3) Muere gente], mientras que en el segundo estudio las premisas de los argumentos se redujeron: (1) Si muerto, entonces morgue (2) Muerto (3) Morgue. En ambos experimentos, los autores hallaron una amplitud mayor de los componentes P3b y N400 para la condición de inferencia frente a una condición de línea base en la que se producía simplemente una repetición de la premisa menor: [(1) Si muerto, entonces morgue (2) Muerto (3) Muerto]. Estos resultados no encajan con la literatura, al producirse un incremento de la amplitud del N400 en la condición en la que es posible realizar una inferencia. Los autores interpretaron que este efecto era debido a que la integración y la validación de las conclusiones aún no se habían completado.

Nuevamente, los estudios que abordan la cuestión de las inferencias deductivas encuentran resultados dispares. Esto puede deberse en parte al análisis de diferentes componentes de los ERPs asociados con distintas partes de los argumentos, ya que en algunos estudios se ha medido la actividad a la segunda premisa y en otros a las conclusiones. Por otro lado, parece necesario plantear estudios con otro tipo de razonamientos diferentes al condicional, como el razonamiento de tipo categórico, con silogismos como los siguientes: (1) Todos los hombres son mortales (2) Juan es un hombre (3) Por lo tanto, Juan es mortal, dado que alguno de los componentes analizados en estudios previos como el N400 es sensible además al grado de predictibilidad/anticipación de la palabra final de un argumento o discurso tal y como se expuso en la introducción. Al igual que los argumentos condicionales expuestos previamente, los silogismos categóricos son una forma de razonamiento deductivo que consta de tres partes: premisa mayor, premisa menor y conclusión (Striker, 2009). En esta clase de silogismos se asume que una conclusión válida se obtiene si el silogismo sigue una estructura lógica. En el ejemplo anterior, (1) Todos los hombres son mortales (2) Juan es un hombre (3) Por lo tanto, Juan es mortal, la conclusión puede anticiparse si se sigue la estructura lógica del silogismo. Este tipo de silogismo se denomina DARII, donde la premisa mayor es una verdad universal afirmativa (A) y la premisa menor y la conclusión son proposiciones particulares afirmativas (I). Nuestro ejemplo es una forma válida de silogismo, puesto que sigue una estructura lógica y su conclusión es necesariamente cierta al partir de premisas verdaderas. Los silogismos DARII son sólo uno de los 24 tipos de silogismos válidos descritos en la literatura (BARBARA, BOCARDO, FERIO…) (Johnson-Laird & Steedman, 1978). Sin embargo, las premisas de las que consta un silogismo también pueden ser falsas. En estos casos, aunque la estructura sea lógica, la conclusión que se obtendrá a partir de la información contenida en las premisas mayor y menor podrá ser verdadera o falsa (por ejemplo, si la conclusión se deriva de la premisa mayor "*todas las rubias son tontas*"). Una pregunta relevante que permanece sin respuesta tiene que ver con el procesamiento de conclusiones inferidas (o no) por parte del individuo a partir de unas premisas falsas que chocan con nuestras propias creencias y conocimiento del mundo. Esta es la cuestión que intentamos resolver con el tercer estudio de esta tesis doctoral (capítulo 6).

Influencia del estado de ánimo en la capacidad de generar inferencias

Varios autores coinciden en la importancia de la influencia del estado del lector y sus estándares de coherencia en la generación de inferencias (Van den Broek et al., 2011; Van den

Broek et al., 2001; Van den Broek et al., 1995). Como cualquier otro proceso cognitivo, nuestra capacidad de inferir a partir de unas premisas se puede ver afectada por nuestro estado de ánimo (Blanchette & Richards, 2010). El modelo de procesamiento dual del razonamiento distingue entre un procesamiento heurístico de la información (implícito, automático, asociativo e intuitivo) y un procesamiento analítico (explícito, lento y que implica un mayor esfuerzo cognitivo) (Evans, 2003). Una de las principales razones por las que se piensa que los estados emocionales afectan al razonamiento y la generación de inferencias tiene que ver con la sobrecarga de la memoria de trabajo (Tremoliere, Gagnon, & Blanchette, 2016; Tremoliere, Maheux-Caron, Lepage, & Blanchette, 2018). De manera general, se piensa que nuestra capacidad de razonar empeora cuando tenemos que procesar contenido emocional (Blanchette & Richards, 2004; Lefford, 1946; Tremoliere et al., 2016), así como cuando nos encontramos bajo estados de ánimo positivos y negativos (Jung, Wranke, Hamburger, & Knauff, 2014; Melton, 1995; Salovey, 1993). No obstante, estudios recientes parecen indicar que la relación entre emoción y razonamiento es más compleja de lo que en un principio cabría esperar (Blanchette & El-Deredy, 2014). Por ejemplo, parece que el contenido emocional puede conducir a un mejor rendimiento a la hora de razonar de manera lógica, ya que facilita el acceso a información relevante (Gangemi, 2014). Otros autores defienden que no se debe hablar de peor o mejor razonamiento sino que nuestro estilo de razonamiento se ve afectado en función del estado de ánimo en el que nos encontremos (Clore & Huntsinger, 2007). En concreto, bajo un estado de ánimo positivo se realiza un procesamiento más flexible y global que basado en heurísticos (Ruder & Bless, 2003). Por el contrario, un estado de ánimo negativo fomenta un estilo de procesamiento más costoso, analítico y estricto (Clore & Huntsinger, 2007). Sin embargo, los resultados de un estudio reciente (Huntsinger, 2014), muestran lo contrario: bajo un estado de ánimo positivo se puede poner en práctica un estilo de procesamiento más analítico, mientras que en un estado de ánimo negativo se pueden poner en marcha procesos heurísticos. En el único estudio en el que se ha utilizado la técnica de los ERPs para estudiar la interacción entre razonamiento y emoción (Blanchette & El-Deredy (2014)), los autores manipularon el contenido emocional de argumentos condicionales: (1) Si el país está en guerra, la gente muere (2) Gran Bretaña está en guerra (3) La gente muere. Asimismo, también utilizaron argumentos de contenido neutro: (1) Si riegas las plantas, crecerán (2) Mi madre riega las plantas (3) Las plantas crecen. El único efecto del contenido emocional marginalmente significativo que encontraron fue en una ventana temporal tardía (800-1050 msegs). Los estímulos neutros se relacionaron con amplitudes más negativas que los emocionales. Los autores concluyeron que el efecto del contenido emocional de las premisas y las conclusiones ocurre en etapas tardías del razonamiento, incluso después de que se generara la inferencia. Sin embargo, los resultados arrojados en este estudio no pueden por sí mismos explicar la interacción entre el razonamiento y el contenido emocional de los argumentos. Además, no hay estudios previos con ERPs que exploren cómo aspectos extralingüísticos (por ejemplo, el estado de ánimo del lector) pueden influir a la hora de generar inferencias. Esta cuestión es abordada por el cuarto y último estudio que comprende esta tesis doctoral (capítulo 7).

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Capítulo 3

Objetivos e hipótesis

JUSTIFICACIÓN

La comprensión lectora es un elemento clave del éxito académico. Constituye el principal vehículo de adquisición de conocimientos en las fases más avanzadas del proceso educativo. Tanto las pruebas internacionales de rendimiento académico (PIRLS en educación primaria, y PISA en educación secundaria), como las de evaluación académica a nivel de Comunidad Autónoma, incluyen pruebas de comprensión lectora. Los alumnos de la Comunidad de Madrid, según datos del curso 2017-2018, obtuvieron una puntuación de 7.18 sobre 10 en la prueba de comprensión lectora de 3º curso de Educación Primaria, y de 7.08 sobre 10 en la prueba de texto literario de 6º de Educación Secundaria (datos obtenidos del informe de evaluación de la Comunidad de Madrid, Consejería de Educación e Investigación, 2018).

Según el programa internacional para la evaluación de las competencias en la edad adulta (16-65 años), las puntuaciones medias en comprensión lectora más bajas corresponden a Italia (250.5) y España (251.8), siendo significativamente inferiores a las del resto de los países de la OCDE (272.8) y de la UE (270.5) (PIACC, Instituto Nacional de Evaluación Educativa, 2013).

La capacidad de generar inferencias online juega un papel muy importante en la comprensión lectora, y constituye uno de los principales predictores del éxito de la misma (Cain, Oakhill, Barnes, & Bryant, 2001; Cromley & Azevedo, 2007; Hannon & Daneman, 1998; Kendeou, Bohn-Gettler, White, & van den Broek, 2008; Kendeou, White, van den Broek, & Lynch, 2009; Oakhill & Cain, 2012). Además, en la introducción de la presente tesis doctoral se ha puesto de manifiesto la variabilidad, la complejidad y los numerosos puntos de vista que existen acerca de los diferentes tipos de inferencia en la literatura y su papel en la comprensión lectora. Esta multiplicidad de modelos y taxonomías precisa de medidas cerebrales como apoyo para profundizar en su caracterización funcional y en los mecanismos neurales implicados en la su generación.

OBJETIVOS E HIPÓTESIS

El objetivo principal de la presente tesis doctoral consiste en explorar la posible relación de algunos de los componentes más estudiados en tareas de lenguaje (N400 y P600) con los procesos de activación e integración necesarios para la generación de una inferencia. Para ello, se llevarán a cabo cuatro estudios con diferentes paradigmas experimentales. El conjunto de estos cuatro estudios nos permitirá elaborar un modelo de generación de inferencias basado en la evidencia electrofisiológica, en el que se pretende relacionar cada uno de los procesos involucrados en dicha generación con un componente.

En primer lugar, queremos explorar la dinámica temporal cerebral relacionada con la generación de inferencias con pseudopalabras como referentes. Esto nos permitirá profundizar en la necesidad de establecer cohesión local, en la capacidad de los participantes de realizar inferencias de manera automática y en la importancia del contexto en la búsqueda de significado. Esperamos un incremento de la amplitud del N400 en el caso de pseudopalabras como referentes cuando el contexto es insuficiente para otorgar un significado. No obstante, tras la adición de nueva información que ayude a la generación de la inferencia esperamos una disminución de la amplitud del componente y de las diferencias a nivel neural de la respuesta a palabras y pseudopalabras como referentes. [Capítulo 4, artículo: *When birds and sias fly: a neural indicator of inferring a word meaning in context*].

En segundo lugar, pretendemos caracterizar los mecanismos cerebrales involucrados en la generación de diferentes tipos de inferencias. En función del tipo conocimiento del mundo que se activa, incluiremos tres tipos de inferencia para nuestro estudio: inferencias causales, inferencias emocionales e inferencias de lugar. El carácter de este estudio es exploratorio, ya que no existen estudios de ERPs en la literatura que hagan esta distinción. Sin embargo, parece que las inferencias que se realizan de manera más rutinaria son las causales, mientras que las emocionales presentan una dificultad añadida debido a la complejidad de su estudio. Diferentes procesos de revisión y análisis pueden entrar en juego en función de la naturaleza de cada inferencia. [Capítulo 5, artículo: *On the violation of causal, emotional, and locative inferences: an event-related potentials study*].

En tercer lugar, queremos caracterizar los mecanismos neurales involucrados en la generación de inferencias deductivas a partir de premisas falsas. Para ello plantearemos una tarea de razonamiento con silogismos categóricos en la que manipulamos la veracidad de la premisa mayor, pudiendo ser ésta verdadera o falsa, y pediremos a los participantes que juzguen si la conclusión les parece lógica o no. Cuando los participantes se encuentren con conclusiones lógicas que se deriven de premisas falsas, éstas entrarán en competición con su propio conocimiento del mundo y nos permitirá determinar qué tiene más peso para ellos. Esto nos permitirá, además, determinar la primacía de una expectativa léxica en función de si se obtiene siguiendo las reglas de la lógica o en función de su veracidad. Las conclusiones lógicas derivadas de premisas verdaderas serán más fáciles de anticipar, por lo que esperamos una reducción en el componente N400 en comparación con las ilógicas. Sin embargo, este patrón no se replicará en el caso de conclusiones derivadas de premisas falsas si los participantes recurren a sus propias creencias y conocimiento del mundo [Capítulo 6, artículo: *When logical conclusions go against beliefs: an ERP study*].

Por último, pretendemos examinar la influencia del estado de ánimo sobre la generación de inferencias. Para ello, induciremos experimentalmente un estado de ánimo positivo, negativo o neutro a nuestros participantes mediante una selección de fragmentos de vídeos. Los participantes juzgarán la logicidad de las conclusiones de silogismos categóricos con premisas exclusivamente verdaderas. La disparidad de resultados en la literatura dificulta la elaboración de hipótesis. Sin embargo, algunos estudios señalan que el estado emocional influye en el estilo de procesamiento heurístico o analítico de la información (Federmeier, Kirson, Moreno, & Kutas, 2001). Así, por ejemplo, la inducción de un estado de ánimo positivo reduce la respuesta N400 a elementos léxicos semánticamente más lejanos a lo altamente esperado durante la comprensión lectora. [Capítulo 7, artículo: *Please be logical, I am in a bad mood: An electrophysiological study of mood effects on reasoning*].

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Capítulo 4

Generación de inferencias a partir de pseudopalabras

Esta primera publicación de la tesis doctoral nos permitió explorar la generación de inferencias a partir de pseudopalabras como referentes. Los resultados de este estudio relacionan la amplitud del componente N400 con procesos de activación y anticipación del significado de dichas pseudopalabras. Cuando la información disponible es insuficiente para generar una inferencia, aumenta la amplitud del N400. En cambio, cuando los participantes fueron capaces de generar una inferencia acerca del significado de las pseudopalabras, esta amplitud disminuyó, lo que se relacionó con la elaboración *online* de dicha inferencia. A su vez, la presentación progresiva de las pseudopalabras propició un aumento de la amplitud del componente P600, que sugerimos puede estar relacionado con la posible formación de una huella de memoria de su significado.

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Registered Reports

When birds and *sias* fly: A neural indicator of inferring a word meaning in context

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A R T I C L E I N F O

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A B S T R A C T

Inference generation is a crucial skill in language comprehension. Recent research suggests that readers use both the contents from prior written text and their background knowledge, stored in long-term memory, to generate predictive inferences about what will come up next in a sentence. We recorded Event-Related Potentials (ERPs) to examine the reader's ability to make online inferences even in the presence of pseudowords (orthographically legal, but meaningless letter strings), that is, in the presence of referents with no a priori match to vocabulary stored knowledge. As expected, a large and sustained negativity (250–900 ms) was elicited by the target word '*fly*' when preceded by the pseudoword '*Sias*' in the sentence '*Sias fly*.' relative to when preceded by '*Birds*' in the sentence '*Birds fly*'. However, when readers were provided with an initial statement inviting to make an inference: '*Sias have wings*', the word '*fly*' in '*Sias fly*' only elicited a negative voltage deflection over 100 ms period (250–350), rapidly falling down to baseline. This result indicates that participants rapidly generated online inferences even with a hindered access to a referent's meaning (i.e. not knowing what '*Sias*' are). Remarkably, brainwave traces to the access to a word's meaning in long-term memory (access to a well-known fact such as '*Birds fly*') only diverged from ERPs for an inferred-from-reading knowledge ('*Sias fly*') for 100 ms. We conclude that a fundamental search for across sentence coherence drives fast inference making processes in reading tasks. This pattern of brain response is critical to understand the rapid acquisition of new vocabulary when learning first and second languages.

1. Introduction

Inference generation is a crucial skill for language comprehension. The Landscape Model of reading (van den Broek et al., 1999) posits that two types of comprehension processes (i.e., passive memory-based and active constructive ones) operate during reading comprehension. Both mechanisms interact to provide semantic coherence to reading passages. Strategic constructionist processes (i.e., elaboration) comes into play when the activations that result from the automatic memory-based processes fail to yield a sufficient coherence. The degree of activation of concepts either mentioned in a text or retrieved from background knowledge, constantly fluctuate as a reader proceeds through a text (Yeari and van den Broek, 2011). Psycholinguistic theories have traditionally made a distinction between necessary inferences (e.g. anaphoric reference, backward bridging inferences) and elaborative or optional inferences (e.g. propositional logic inferences, instrumental inferences, predictive inferences) (Cook and O'Brien, 2015). An example of a necessary inference is pronoun resolution. After reading the sentence: "*Paul and Mary went to the gym. He really wanted to exercise*" the reader needs to infer that the pronoun "*He*" refers back to Paul and not to Mary. The automatic activation of our world knowledge (e.g. male and female proper nouns) allows the inference. In this example, optional inferences might additionally be made on whether they both ended up exercising or not, whether they went to the gym by car or walking, and so on. Making this type of "optional" inferences might facilitate the processing of upcoming words later in the discourse.

Despite the fact that inference making is a fairly common process during reading, the neural mechanisms that allow it have only recently been explored. Brain imaging techniques have found that the left inferior frontal gyrus (LIFG) and the right lingual gyrus are involved in predictive inference generation (Jin et al., 2009). Also, dorsomedial prefrontal cortex activation has been implicated in coherence building, and the left frontal lobe region has been involved in knowledge-based inferences (Ferstl, 2015). Research using the Event-Related Potential

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(ERP) technique supports the view that readers anticipate upcoming words in discourse while reading (Kutas et al., 2011; Van Berkum et al., 2005). However, it is still a matter of debate under what circumstances predictions are made and how robust predictions can be (Ito et al., 2016).

1.1. Event-related brain potential studies of inference generation

A critical issue is how fast inferences, even elaborative/optional ones, not required for comprehension to proceed, are made in reading comprehension tasks. Due to its high temporal resolution, the ERP technique is ideally suited to explore the point in time at which inferences were most likely drawn during reading. It provides a continuous measure of ongoing electrical brain activity from the onset of a critical word in a reading passage. A pioneering ERP study on inference generation (St George et al., 1997), used the amplitude of the N400 component (Kutas and Hillyard, 1980a), sensitive to semantic priming and context integration processes, to show that readers were able to make fast online inferences during reading tasks. When the final sentence of a paragraph stated explicitly an inference that readers were invited to make based on earlier context, the N400 averaged peaks to the words in the final sentence were reduced. Similarly, the establishment of causal coherence across sentences, was marked by a attenuation of the N400 response to words that were inserted in highly causally related scenarios relative to those inserted in causally unrelated scenarios (Kuperberg et al., 2010; Kuperberg et al., 2011). According to Yang et al. (2007) word-to-text integration processes also occur across sentence boundaries (e.g. a reduction in the N400 for the word 'rain' in a sentence preceded by a coreferent paraphrase: 'storm'). Moreover, lexical decision tasks on probe words that could have been inferred after reading a sentence elicited an attenuated N400 and a larger late positivity (P600) probably indexing a causal coherence inference generation (Steele et al., 2013). Finally, in a study by Burkhardt (2007), the need to establish causal coherence across sentences was indexed by an incremental amplitude of the P600 in response to a word that represented addition of new information to an statement made earlier. Specifically, an incremental larger P600 amplitude was found to the word '*pistol*' in the sentence: "the press reported that the *pistol* was probably…" when preceded respectively by: Yesterday a Ph.D. student was: (1) shot down (2) killed and (3) found dead downtown. Overall, these studies reveal that inference generation can be traced down by measuring the ERP responses to target words that carry information that could have been inferred based on prior text information and/or on prior knowledge. All above mentioned studies have made use of meaningful contexts and targets and meaningful discourse. However, the real need to make an inference is when the comprehension system is challenged by the use of a lexical entry that has no access to vocabulary stored knowledge. Pseudowords (e.g. *sias*) follow orthographical rules and resemble real words. However, they are devoid of links to long term memory stored knowledge. A recent study by Batterink and Neville (2011) embedded pseudowords in narrative contexts that either allowed or not the inference of what the word meaning might be. In one condition pseudowords were embedded in the text always replacing a real word whereas in condition 2 the replacement was pseudorandom, lacking thus a consistent link to meaning across the text. According to brain responses, pseudowords in inference supportive contexts seemed to acquire meaning across ten consecutive presentations, showing a reduction in N400 amplitude. Nonetheless, constant repetition of the same pseudoword target had an impact in itself on brainwave responses (an additional N400 reduction). The interaction of these two effects made facilitation due to the type of context produce no additional effect over the sixth through the eight presentation of the pseudoword.

1.2. The present study

The current study measured the response to the final real word of the sentence depending on whether it was preceded by a word or a pseudoword referent. In addition, it used a two-block design in order to control for the repetition of pseudowords. In the first block, words or pseudowords were presented in an isolated sentence whereas in a second block they were preceded by an inference inviting sentence. Critically, participants either saw the real word in block 1 and the pseudoword in block 2, or viceversa. Thus, our aim was to explore how the brain responds to sentence final word endings (e.g. "*fly*") when prior world knowledge is available (*Birds fly*) and compare it to when an inference making process ought to be implemented for comprehension to proceed (e.g. *Sias fly*). In the later example, no long-term memory (LTM) trace is available for the meaning of the lexical entry '*Sias*'. However, if we stated in a preliminary sentence that '*Sias* have wings. *Sias* fly' (block 2), regardless of our lack of knowledge of what '*sias*' are, we may be ready (or not) to make an inference on its meaning, thus anticipating the word: 'fly'. Our ability to make fast online inferences (Steele et al., 2013) could thus be extended to unknown pseudoword referents and affect the successful prediction of meaningful upcoming words in discourse. Thus, according to prior literature on inference making, an N400 reduction or absence is expected for the final word of the second sentence (in block 2), i.e. when, regardless of word status, an inference supportive sentence was included. However, the inclusion of a pseudoword referent in the initial sentence (block 1) might distort or prevent the process of anticipation of sentence word endings, in which case the target word 'fly' in the context 'Sias have wings. Sias fly' would still show an N400 effect. Thus, we measured the brain responses to both the final word of the sentence (e.g. *fly*) which will remain constant across conditions, as well as the response to the word/pseudoword referents themselves (e.g. *birds/sias*).

Regarding the second aim, prior literature shows that ERPs to words and pseudowords differ in the amplitude of the N400 component, starting at about 200 ms (Kutas and Van Petten, 1994). Most studies showing this lexicality effect (a larger N400 for pseudowords than words) have used paradigms of lexical/semantic priming and decisions tasks on single words. A recent lexical decision study (Bermudez-Margaretto et al., 2015), reports that repeated exposure to meaningless pseudowords produces an increase in the Late Positivity Complex (LPC), while a frontal N400 component (FN400), larger for pseudowords relative to words, is unaffected by repetition.

Thus, as a secondary goal, we explored how the ERP response to words and pseudowords evolves in time at each of their occurrences during the reading session: (1) as the subject of the unique sentence (block 1), (2) as the subject of the first sentence (block 2), and (3) as a subject of the second sentence (block 2). Initially, at block 1, a larger N400 is expected to be elicited by pseudowords relative to words (i.e., lexicality effect). In addition, we anticipate an N400 reduction with each word presentation (N400 word repetition effect) (see review by Kutas and Federmeier, 2000). Finally, an increase in the LPC component for the repetition of pseudowords, would replicate the findings for the repetition of isolated pseudowords in lexical decision tasks (Bermudez-Margaretto et al., 2015).

2. Method

2.1. Participants

Twenty-four native Spanish speakers (7 males, mean age = 19.7 - years, range = 18–26 years) volunteered to participate in the study in exchange for course credits. All participants gave written informed consent and reported being right-handed. The average handedness score (Oldfield, 1971) was + 78.9 (range, + 41 to + 100). All participants reported normal or corrected-to-normal vision and none had a history of neurological or psychiatric disorders. The local ethics committee approved the experimental procedures.

2.2. Verbal materials

An initial set of experimental stimuli was created. It consisted of 98 Spanish sentence pairs. The first sentence contained either a real word ('*aves*' = birds) or a pseudoword (*sias*) while providing some information about that word/pseudoword entry (e.g. *birds/sias have wings*). The next sentence provided a definition or an ability of that 'thing' that was either known (knowledgeable condition: birds fly) or that could have been inferred based on the previous sentence (inferred condition: *sias* fly).

Since it is widely established that N400 s are typically larger (more negative) to low cloze probability words in context, before the ERP experiment was setup, these sentence pairs were subjected to a cloze probability norming procedure. Thirty subjects read the sentences with a word and 30 with a pseudoword as the subject of the sentence and completed the last word of the second sentence which was omitted on purpose. A sentence pair was selected for inclusion in the ERP experiment materials if the final word of the last sentence was approximately equally emitted in both the word and the pseudoword conditions (i.e. no more than a ± 20% disagreement; 10 sentence pairs were rejected based on this criteria). A pair of sentences was also rejected if one of the members of the sentence pair had a cloze probability lower than 46.7% ($N = 8$ sentence pairs were rejected based on this criteria). The final pool of sentences consisted of 80 sentence pairs. The final word of the second sentence was emitted on average 85.2% in the word condition (STDV = 14.0) and 83.5% in the pseudoword condition (STDV = 14.5) (t-test = 0.1). Mean frequency of use of the last word in the second sentence was 546 per million. Mean frequency of use of the subject of the sentence was 92.4 per million for the word condition, and zero for the pseudoword condition (Sebastián-Gallés et al., 2000). Frequency of use of the last word of the sentence was perfectly matched across conditions as the same word served as the target word (e.g. fly). Nonetheless, we distributed the materials in two experimental lists such that the target word 'fly' was once included in the first experimental block preceded by a real word and then in the second block preceded by a pseudoword, and viceversa in experimental list number 2. Participants were randomly assigned to experimental list 1 or 2. Table 1 contains sentence examples used in each block and the experimental list they were assigned to.

Thus, in a first experimental block, we tested single sentences in which the subject of the sentence was, unpredictably, a real word or a pseudoword (e.g. Birds/*Sias*…) and we measured the N400 response to the final word of the sentence, 'fly' when preceded by 'birds' and when preceded by '*sias*'. In a second experimental block, a new sentence was introduced prior to the critical sentence. This sentence comprised a new statement and provided information potentially inviting to make an inference (e.g. Birds/*Sias* have wings).

2.3. Procedure

After signing informed consent, participants were fitted with encephalogram (EEG) electrodes while they filled out handedness, vision and health questionnaires. They were seated approximately 100 cm in front of a 19″ computer monitor. The session began with a short set of practice stimuli to acclimate the participants to the reading task. Each word in a sentence was presented in the screen in a black 36-point lower-case Arial font on a white background. Participants were instructed to read the sentence and press the space bar to initiate the next sentence (block 1); read a pair of sentences and press the space bar to initiate the next pair of sentences (block 2). Each word was presented for 300 ms with an inter-words interval of 300 ms. Experimental lists 1 and 2, which counterbalanced the occurrence of a target word in the word/pseudoword condition, were randomly assigned to participants. They read a total of 80 sentences in block 1 and 80 pairs of sentences in block 2. They were presented in random order. The whole reading session lasted about 20 to 30 min. A word and pseudoword recognition test was administered at the end of the session. Participants had previously been informed about a final test in order to motivate them to pay close attention to the reading materials. We presented participants with words and pseudowords previously seen in the experimental session ($N = 40$, 10 per experimental condition) plus 10 new words and 10 new pseudowords. Their task was to press a button to indicate that 'yes, they had seen the word or strings of letters before', or 'no' if they felt they had never seen that word/pseudoword before. Participants were highly accurate in recognizing previously seen words (80.6%) as well as in rejecting never seen words (92.0%) and pseudowords (87.9%). Their performance decreased for the recognition of previously seen pseudowords (56.8%). In addition, participants underwent the Spanish adaptation of the Reading Span Test (Daneman and Carpenter, 1980; Elosúa et al., 1996). The test requires participants to read aloud a series of unconnected sentences, each one presented on a card. Participants are cued to recall the end-of-sentence words by a blank card at the end of a trial. The number of sentences in a series is incrementally increased from 2 to 6 sentences (three trials each). The maximum number of final words correctly recalled, was considered the participant's reading span score, ranging from 2 to 6.

2.4. EEG recording and data analysis

EEGs were recorded from 32 tin electrodes[1] mounted in an electrode cap (Electro-Cap International, Eaton, Ohio, USA). Electrode impedances were kept below 5 KΩ. Electrodes were referenced online to the left mastoid, amplified with Brain Amps amplifiers (Brain Products, Munich, Germany) at a sampling rate of 250 Hz with a bandpass of 0.01–40 Hz. Collected recordings were off-line re-referenced to the average activity of the two mastoids, following a widely employed N400 analysis procedure (see e.g. Wlotko and Federmeier, 2015). Bipolar horizontal and vertical electrooculograms (EOGs) were additionally recorded for artifact rejection and blink correction purposes, using the Gratton et al. (1983) method. Data were processed using BrainVision Analyzer software (Brain Products, Munich). After visual inspection of individual data files, the following artifact threshold criteria were set: maximal allowed voltage step, 50 μV; minimal and maximal allowed amplitude, ± 100 μV; lowest allowed activity (max-min), 5 μV for a 1500 ms interval length. Once a threshold was met in the continuous EEG file, the data recorded were marked and discarded, including 200 ms before and 200 ms after the artifact. EEG raw data from all subjects were scanned and marked using the same criteria. As a result, 8.4% of trials were discarded and an average of 36.6 trials remained per experimental condition. Paired t-tests confirmed no differences in the number of trials that remained per experimental conditions (all $p_s \geq 0.08$).

A Butterworth zero phase filter was applied to the EEG data (low cutoff at 0.1 Hz, time constant = 1.6 s, 24 dB/oct; high cutoff at 20 Hz, 24 dB/oct). The continuous EEG was segmented into 1000-ms epochs starting 100 ms before the onset of the target word ending. Artifact-free average waveforms were calculated for each condition separately, after subtraction of the pre-stimulus baseline (− 100 to 0 ms).

3. Results

3.1. Effect of a word or a pseudoword referent for the processing of the final word of the sentence

Fig. 1 shows the grand averaged ERP responses to the target word that finished the sentence (e.g. 'fly') as a function of whether it was preceded by a word or a pseudoword referent. According to visual inspection, in block 1 (left panel), the ERP response to 'fly' showed an

[1] Electrode sites included: Fp1/z/2, F7/3/z/4/8, FT7/8, FC3/z/4, T7/8, C3/z/4, TP7/8, CP3/z/4, P7/3/z/4/8, O1/z/2, left and right mastoids.

Table 1
Examples of experimental sentences presented in block 1 and block 2, translated into English.

Block 1

Sentence 1	Sentence 2	Target word	Condition	Cloze %	Experimental list
–	Birds…	…fly.	Knowledgeable	–	2
–	Sias…	…fly.	Ignored	–	1
–	Cats can see in the…	…dark.	Knowledgeable	–	1
–	Hiros can see in the…	…dark.	Ignored	–	2
–	Candies are…	…sweet.	Knowledgeable	–	2
–	Zaratemis are…	…sweet.	Ignored	–	1
–	Glasses can be…	…broken.	Knowledgeable	–	1
–	Tuleminos can be…	…broken.	Ignored	–	2
–	Cows are…	…ruminants.	Knowledgeable	–	1
–	Fegas are…	…ruminants.	Ignored	–	2
–	Fruits are good for…	…health.	Knowledgeable	–	2
–	Bofes are good for…	…health.	Ignored	–	1

Block 2

Sentence 1	Sentence 2	Target word	Condition	Cloze %	Experimental list
Birds have wings.	Birds…	…fly.	Knowledgeable	90.0	1
Sias have wings.	Sias…	…fly.	Inferred	90.0	2
Cats are nocturnal animals.	Cats can see in the…	…dark.	Knowledgeable	76.7	2
Hiros are nocturnal animals.	Hiros can see in the…	…dark.	Inferred	83.3	1
Candies are high in sugar.	Candies are…	…sweet.	Knowledgeable	83.3	1
Zaratemis are high in sugar.	Zaratemis are…	…sweet.	Inferred	80.0	2
Glasses are fragile.	Glasses can be…	…broken.	Knowledgeable	96.7	2
Tuleminos are fragile.	Tuleminos can be…	…broken.	Inferred	93.3	1
Cows chew food several times.	Cows are…	…ruminants.	Knowledgeable	76.7	2
Fegas chew food several times.	Fegas are…	…ruminants.	Inferred	63.3	1
Fruits contain lots of vitamins.	Fruits are good for…	…health.	Knowledgeable	80.0	1
Bofes contain lots of vitamins.	Bofes are good for…	…health.	Inferred	90.0	2

N400-like sustained negativity approximately between 200 and 900 ms when preceded by a pseudoword (e.g. *sias*) relative to when preceded by a real word (birds). In block 2 (Fig. 1, right panel), this pseudoword/word precedent effect seemed to vanish. Thus, when either 'birds' or '*sias*' had previously been described as '*having wings*' (block 2), the processing of the target word '*fly*' no longer seemed to exhibit a large sustained ERP negativity for the condition in which it was preceded by a pseudoword relative to when it was preceded by a real word.

Based on previous N400 literature (Kutas and Hillyard, 1980b, 1984; Van Petten and Kutas, 1991),we measured mean amplitude values in the 300–500 ms latency range, corresponding to classical N400 effects. We submitted the values to repeated-measures ANOVAs involving the within-subjects factors Preceding Word Status (two levels: Word, Pseudoword) and Block (two levels: block 1 and block 2), at 31 cephalic electrode positions. In all our analysis, whenever sphericity was violated, we applied the Huynh-Feldt epsilon (ε) correction for degrees of freedom of the within-subject measures. Interaction effects were explored with planned pairwise comparisons. All post-hoc pairwise contrasts were performed and corrected for multiple comparisons by means of the Bonferroni procedure establishing a significance level of $\alpha = 0.05$. According to Picton et al. (2000) indications, uncorrected degrees of freedom, epsilon values and corrected p are reported.

The analysis in the 300–500 ms time-window revealed main effects of Preceding Word Status [F (1,23) = 25.370, $p < 0.001$, $\eta_p^2 = 0.524$], with a larger N400 for the Pseudoword (0.74 μV) relative to the Word Preceding condition (2.35 μV); and Block [F (1,23) = 5.571, $p = 0.027$, $\eta_p^2 = 0.195$], with a larger N400 in block 1 (1.08 μV) relative to block 2 (2.01 μV). There was also an interaction of Preceding Word Status by Block [F (1,23) = 10.764, $p = 0.003$, $\eta_p^2 = 0.319$].

Separate ANOVAS carried out for block 1, confirmed robust main effects of Preceding Word Status [F (1,23) = 26.44, $p < 0.001$; $\eta_p^2 = 0.535$] and Electrode site [F (30,690) = 14.978, $p < 0.001$; $\eta_p^2 = 0.394$], and their interaction [F (30,690) = 10.180, $p < 0.001$; $\eta_p^2 = 0.307$]. In contrast, in block 2, Preceding Word Status and the interaction with Electrode site were not significant [F (1,23) = 2.33, $p = 0.141$; and F (30,690) = 1.006, $p = 0.401$; respectively].

In order to better characterize the visually observed long lasting course of the effect in the first block as well as its a priori absence in the second block, we additionally carried out separate ANOVAs every 50 ms (between 200 and 900 ms) at fourteen consecutive time-windows. The results of these analyses are summarized in Table 2.

In the first block, the main effect of Preceding Word Status extended from 250 ms until the end of the epoch (900 ms). The interaction with a Region of Interest (ROI) factor (Left Anterior: Fp1, F7, F3, FT7, FC3; Right Anterior: Fp2, F8, F4, FT8, FC4; Left Posterior: TP7, CP3, P3, P7, O1; Right Posterior: TP8, CP4, P4, P8, O2) was significant between 350 and 500 ms [all p values < 0.01]. Further analysis revealed that over this time region the N400 amplitude was maximal over the right posterior ROI (3.6 μV difference), in accordance with the typical distribution of N400 effects (Curran et al., 1993). In contrast, an effect of Preceding Word Status was only significant between 250 and 350 ms in block 2 and the interaction with ROI was never significant.

In summary, the ERPs elicited by the final words of sentences where dependent on whether word/pseudoword referents preceded them in the first experimental block (with a sentence presented in isolation). In particular, final words preceded by pseudoword referents elicited a typically distributed N400 effect, relative to those with word as referents. The addition of another sentence in block 2, significantly reduced the impact of whether the final word was preceded by a word or a pseudoword referent. The larger N400 in this case was only significant between 250 and 350 ms and its topographical distribution was not the classical of N400 effects.

As mentioned in the methods section, participants were tested in the Spanish adaptation of the Reading Span Test by Daneman and Carpenter (Daneman and Carpenter, 1980; Elosúa et al., 1996). According to the split that was carried out in the study by St George et al.

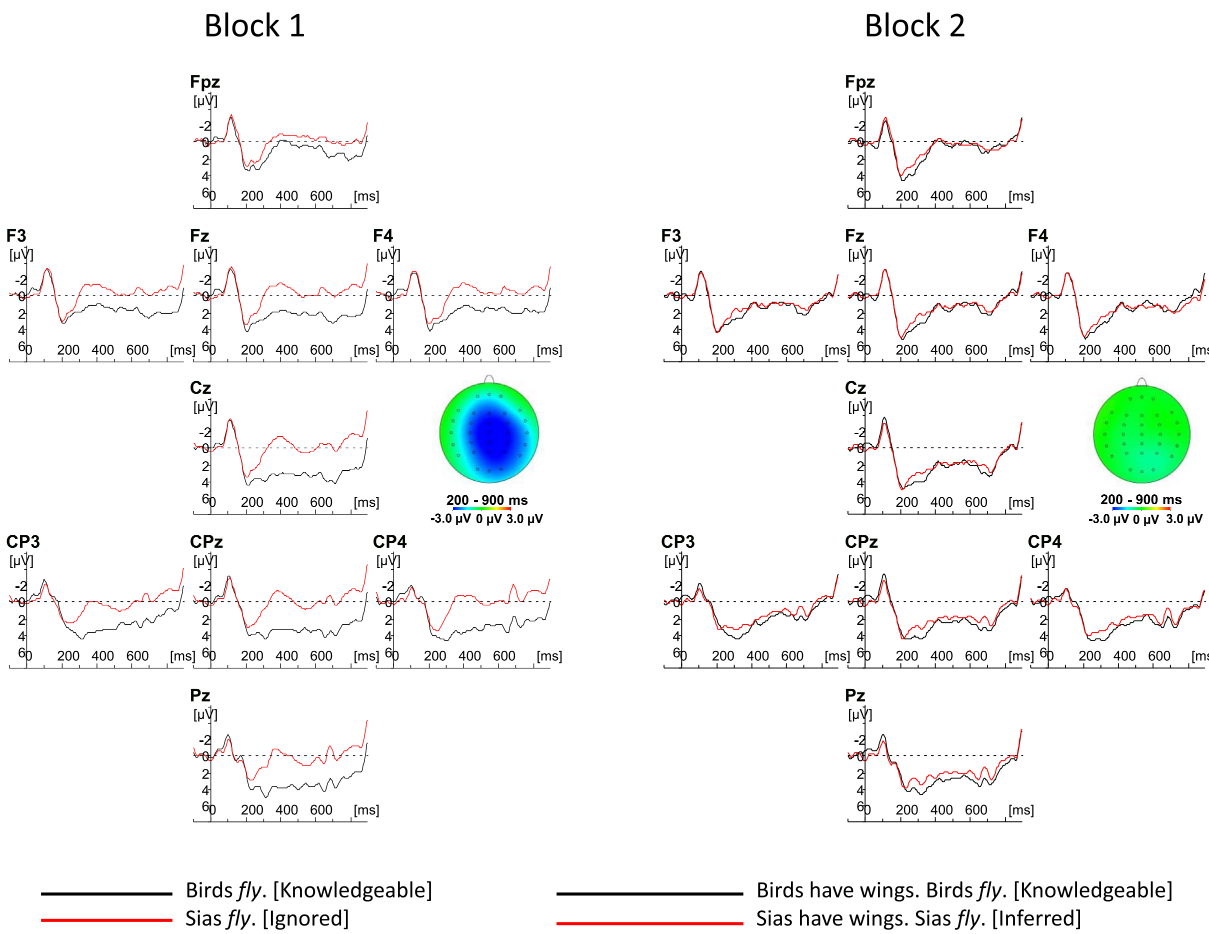

Fig. 1. ERP responses elicited by target words presented at the ending position of a unique sentence (block 1, left panel) and at the ending position of two paired sentences (block 2, right panel), when these targets were preceded by words (black lines) or by pseudowords (red lines). Responses are plotted at a representative selection of 9 electrodes. Frontal sites are at the top; parietal sites at the bottom of the figure. Spherical spline-interpolated isovoltage maps derived from difference waveforms (pseudoword- minus word-preceded targets) are also shown. In block 1, pseudoword-preceded targets elicited a sustained negativity with a right centro-parietal distribution typical of N400 effects. In block 2, ERPs elicited by pseudoword- versus word-preceded targets were only significant over a one hundred time-period (between 250 and 350 ms). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(1997), a 2 to 4 score indicates low working memory capacity whereas 5 or 6 points qualifies for a high working memory capacity. The scores of our participants in the test were not largely dispersed. Most participants scored low (2 and 3 points, $N = 20$ participants). Only 3 subjects scored 4, and only one subject scored high (5 points). Thus, we lacked of an appropriate sample with high scores in working memory capacity. Correlation tests between the score obtained in the SPAN test and the amplitude of the N400 response in the condition in which an inference was required to be made were nonetheless carried out. We specifically run tests over the mean amplitude at a series of centro-parietal electrodes as well as at some individual sensors. None of our tests revealed significant correlations, which as mentioned earlier we attribute to the fact that the scores in the test were not widely enough distributed.

Table 2
Summary of the ANOVAs carried out on the mean amplitude response to the final word of the unique sentence (in block 1) and to the final word of the second sentence (in block 2). Analysis were conducted over a 700 ms period, every 50 ms. Periods at which Condition had a significant main effect are highlighted in bold.

ms	200–250	250–300	300–350	350–400	400–450	450–500	500–550	550–600	600–650	650–700	700–750	750–800	800–850	850–900
BLOCK 1														
ROI	2.083^{ns}	7.891**	17.396***	19.433***	25.838***	19.429***	14.085***	9.054**	6.241*	1.931^{ns}	0.326^{ns}	0.923^{ns}	1.504^{ns}	2.830^{ns}
Condition	1.287^{ns}	6.130*	28.314***	26.655***	19.976***	14.397**	8.178*	7.121*	12.035**	12.122**	9.499*	9.441*	10.896**	10.362**
ROI* Condition	1.329^{ns}	2.885^{ns}	3.244^{ns}	7.794**	9.835***	4.780*	3.033^{ns}	3.626*	2.930^{ns}	2.433^{ns}	2.825^{ns}	2.168^{ns}	3.702*	1.997^{ns}
BLOCK 2														
ROI	7.907**	2.042^{ns}	6.967**	13.622***	16.396***	7.137**	6.635*	3.277*	9.437**	1.538^{ns}	3.374^{ns}	4.076*	3.961*	6.601**
Condition	0.133^{ns}	4.447*	6.529*	2.105^{ns}	0.552^{ns}	1.280^{ns}	0.368^{ns}	0.023^{ns}	0.229^{ns}	3.254^{ns}	0.409^{ns}	0.110^{ns}	0.028^{ns}	0.226^{ns}
ROI* Condition	1.006^{ns}	0.100^{ns}	0.666^{ns}	2.847^{ns}	1.984^{ns}	0.746^{ns}	2.177^{ns}	1.900^{ns}	1.138^{ns}	1.245^{ns}	1.081^{ns}	2.412^{ns}	0.748^{ns}	0.714^{ns}

^{ns}: non-significant.
* $p < 0.05$.
** $p < 0.005$.
*** $p < 0.001$.

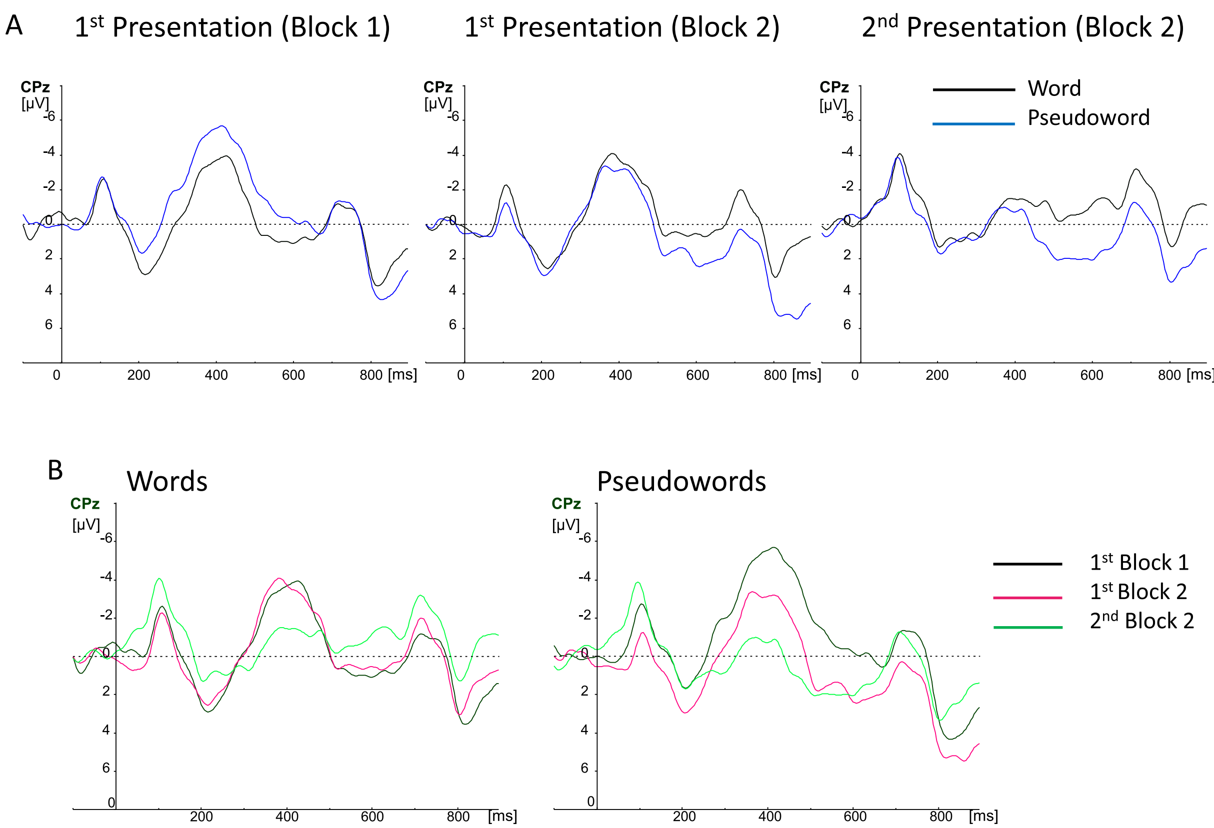

Fig. 2. A. Lexicality effects (difference between pseudoword and word items) at electrode CPz, as a function of Presentation Time. A larger N400 was elicited by pseudowords relative to words at their initial presentation (as the subject of the unique sentence in block 1). As a subject of the second sentence in block 2, pseudowords elicited a larger P600 than words. B. Words elicited a reduced N400 at the second presentation in block 2, relative to previous presentations. By contrast, pseudowords show a linear decrease in N400 amplitude at each presentation time.

3.2. Words versus pseudowords processing

In addition to exploring the response to the last word of a sentence, we measured the response to the precedent word/pseudoword referent items themselves. As Fig. 2A shows, pseudowords elicited a larger N400 amplitude than words at their initial presentation (block 1). In block2, the ERP response to words and pseudowords was undistinguishable in terms of N400 amplitude. Instead, pseudowords seem to elicit a larger late positivity (500–700 ms) relative to words. Fig. 2B shows how the N400 amplitude to pseudowords decreases in amplitude at each occurrence. Instead, for words, the N400 response is similar at the initial presentations in block 1 and block 2, whereas at their 2nd presentation, that is, as the subject of the second sentence of a pair in block 2, the N400 response is reduced.

Based on visual inspection of the waveforms as well as on previous ERP language studies (Kutas and Hillyard, 1980b, 1984; Van Petten and Kutas, 1991), we measured mean amplitude values in the 300–500 ms and 500–700 ms latency ranges, corresponding to classical N400 and P600 effects, respectively. We submitted the values to repeated-measures ANOVAs involving the within-subjects factors Word Status (two levels: Word, Pseudoword) and Presentation Time (three levels: as a subject of the unique sentence in block 1, as a subject of the first sentence in block 2, and as a subject of the second sentence in block 2), at 31 cephalic electrode positions.

In the 300–500 ms time-window, the analysis revealed a main effect Presentation Time [F (2,46) = 7.96, p = 0.003, η_p^2 = 0.257] and an interaction of Word Status by Presentation Time [F (2,46) = 4.83, p = 0.012, η_p^2 = 0.174]. In the 500–700 ms time window the interaction Word Status by Presentation Time was significant [F (2,46) = 7.45, p = 0.002, η_p^2 = 0.245] and no main effects emerged.

Based on these results, follow-up ANOVAS were carried out at each presentation time, separately. In the 300–500 ms time-window, a Word Status main effect was significant at first presentation in block 1. Relative to words, the N400 response to pseudowords was larger [Pseudowords: − 2.82 μV, Words: − 1.49 μV; F (1,23) = 15.21, p = 0.001, η_p^2 = 0.398]. However, at second and third presentations no main effect of Word Status emerged in the N400 time-window (p = 0.82 and 0.90, respectively). In the 500–700 ms time-window, pseudowords remained eliciting a more negative ERP deflection than words at first presentation in block 1 [Pseudowords: − 0.16 μV; Words: 0.8 μV; F (1,23) = 4.60, p = 0.04, η_p^2 = 0.167]. However, in block 2, pseudowords elicited a more positive ERP deflection than words. The effect was only marginally significant at first presentation [Pseudowords: 1.64 μV, Words: 0.69 μV; F (1,23) = 3.34, p = 0.08, η_p^2 = 0.127] and significant at their second presentation [Pseudowords: 0.83 μV, Words: − 0.45 μV; F (1,23) = 9.21, p = 0.006, η_p^2 = 0.286].

Summarizing, (1) pseudowords elicited a larger N400 than words in block 1 (p = 0.001); (2) the N400 amplitude to pseudowords and words in block 2 was not statistically significant (p = 0.82 and p = 0.90); (3) In block 2, a larger positivity (P600) was elicited by pseudowords relative to words at their second presentation (p = 0.006).

4. Discussion

The present study explored predictive inference making processes during language comprehension tasks using electrophysiological measures and meaningless pseudoword referents. As expected based on prior literature, in the first experimental block, the ERP response to the final target word of an isolated sentence (e.g. fly) was clearly influenced by whether it was preceded by a meaningful word (e.g. birds) or a meaningless pseudoword (*sias*). A long lasting (250–900 ms) negative going deflection was elicited by pseudoword preceded targets. In contrast, at block 2, where an initial sentence gave support to make an inference, pseudoword preceded targets provoked a limited (250–350 ms) enhanced negativity. Thus, whereas the contrast between knowledgeable versus ignored conditions in block 1 reveals a robust and long lasting ERP effect between 250 and 900 ms (a long sustained N400), in block 2 the processing of the target word 'fly' had only a short-lived enhancement between 250 and 350 ms when preceded by a pseudoword lexical entry. This result has initially two potential interpretations. Perhaps, other words in the first sentence (e.g. wings) facilitated the processing of the last word of the sentence (e.g. semantic priming between 'wings' and 'fly'). Alternatively, an inference was made based on the recently acquired knowledge (e.g. Sias have wings), such that the first sentence facilitated inferencing processes (Sias are capable of flying). In favor of the second hypothesis is the fact that the two conditions in our study (word/pseudoword preceded targets) included semantic associations from other words in the sentence. Nonetheless, only pseudoword preceded targets showed this initial negative deflection from baseline, indicating that the prediction of the last word of the sentence was perhaps less straightforward as the one elicited by real words. In this regard, knowledgeable versus inferred from previous reading conditions can almost be equated in terms of ERP responses. When participants were given the opportunity to make an inference about what '*sias*' might be, the processing of the target word '*fly*' no longer elicited a long sustained N400 response. In a sense, pseudoword referents functioned almost as real words in the second block of the experiment. Thus, our study goes in line with previous studies in which the fast generation of online inferences is claimed (Kuperberg et al., 2011; St George et al., 1997; Yang et al., 2007) most likely to provide an across sentence coherence (e.g. if they have wings, whatever they are, they might as well fly). Thus, the initial impairment to make a link between pseudowords and vocabulary stored knowledge (experienced in block 1) is overridden when additional context allows for an inference making process. When inferences can be drawn, previously known and recently inferred facts (e.g. birds fly/*sias* fly) are almost equally processed in terms of ERP responses. That is, the response to upcoming words in the sentence is driven by both word and even pseudoword referents. The distinction is only a short-lived 250–350 negativity for upcoming words preceded by pseudowords relative to real words. These results are in line with recent results by Tabullo et al. (2015) showing that previously learned associations of meaningless pseudowords elicit functionally similar electrophysiological correlates than semantic association priming effects for real words do. They also reinforce the finding that a single exposure to a new word in context can foster the development of rapid semantic associations measured through ERPs (Borovsky et al., 2012) as well as the finding that after two exposures only, novel words presented in contexts allowing for meaning derivation are almost indistinguishable from real words in terms of brainwave response (Mestres-Misse et al., 2007). Our data suggests that a predictive inference is mostly responsible for such a short lived deviation from baseline. Clearly, predictive inferences were more rapidly generated by participants following real words (Van Berkum et al., 2005) but also even when unreal words (pseudowords) were used as the referent of the sentence. In terms of ERP response, being able to make a link to previous long term memory stored knowledge about 'birds' (i.e., they fly) was only slightly advantageous relative to recently acquired knowledge about '*sias*' (i.e. they have wings). Thus, in line with previous results (Steele et al., 2013), an N400 attenuation to the target word 'fly' in the inference making condition ('Sias have wings. Sias *fly*') can be taken as evidence of a fast inference generation process, even in the absence of a LTM trace for the referent in the sentence.

N400 effects are typically elicited in the 200 to 500 ms latency range. However, the contrast in our study (at block 1) is longer sustained, lasting until the end of the epoch (900 ms). Topographic brain maps and ROI analysis revealed a typical N400 voltage distribution, that is, maximal amplitude at right centro-parietal electrode sites (see Fig. 1). It is widely known that semantically incongruent and semantically unexpected target words in context elicit a clear ending N400 effect. The N400 component typically drops down to baseline at around 500 ms, despite sometimes parietal or frontally distributed post-N400 positivities are subsequently elicited (see Kutas and Federmeier, 2011 for a review; Van Petten and Luka, 2012). However, longer lasting N400 effects have been reported for the processing of ambiguous probe words when they unmatched the use of an alternative meaning in a previous sentence (Kotchoubey and El-Khoury, 2014). The long-lasting N400 in this study was interpreted as an indicator of an effort needed to deactivate the irrelevant and activate the relevant meaning of the ambiguous word. Since meaningless pseudowords acted as the referent of a sentence in our study, we speculate that the N400 sustained effect (in contrast to classic short-lived N400 effects), might also indicate a persistent attempt to integrate the last word of the sentence into previous context. In this regard, pronounceable strings of letters might have been processed as an unknown concept to the reader (e.g. an unknown type of bird) that deserved an enduring effort to be integrated in previous context.

As a secondary goal in our study, prior to the processing of the critical word '*fly*' we measured the ERP response to preceding word and pseudoword items. As expected, pseudowords in block 1 elicited an N400 enhancement relative to words (a lexicality N400 effect), indexing a semantic access difficulty. Interestingly, in block 2 the lexicality effect previously obtained in the N400 component disappeared. Words and pseudowords in the second block (1st sentence) turned to be equally processed due to a reduction in N400 amplitude for pseudowords. This finding was unexpected according to our two lists design. Pseudowords in the second block had never been seen before. We can only speculate that habituation to pseudoword exposure during the first block might explain this lack of lexicality effect. Alternatively, reading at this point in the sequence of events was not really informative and as a consequence participants stopped paying attention to the subject of the sentence. Interestingly, in block 2 (2nd sentence) the lexicality effect switched to a P600 effect; a larger P600 was elicited by pseudowords relative to words. This finding is similar to a previously observed increase of LPC (Late Positive Complex) amplitude across pseudoword repetition (Bermudez-Margaretto et al., 2015). The LPC component enhancement in this study was related to the formation and strengthening of memory traces for repeated pseudowords. Our results go in line with this interpretation. Based on their repetitive occurrence, pseudowords in the second sentence of block 2 elicited a P600 rather than an N400 response. The P600 effect thus might be indexing the establishment of a link to memory based on a prior occurrence.

In accordance with previous ERP results on inferential processes (St George et al., 1997; Kuperberg et al., 2011; Steele et al., 2013; Yang et al., 2007), our study reveals that the main neural correlate of an inference generation is an attenuation in the N400 amplitude to the processing of upcoming words later in the discourse. Only two studies have found inference-making ERP effects in a later P600 component (Burkhardt, 2007; Steele et al., 2013). Particularly, the study by Steele et al. (2013) found inference effects in both time-ranges (N400 and P600). Further studies are needed to clarify what precise inference making mechanisms drive dissociated N400 and P600 effects. The few ERP studies on inference processes so far nonetheless suggest that the N400 reduction is probably best linked to predictive inferences whereas the P600 reduction might be linked to other elaborative or optional inferences, e.g., instrumental inferences (Burkhardt, 2007).

The present study provides further support to psycholinguistic models that postulate the generation of fast online inferences (van der Broek and Odega, 2015). It proves that online inferences are easily drawn at a high speed during language comprehension tasks, even when referents are meaningless pseudowords. Our electrophysiological measures support a model in which passive activation of information previously processed (in prior discourse) encourages the generation of inferences even in the absence of LTM semantic traces about an unknown lexical entry. Our brainwave results indicate that participants are able to draw inferences based on previous reading. Quite remarkably while the processing of knowledgeable and inferred facts diverged from the processing of ignored facts, the access to a word's meaning in long-term memory did diverge only for 100 ms from inferring its meaning from prior context. This result is critical to understand the rapid mechanism of acquisition of new vocabulary in first and second languages.

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Capítulo 5

Generación de inferencias causales, emocionales y de lugar

Esta segunda publicación de la tesis doctoral nos permitió explorar posibles diferencias a nivel neural en la generación de tres tipos de inferencias: causales, emocionales y de lugar, clasificadas en función del tipo de conocimiento del mundo que se activa para cada una de ellas. La violación de los tres tipos de inferencia se tradujo en aumento de la amplitud del componente N400. En cambio, se pusieron en marcha diferentes mecanismos neurales para la revisión y el análisis de dicha violación. Con respecto a las inferencias causales, su violación provocó un aumento de la amplitud del componente pN400FP. Por otro lado, encontramos un aumento del componente P600 para la violación de las inferencias de lugar.

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On the violation of causal, emotional, and locative inferences: An event-related potentials study

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Previous event-related potential studies have demonstrated the online generation of inferences during reading for comprehension tasks. The present study contrasted the brainwave patterns of activity to the fulfilment or violation of various types of inferences (causal, emotional, locative). Relative to inference congruent sentence endings, a typical centro-parietal N400 was elicited for the violation of causal and locative inferences. This N400 effect was initially absent for emotional inferences, most likely due to their lower cloze probability. Between 500 and 750 ms, a larger frontal positivity (pN400FP) was elicited by inference incongruent sentence endings in the causal condition. In emotional sentences, both inference congruent and incongruent endings exerted this frontally distributed late positivity. For the violation of locative inferences, the larger positivity was only marginally significant over left posterior scalp locations. Thus, not all inference eliciting sentences evoked a similar pattern of ERP responses. We interpret and discuss our results in line with recent views on what the N400, the P600 and the pN400FP brainwave potentials index.

1. Introduction

Readers are not just passive receivers of information. Good readers transcend what is explicitly stated in a text and make online inferences beyond a given message using their world-knowledge. Various taxonomies of inferences have been proposed in the literature (Kendeou, 2015). Based on the source of information activated for the inference, bridging inferences (also called text-connecting, inter-sentence, or coherence inferences) have been distinguished from elaborative inferences (also called knowledge-based or extra-textual inferences). Regarding the nature of the inferential process, a division has been made between automatic versus strategic or controlled inferences. The taxonomy by Van den Broek et al. (1993) combines both the function and the source of the information to derive the following inference types: backward inferences (e.g. anaphoric inferences), connecting inferences, reinstatements, backward elaborations, orthogonal elaborations, forward elaborations, and associations. Some authors argue that creating a taxonomy of inferences has limited value, as a basic common initial process of inference activation takes place regardless of inference type (Gerrig and O'Brien, 2005). Nevertheless, some types of inferences may have a higher likelihood of being generated than others (Gernsbacher et al., 1992, 1998; Morishima, 2015). According to Griffiths and Tenenbaum (2009), causal inferences are typically and routinely generated by humans. Thus, spontaneity (i.e., unintentionality and a lack of awareness) of causal inferences has been claimed (Hassin et al., 2002). Theories of inference generation during narrative comprehension diverge on the classes of inferences that can be drawn on-line (Graesser et al., 1994). In this regard, there is a continuum from a minimalist hypothesis (McKoon and Ratcliff, 1992) that supports the online making of the most basic inferences (such as referential, case structure, role assignment, and causal antecedent) to a promiscuous position, that postulates a very large and unconstrained set of inferences up to the author's communicative intention (Graesser et al., 2015).

There is now a growing body of studies exploring the neural correlates of inference making processes. Brain imaging techniques have found that the left inferior frontal gyrus (LIFG) and the right lingual gyrus are involved in predictive inference generation (Jin et al., 2009). Also, dorsomedial prefrontal cortex activation has been implicated in coherence building, and the left frontal lobe region has been involved in knowledge-based inferences (Ferstl, 2015).

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The Event-Related Potential (ERP) technique affords millisecond accuracy in the timing of brain processes. Studies using ERPs showed that, as a sentence unfolds, readers use the contextual constraint of the sentence and their knowledge stored in long-term memory to make online predictions in reading for comprehension tasks (Boudewyn et al., 2015; Federmeier and Kutas, 1999; Hagoort et al., 2004; Hald et al., 2007; Van Berkum et al., 2007). The amplitude of the so called N400 ERP component (a negative deflection that reaches its maximal amplitude around 400 ms post-word onset) reflects the build-up of contextual constraint over the course of a sentence (Kutas and Federmeier, 2000). Thus, in the N400 epoch (around 200–500 ms) the ERP to a word is, among other factors, affected by the position of the word in the sentence. Relatively larger N400s are elicited by words in the 2nd – 3rd position becoming progressively smaller as word position increases up to the 13th position and beyond. Whether predictions go down to the level of a particular lexical item, or there is instead a rather vague *anti*cipation of some pre-activated semantic features of the most likely upcoming word, is a matter of debate (see Boudewyn et al. (2015) and Kutas et al. (2011)). According to Boudewyn et al. (2015), specific lexical items may be activated when the context is sufficiently constraining.

In a pioneering ERP study on inference generation by St. George et al. (1997) all readers showed, overall, to be able to make bridging inferences (those required to establish coherence between two sentences in a text). Moreover, good readers (those scoring high in a Reading Span Task) additionally made elaborative or optional inferences. Thus, when the last sentence of a paragraph explicitly stated what could have been inferred from previous reading, the N400 peak amplitudes from good readers were attenuated.

Based on the claim that some inferences are more readily made than others (Graesser et al., 1994; Seifert et al., 1985) the present study aimed to explore whether the violation of different types of inferences leads to brain wave patterns of activation that diverge in amplitude, latency or distribution across the scalp. Causal coherence has been proposed to have a special status in reading comprehension (Morishima, 2015). Likewise, an ability to automatically infer a character emotional state has also been claimed (Gernsbacher et al., 1992, 1998). The debate on the automaticity of inference generation has suggested that if an inference is not drawn within a particular time-frame (200 ms), then access to stored knowledge must not be readily accessible (cited in Gernsbacher et al. (1998)). Thus, grounded on the type of world-knowledge that they activated, we selected: (1) causal inferences (e.g. *He bought a house and a new car. He had won the*…); (2) emotional prediction inferences (e.g. *Maribel no longer had relatives or friends. She felt very*…); and (3) locative inferences (e.g. *There were hens, chickens and rabbits. We were on a*…). Then, we set out to examine the brain wave responses to fulfilled (e.g. *lottery*, *lonely*, and *farm*, respectively) and unfulfilled inferences (e.g. *guitar*, *proud*, and *swimming pool*, respectively) within the same individuals.

In the following, we review various language-related ERP components that are critical to our experimental design: the N400, P600, and post-N400 frontal positivity (postN400FP).

As we mentioned above, the N400 ERP component is sensitive to the processing of information that could have been inferred from previous reading, exhibiting a reduction in its amplitude (St George et al., 1997). Similarly, the establishment of causal coherence across sentences is marked by an attenuation of the N400 response. Words that are inserted in highly causally related scenarios elicit a relatively smaller N400 in comparison to those inserted in causally unrelated scenarios (Kuperberg et al., 2010). Yang et al. (2007) showed that word-to-text integration processes occur across sentence boundaries (e.g. there is a reduction in the N400 for the phrase: 'The rain' when the prior sentence mentioned a coreferential paraphrase: 'storm').

In contrast, a study by Burkhardt (2007) showed modulations later on the P600 ERP component which generally indexes sentence reanalysis processes (see Kuperberg (2007) for a review). Specifically, an incremental reduction of P600 amplitude to the word '*pistol*' occurred in the contexts: '*Yesterday a Ph.D. student was: (1) found dead (2) killed (3) shot down downtown. The press reported that the pistol was probably*… ' Maximal reduction of P600 amplitude in response to the word '*pistol*' in the '*shot down*' condition suggests that an instrumental forward inference was most likely made before the word '*pistol*' appeared. It is intriguing why a P600 reduction rather than an N400 reduction occurred in this particular case. Authors proposed that a P600 enhancement was elicited in response to a word that represented an addition of new information to a statement made earlier (e.g. to '*pistol*' in the '*found dead*' and '*killed*' conditions).

Finally, lexical decision tasks on probe words that could have been inferred after reading a sentence elicited a combination of an attenuated N400 and a larger late positivity (P600). These effects were taken to index a causal coherence inference generation (Steele et al., 2013).

According to our experimental design, which included the processing of unexpected inference violating word endings, we must consider that, in highly constraining contexts, the processing of unexpected words sometimes elicits, besides the typical parietal N400, a subsequent post-N400 (500–900 ms) frontal positivity (pN400FP) (DeLong et al., 2011; Federmeier et al., 2007; Moreno et al., 2002). The cognitive process(es) underlying this late pN400FP effect are not yet fully established. It was first linked to the need to inhibit or suppress a pre-activated lexical item (Federmeier et al., 2007). Some researchers further suggested that the pN400FP indexes the *anti*cipation of lexical versus conceptual (N400-linked) items during sentence processing (Thornhill and Van Petten, 2012). When a causal assumption is not satisfied by reality, an N400 followed by a late positivity also emerges (Xu et al., 2015). Finally, it has been suggested that the component is related to more domain-general processes of cognitive control and conflict monitoring (Kutas et al., 2011). In a language environment, the conflict arises when readers are presumably engaged in the making of some form of prediction (more or less physical, lexical, conceptual) and their prediction/inference becomes disconfirmed by the input actually presented for reading. As Davenport and Coulson (2011) put it, this effect appears when input stimuli "defy the expectations encoded in the comprehender's situational model".

Contrasting the brainwave patterns of activity within the same participants to various types of inferences, will shed some light on the neural processes underlying inference generation processes. Overall, differences in the ERPs elicited by target words that do not fulfill an inference earlier invited to be made are expected to be characterized by an N400 and a pN400FP effect. The N400 component amplitude to unfulfilled inferences is expected to depend on the cloze probability of the items that do fulfil inferences in paper-and-pencil tests (Kutas and Hillyard, 1984). We will further examine whether, beyond cloze probability, each type of inference (causal, emotional, locative) produces N400s of different amplitude, latency or scalp distribution. In addition, violated inferences are expected to correlate with a later pN400FP effect. A priori, those inferences with stronger candidates to finish the sentence (i.e. more strongly made inferences) will show a larger pN400FP effect. Our results will be discussed in line with previous views of the cognitive processes that this component reflects (e.g. inhibition of lexical predictions and general conflict monitoring). We generally aim to establish whether a classification of inference types finds support from a brain processing perspective.

2. Methods

2.1. Participants

Twenty-six Spanish native speakers participated in the experiment in exchange for class credit. From this initial sample, one participant failed 32 out of 40 items in the final recognition test and her data were discarded. Data from five participants were also discarded because they did not contribute at least 60% artifact-free trials to one or more of the experimental conditions. The mean age of the 20 remaining participants was 19.9 (range = 18–27, *SD* = 2.22), 15 of whom were female and 3 left-handed. All participants provided informed consent to take part in the study and reported normal or corrected-to-normal vision, and no history of neurological or psychiatric disorders.

2.2. Stimuli

One hundred and fifty sentences were created (in Spanish) that supported the making of either a causal, emotional or locative inference in a subsequent sentence; 50 sentences per condition (see Appendix A). Before the ERP experiment was conducted, these two-sentence long experimental items were subjected to a cloze probability (CP) norming study with 30 participants (none of whom participated in the following ERP study). The aim was to determine, if an inference was generated, the word item that people would choose to complete the second sentence. Participants were instructed to read the first sentence and give the most likely plausible completion for the second sentence, which was left incomplete on purpose. The word with the highest cloze probability in this CP test was used as a target in the ERP study (see Table 1). Detailed results of this paper-and-pencil test are reported below in the Results section. Additionally, an incongruent version of each sentence was created by using a target word ending belonging to another sentence from within the same experimental condition (causal, emotional, locative). Two experimental lists were created such that the congruent and the incongruent versions of each sentence were assigned to either of the two lists. Therefore, participants in the ERP study never saw both the congruent and the incongruent versions of a sentence. Each participant thus read 25 incongruent and 25 congruent sentences for each inference condition. The frequency of use (Sebastián-Gallés, 2000) of the target words were similar for all congruent and incongruent endings across all inference sentences (all $ps > 0.17$).

2.3. ERP experiment procedure

Participants were tested in a single experimental session. They filled out handedness, vision and health questionnaires and were seated in front of a 19″ computer monitor at a distance of approximately 100 cm. They were pre-exposed to a short set of practice sentences to acclimate them to the reading task. They were informed that they would be given a memory test over the sentences at the conclusion of session. Sentences were always presented one word at a time in the centre of the screen in black lower-case 36-point size Arial font, on a grey background (Shade: 160, Saturation: 0, Luminescence: 187). Stim 2 (Compumedics Neuroscan, El Paso, TX, USA) was the stimuli presentation software. Each word was presented for 300 ms, with the exception of the final word of each sentence, which was presented for 500 ms. Interstimulus interval was set to 200 ms. Participants were prompted to press a button to initiate the next pair of sentences. Experimental lists 1 and 2 were randomly assigned to participants and were divided into 3 blocks of 50 sentence pairs each. Participants proceeded from one block to the next at their own pace.

After the recording session ended, participants were presented with words for 500 ms on the centre of the screen and were prompted to respond yes or no to the question of whether they had previously seen that word during the ERP session. The presentation of words was controlled by the E-Prime software package (E-Studio). A list of 40 words was selected such that 10 of the words were never seen during the experiment, and, of the remaining 30 words, 5 came from each experimental condition (causal congruent, causal incongruent, emotional congruent, emotional incongruent, locative congruent, locative incongruent).

2.4. Electrophysiological recordings and analysis

Scalp electroencephalographic activity (EEG) was recorded from 31 tin electrodes mounted in an electrode cap (Electro-Cap International, Eaton, Ohio, USA) at a sampling rate of 250 Hz, a recording bandpass of 0.01–40 Hz (Brain Amps amplifiers, Brain Products, Munich, Germany), and impedance < 5 KΩ. Electrodes were referenced online to the left mastoid and re-referenced off-line to a linked mastoid reference. Bipolar horizontal and vertical electrooculograms (EOGs) were recorded for blink correction purposes using Gratton et al.s method (Gratton et al., 1983). EEG data was processed using BrainVision Analyzer software (Brain Products, Munich). For artifact rejection purposes, the following thresholds were set: maximal allowed voltage step, 50 μV; minimal and maximal allowed amplitude, ± 100 μV; lowest allowed activity (max-min), 5 μV for a 1500 ms interval length. Once any threshold was met in the continuous EEG file, data recorded at that point were marked and discarded, together with data recorded during the 200 ms before and after the detection. This was performed to avoid including any residual artifacts in subsequent computations of ERP averages. EEG raw data from all subjects were scanned and marked using the same criteria. Five participants with less than 15 artifact-free trials in at least one of the critical conditions were excluded from analysis. For the remaining participants, 12.6% of trials were discarded and an average of 21.8 trials remained per experimental condition. A Butterworth zero phase filter was applied to the EEG data (low cutoff at 0.1 Hz, time constant = 1.6 s, 24 dB/oct; high cutoff at 20 Hz, 24 dB/oct). The continuous EEG was segmented into 1000-ms epochs starting 100 ms before the onset of the target word item. Artifact-free average waveforms were then computed for each condition separately, after subtraction of the pre-stimulus baseline.

Mean ERP amplitudes were extracted in two time windows (250–450, 500–750 ms) corresponding to N400 and post-N400 effects, respectively. These time windows were selected based on prior language processing ERP studies (Moreno et al., 2002; Wlotko and Federmeier, 2015), and after careful visual examination of waveforms. In order to test for Hemisphere and Anteriority factors, we used a selection of 20 electrodes: Fp1, F7, F3, FT7, FC3, FP2, F4, F8, FT8, FC4, TP7, CP3, P7, P3, O1, TP8, CP4, P8, P4, O2. For each time-window, a repeated-measures ANOVA was computed including the following factors: (1) Inference Type (Causal vs. Emotional vs. Locative); (2) Congruity (Congruous vs. Incongruous); (3) Anteriority (Anterior vs. Posterior); (4) Hemisphere (Left vs. Right) and Electrode (each of the five electrodes comprising an electrode quadrant). Table 2 shows the results of these overall analyses. Additional analyses were conducted at each quadrant. The goal of these analyses was to verify the distribution of effects across the scalp. We also performed ANOVAs separately for each type of Inference. In subsequent reports, all *p* values used the Huynh-Feldt correction for repeated measures with more than 1 degree of freedom. Effect sizes were computed using the partial eta-square (η_p^2) method. Relevant pair-wise comparisons are reported based on Bonferroni correction for multiple comparisons. These primary statistical analyses were carried out using IBM SPSS Statistics (version 22).

In addition, we conducted a further set of analyses using linear mixed effects modeling applied to single trial EEG data. The purpose of these analyses was to address the fact that sentence endings in the congruent Emotional inference condition on average had smaller cloze values than in the other two inference conditions. For a practical guide to mixed effects modeling as applied to EEG data, please see Payne et al. (2015). As an index of N400 amplitude, we used the mean voltage at 250–450 ms post stimulus onset for each trial, aggregated across nine centro-parietal electrode sites (C3, Cz, C4, CP3, CPz, CP4, P3, Pz, P4). Electrode sites were selected a priori on the basis of where N400 effects typically appear largest. Variance due to subject and the identity of the sentence final word were modeled using random intercepts for subject and word. Trials contaminated with artifacts were excluded from the analyses. All models were fit using maximum likelihood

Table 1
Cloze probabilities and frequency of use of congruent and incongruent endings for causal, emotional and location sentences.

		Congruent			Incongruent		
		Causal	**Emotional**	**Location**	**Causal**	**Emotional**	**Location**
Word Cloze Probability[a]	*Mean*	78.90	52.07	78.73	–	–	–
	Range	100–33.3	96.6–13.3	100–26.6	–	–	–
	SD	18.7	22.6	21.2	–	–	–
Word frequency of use	*Mean*	161.48	157.00	186.98	155.48	70.68	102.70
	Range	1159–4	1156–3	694–3	2646–4	1156–3	688–3
	SD	231.7	259.0	180.8	438.1	184.9	160.0

[a] Incongruent completions were never reported by our participants and therefore had always a cloze probability of zero.

Table 2
Overall results in the N400 and the post-N400 time-windows.

	F (250–450)	F (500–750)
Inference	2.428ns	0.918ns
Congruity	**6.933*** $I<C$	**4.520*** $I>C$
Anteriority	**10.388**** $F<P$	**13.423**** $F<P$
Hemisphere	2.584ns	**5.533*** $L<R$
Electrode	**12.773****	**36.119****
Inference* Congruity	2.175ns	0.498ns
Inference* Anteriority	**12.218****	**4.440***
Inference* Hemisphere	0.439ns	1.697ns
Inference* Electrode	**5.514****	**2.774***
Congruity* Anteriority	**5.914***	1.346ns
Congruity* Hemisphere	0.225ns	0.324ns
Congruity* Electrode	**11.347****	1.668ns
Ant* Hemisphere	0.534ns	2.553ns
Ant* Electrode	**16.846****	**38.044****
Hemisphere* Electrode	**17.383****	**28.735****
Inference* Congruity* Anteriority	1.619ns	**4.212***
Inference* Congruity* Hemisphere	1.066ns	0.194ns
Inference* Congruity* Electrode	1.579ns	2.332ns
Inference* Anteriority* Hemisphere	0.402ns	0.209ns
Inference* Anteriority* Electrode	1.959ns	2.248ns
Inference* Hemisphere* Electrode	2.229ns	0.943ns
Congruity* Anteriority* Hemisphere	**5.172***	0.118ns
Congruity* Anteriority* Electrode	**6.157****	1.009ns
Congruity* Hemisphere* Electrode	1.666ns	**4.995****
Anteriority* Hemisphere* Electrode	**29.984****	**32.826****
Inference* Congruity* Anteriority* Hemisphere	0.356ns	1.096ns
Inference* Congruity* Anteriority* Electrode	0.377ns	1.212ns
Inference* Congruity* Hemisphere* Electrode	0.571ns	1.032ns
Inference* Anteriority* Hemisphere* Electrode	**2.962****	2.063ns
Congruity* Anteriority* Hemisphere* Electrode	1.366ns	**6.166****
Inference* Congruity* Ant* Hemisphere* Electrode	1.563ns	0.768ns

ns: Non-significant, I: incongruent, C: congruent, F: frontal, P: posterior, L: left, R: right.
* $p<0.05$.
** $p<0.01$.

estimation, with the *lme4* package (Bates, 2014) in the R language for statistical computing (Cumming, 2014).

3. Results

3.1. Cloze probability norms

On average, incomplete sentences lead to the production of a congruent target word with a cloze probability of 69.9% (range: 100–13.3; SD=24.3). Congruent target words' cloze probability was lower in the emotional (52.1%) than in the causal (78.9%, $t_{98}=6.456$, $p<0.001$) and the locative (78.7%, $t_{98}=-6.08$, $p<0.001$) conditions. No difference emerged in cloze probability values between causal and locative sentence endings ($t_{98}=0.033$, $p=0.973$).

3.2. Recognition test

Participants recognized on average 68.77% of old words (Mean=20.73 out of 30; SD=3.38) and correctly rejected 11.5% of new words (Mean=1.15 out of 10; *SD*=1.01). The percentage of hits for incongruous (67.6%) and congruous (63%) sentence endings was not significantly different ($t_{568}=-1.265$, $p=0.206$). There was a higher recognition of words in the emotional (83%) relative to the causal (59.5%) and the locative (64.5%) conditions ($t_{492}=4.353$, $p<0.001$ and $t_{512}=4.400$, $p<0.001$, respectively).

3.3. ERP data

Grand average ERPs for inference congruent and incongruent sentence endings are presented in Fig. 1. As expected, incongruent endings elicited a negative-going brainwave in the 250–450 ms time-window. A Congruity by Anteriority interaction [$F(1,19)=5.914$, $p=0.025$, $\eta_p^2=0.237$] further revealed that the congruity effect was only significant over right and left posterior quadrants [Right Posterior: $F(1,19)=7.979$, $p=0.011$, $\eta_p^2=0.296$; Left Posterior: $F(1,19)=12.712$, $p=0.002$, $\eta_p^2=0.401$]. In addition, there was a main effect of Inference Type [Right Posterior: $F(2,38)=7.084$, $p=0.002$, $\eta_p^2=0.272$; Left Posterior: $F(2,38)=6.765$, $p=0.003$, $\eta_p^2=0.263$]. Post hoc tests revealed that emotional endings elicited larger negative-going brainwaves than locative endings both at the right posterior ($p=0.006$) and the left posterior ($p=0.016$) quadrants. Causal endings also elicited larger negative-going brainwaves than locative endings at the left posterior quadrant ($p=0.032$). In summary, over posterior scalp sites, where N400 effects are typically most prominent, the response was larger for: (1) inference incongruent than inference congruent endings; (2) for emotional than locative endings; (3) for causal than locative endings (over the left posterior quadrant).

In the later epoch (500–750 ms), a congruity effect was significant over posterior quadrants. Incongruent endings evoked a larger positivity relative to congruent endings [Right Posterior: $F(1,19)=4.796$, $p=0.041$, $\eta_p^2=0.202$; Left Posterior: $F(1,19)=7.271$, $p=0.014$, $\eta_p^2=0.277$]. A main effect of Inference Type emerged over frontal quadrants [Right Anterior: $F(2,38)=5.736$, $p=0.007$, $\eta_p^2=0.232$; Left Anterior: $F(2,38)=3.631$, $p=0.043$, $\eta_p^2=0.160$]. There was a significant interaction of Inference, Congruity, and Anteriority [$F(2,38)=4.212$, $p=0.029$, $\eta_p^2=0.181$]. Post hoc tests revealed that emotional endings elicited a larger positivity than locative endings at right and left anterior quadrants ($p=0.019$ and $p=0.052$, respectively). Causal endings also elicited a larger positivity than locative endings at the right anterior quadrant ($p=0.022$). In summary, a larger positivity was elicited for incongruent relative to congruent endings over posterior quadrants (P600) and a frontal post-N400 positivity was elicited for emotional and causal endings at the right anterior quadrant. Emotional endings elicited this pN400FP at the left anterior quadrant as well.

As Figs. 2 and 3 illustrate, the size and the distribution of N400 and later positive effects varied as a function of type of inference. In order to best characterize the different patterns of ERP response, we carried out separate ANOVAs for each type of inference. For each Inference Type (causal, emotional, locative) and on two time-windows (250–450 and 500–750 ms), a repeated-measures ANOVA was computed including the following factors: (1) Congruity (Congruent vs. Incongruent); (2) Anteriority (Anterior vs. Posterior); (3) Hemisphere (Left vs. Right) and Electrode (each of the five electrodes comprising an electrode quadrant). Table 3 provides a summary of results.

3.3.1. Causal inferences

The ANOVA in the 250–450 ms time-window revealed a main effect of congruity [$F(1,19)=5.282$, $p=0.033$, $\eta_p^2=0.218$] with more negative-going brainwaves (N400) for inference incongruent relative to inference congruent endings. There was a significant congruity by anteriority interaction [$F(1,19)=8.848$, $p=0.008$, $\eta_p^2=0.318$], revealing that the effect was larger over posterior (2.26 μV difference) than anterior sites (1.04 μV difference). Table 3 summarizes this and all subsequent ANOVA results. Fig. 3 shows the scalp distribution of this and all subsequently described effects.

In the 500–750 ms time range, the main effect of congruity did not reach statistical significance [$F(1,19)=3.042$, $p=0.097$, $\eta_p^2=0.138$]. The positivity was larger over the right (3.9 μV) than

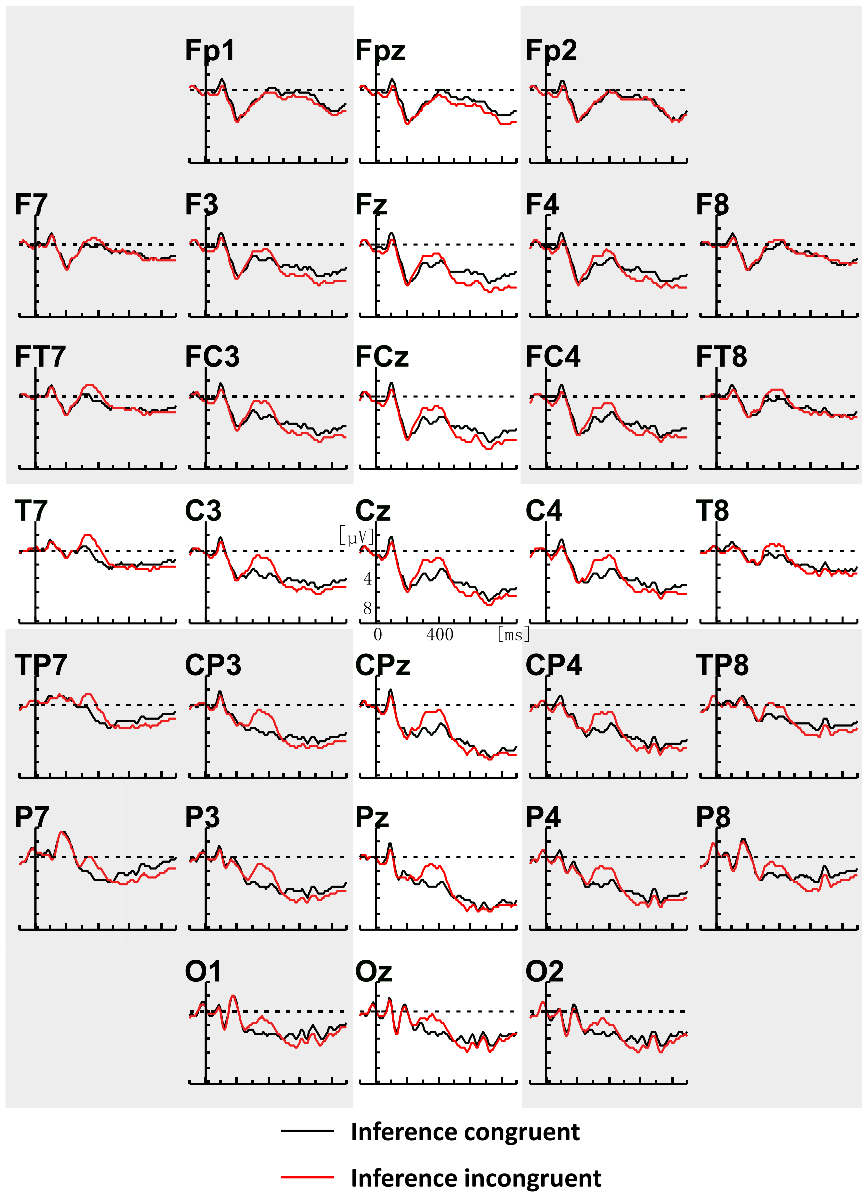

Fig. 1. Grand averages to inference congruent and incongruent endings. ERP responses time-locked to the onset of the inference congruent (black) and inference incongruent (red) sentence final word are shown. Grey shading represents electrode quadrants at which statistical analyses were further conducted. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the left hemisphere (3.2 μV) [F(1,19)=10.913, p=0.004, η_p^2=0.365] and, critically, there were significant interactions of congruity with electrode location factors [Congruity by Hemisphere by Electrode: F(4,76)=3.446, p=0.024, η_p^2=0.154 and Congruity by Hemisphere by Anteriority by Electrode: F(4,76)=6.259, p=0.001, η_p^2=0.248]. The effect of congruity was not significant at the right and left posterior quadrants (ps $>$0.2) and was marginally significant at the frontal right and left quadrants (p=0.072 and p =0.076, respectively). An ANOVA including the two frontal quartiles plus the frontal midline electrodes (Fpz, Fz and FCz) revealed a significant congruity effect [F(1,19)=4.733, p=0.042, η_p^2=0.199], with larger positivity for incongruent (4.1 μV) than congruent (2.4 μV) endings. Due to its anterior focus this congruity effect could be regarded as a pN400FP effect (see Fig. 3).

3.3.2. Emotional inferences

An N400 effect (larger negativities for incongruent than congruent endings) was not obtained for the emotional sentences [F (1,19)=0.015, p =0.905, η_p^2=0.001]; the interactions of congruity by anteriority [F(1,19)=2.482, p=0.132, η_p^2=0.116] and congruity by hemisphere [F(1,19)=0.140, p=0.712, η_p^2=0.007] were not significant. Considering the lower cloze probability for the congruent emotional endings in the paper-and-pencil tests, we carried out further analysis excluding data corresponding to sentences with very low CP (CP $<$33.3%). A total of 10 sentences were excluded from analysis, five for the congruent and five for the incongruent emotional conditions. An average of 17.4 trials still remained per experimental condition. The congruity effect then became significant over the left and right posterior quadrants [F (1,19)=12.188, p=0.002, η_p^2=0.391, and F (1,19)=7.863, p=0.011, η_p^2=0.293, respectively].

In the 500–750 ms time-window there was no effect of congruity [F(1,19)=1.832, p=0.192, η_p^2=0.088]; the interactions of congruity by anteriority [F(1,19)=1.121, p=0.732, η_p^2=0.006] and congruity by hemisphere [F(1,19)=0.068, p=0.798, η_p^2=0.004] were not significant. Fig. 4 shows the lack of a frontal congruity effect for the emotional inferences (left panel) relative to the

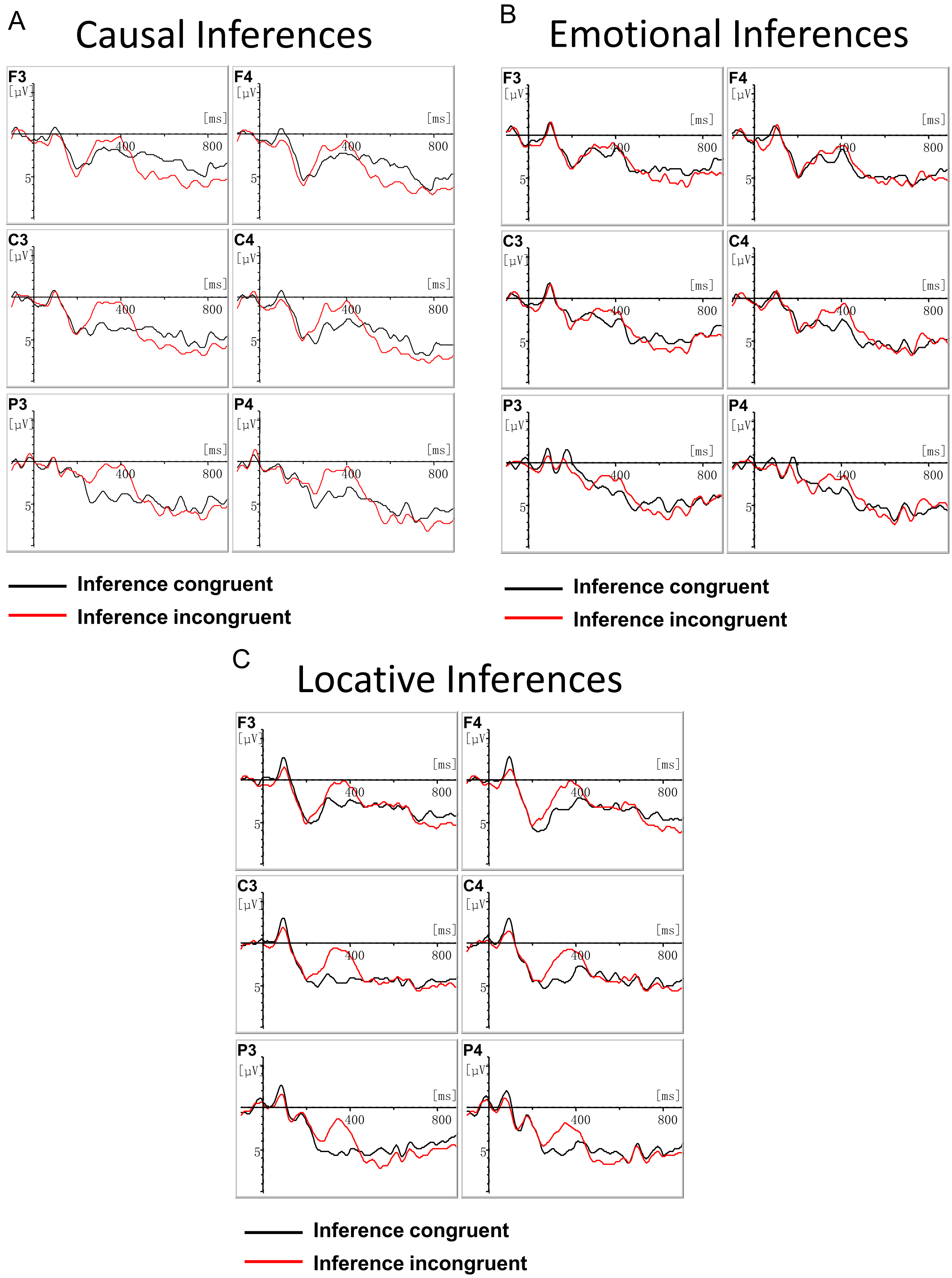

Fig. 2. Inference congruity effects for each type of inference. ERP responses to inference congruent (black) and inference incongruent (red) sentence final words are presented as a function of type of inference (2a. causal; 2b. emotional; and 2c locative). Six left and right representative electrodes are shown (front to back). Fig. 2 (b) displays grand averaged data after a manual subtraction of ERP trials with a low cloze probability value (13–33%). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

congruity effect in the causal inferences, i.e., a larger late positivity for incongruent than congruent endings (right panel).

3.3.3. *Locative inferences*

A clear N400 effect emerged for the incongruent locative condition [$F(1,19)=9.916$, $p=0.005$, $\eta_p^2=0.343$]. The N400 had a classical scalp distribution, being larger over posterior [1.8 μV difference; $F(1,19)=9.160$, $p=0.007$, $\eta_p^2=0.325$] than anterior (1.5 μV difference; $F(1,19)=7.722$, $p=0.012$, $\eta_p^2=0.289$) electrode sites.

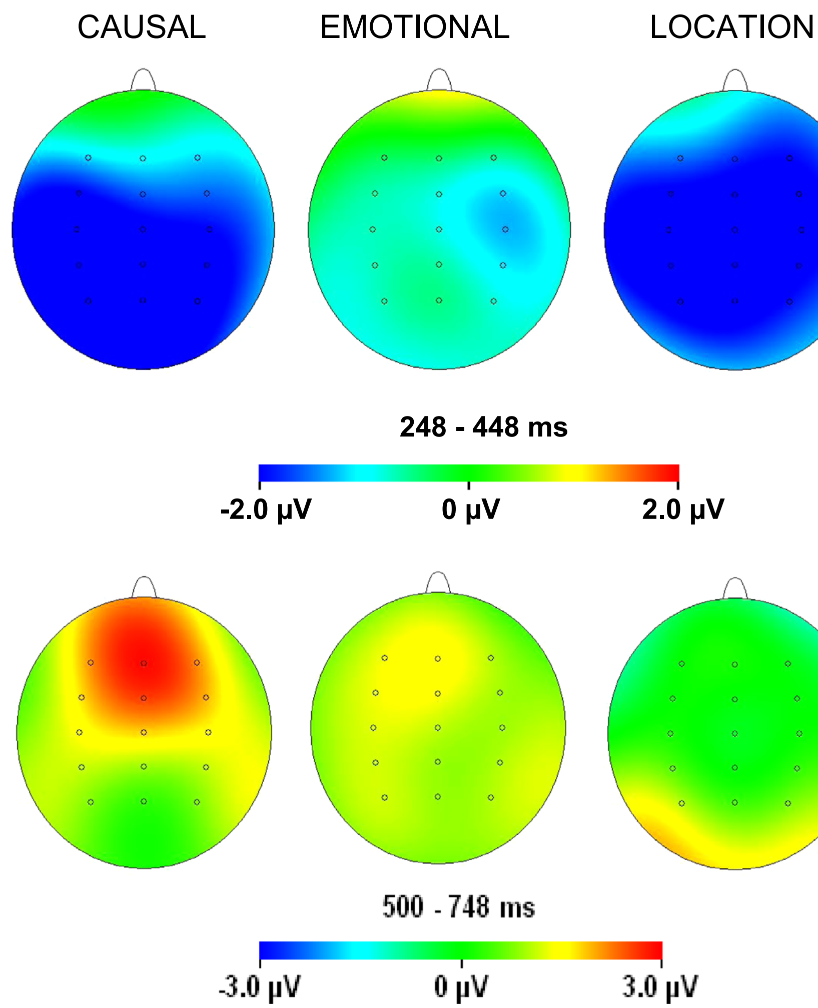

Fig. 3. Spherical spline-interpolated isovoltage maps derived from difference waveforms (inference incongruent minus inference congruent endings). Top figures show a posteriorly distributed negativity between 248 and 448 ms post-word onset for causal, emotional and locative inferences. Bottom figures show a subsequent postN400 frontal positivity (500–748 ms) for causal inferences.

No significant overall positivity emerged in the 500–750 ms time-window [F(1,19)=0.368, p=0.551, η_p^2=0.019] for incongruent locations. There was a significant interaction of congruity by anteriority [F(1,19)=7.199, p=0.015, η_p^2=0.275]. Collapsing posterior electrodes (two posterior quartiles plus midline CPz, Pz and Oz electrodes) failed to reveal significant effects [F(1,19)=2.490, p=0.131, η_p^2=0.116]. The same holds true for the collapsing of frontal electrodes (two anterior quartiles plus midline Fpz, Fz, and FCz electrodes) [F(1,19)=0.296, p=0.593, η_p^2=0.015]. However, analysis at each quartile revealed a marginally significant larger positivity for incongruent (4.67 μV) vs. congruent (3.45 μV) locatives at the left posterior quadrant [F(1,19)=3.518, p=0.076, η_p^2=0.156].

3.3.4. *Linear mixed effects modeling*

Linear mixed effects models corroborated the lack of an interaction between the effect of cloze probability and inference condition on the N400. Nested models including predictors of cloze probability, inference condition and the cloze by inference condition interaction were compared. There was a significant main effect of cloze probability (β=.015, SE=.005, Wald statistic t=3.012; likelihood ratio test statistic $\chi^2(2)$=9.024, p=.003). There was also a significant main effect of inference condition (likelihood ratio test statistic $\chi^2(2)$=7.381, p=.025), with emotional inference trials exhibiting the most numerically negative N400s, and locative inference trials the most numerically positive. However, there was no significant interaction between cloze and inference condition (likelihood ratio test statistic $\chi^2(2)$=1.515, p=.469), suggesting that emotional inferences did not elicit an attenuated N400 effect relative to the other conditions.

3.3.4.1. Summary of results. A centro-parietal N400 was elicited for the violation of causal and locative inferences relative to inference congruent sentence endings. This N400 effect was initially absent for emotional inferences. However, when low cloze probability sentences were excluded from the analysis, the N400 congruity effect emerged for emotional sentences as well. Between 500 and 750 ms, a larger frontal positivity (pN400FP) was elicited by inference incongruent sentence endings in the causal condition. For emotional sentences, both inference congruent and incongruent endings exerted this frontally distributed late positivity. For the violation of locative inferences, a larger positivity relative to inference congruent locations was only marginally significant over left posterior scalp electrodes.

4. Discussion

This study set out to examine the brainwave pattern of responses to the violation *versus* fulfilment of different types of inferences. An initial sentence invited readers to make a causal, emotional or locative inference while a second target sentence

Table 3
Effects of congruity and significant interactions with scalp location factors for causal, emotional and locative inferences.

250–450 ms	F (causal)	F (emotional)	F (locative)
Congruity	**5.282***	0.464ns	**9.916***
Anteriority	**4.871***	1.754ns	**24.377****
Hemisphere	**6.873***	1.483ns	0.918ns
Electrode	**9.914***	0.739ns	**18.003****
Congruity* Anteriority	**8.848***	1.228ns	0.160ns
Congruity* Hemisphere	1.777ns	0.137ns	0.004ns
Congruity* Electrode	**7.273***	**3.167***	**3.486***
Anteriority* Hemisphere	0.135ns	0.273ns	1.189ns
Anteriority* Electrode	**17.954****	1.121ns	**12.310****
Hemisphere* Electrode	**13.106****	**8.856****	**15.381****
Congruity* Anteriority* Hemisphere	2.730ns	0.154ns	2.145ns
Congruity* Anteriority* Electrode	1.507ns	3.027ns	**4.276***
Congruity* Hemisphere* Electrode	0.511ns	2.038ns	1.290ns
Anteriority* Hemisphere* Electrode	**21.519****	**20,904****	**31.645****
Congruity* Ant* Hemisphere* Electrode	1.934ns	0.686ns	1.582ns
500–750 ms	F (causal)	F (emotional)	F (locative)
Congruity	3.042ns	0.322ns	0.368ns
Anteriority	**10.171***	1.934ns	**11.709***
Hemisphere	**10.913***	2.332ns	2.118ns
Electrode	**32.697****	**3.657***	**30.116****
Congruity* Anteriority	0.671ns	0.285ns	**7.199***
Congruity* Hemisphere	0.018ns	1.927ns	0.173ns
Congruity* Electrode	1.464ns	0.443ns	**3.033***
Anteriority* Hemisphere	0.959ns	2.712ns	0.001ns
Anteriority* Electrode	**30.575****	**12.234****	**12.057****
Hemisphere* Electrode	**30.617****	**14.290****	**21.401****
Congruity* Anteriority* Hemisphere	0.053ns	1.045ns	2.162ns
Congruity* Anteriority* Electrode	1.710ns	0.123ns	1.617ns
Congruity* Hemisphere* Electrode	**3.446***	0.501ns	**4.294***
Anteriority* Hemisphere* Electrode	**27.629****	**60.546****	**38.457****
Congruity* Ant* Hemisphere* Electrode	**6.259***	0.537ns	2.473ns

* $p < 0.05$, ns: non significant.
** $p < 0.01$.

presented either the most likely inferred target word or an inference incongruent one. Prior to the ERP recording session, incomplete sentences were presented to readers to estimate whether participants were able to make an inference and the consensus on selecting a particular target word to finish the sentence. Based on prior ERP research on sentence reading, we selected the N400 and the post-N400 time windows to characterize the different response patterns.

Initially, the emotional inference condition did not reveal an incongruity effect in the N400 time-window. This result was, however, unclear considering that the value of cloze probability (CP) for the ending of these sentences was lower (52%) than the one to causal and locative inferences (79%) in paper-and pencil tests. For example, for sentences such as: "*The sportsman could not go one step forward. He felt*…" the incongruent emotion "*inspired*" did not elicit an N400 effect relative to the word "*exhausted,*" which had a 50% CP. Our results initially suggested that emotional incongruities or inaccuracies were not as difficult to integrate in their context as causal or locative incongruities were. However, there are at least two possible explanations for this: (1) the generation of emotional inferences in text reading is not as automatic as the generation of causal and locative inferences; and (2) the processing of emotional incongruities or inappropriate emotions does render semantic processing more difficult relative to causal or locative inappropriate statements. However, once the variability in cloze probability was controlled for, by rejecting ERP trials corresponding to low cloze probability emotional sentences, a typical N400 pattern emerged with larger N400s to emotionally incongruent versus congruent sentence endings. Moreover, linear mixed effects modelling suggested that emotional inferences did not elicit an attenuated N400 effect relative to the other conditions. Thus, our data is compatible with the view that automatic emotional state inferences were also made (Gernsbacher et al., 1998) whenever contextual constraint allowed them.

Causal and locative incongruities elicited a robust N400 enhancement with a typical posterior scalp distribution. This result reveals that these types of inferences were made by participants before they encountered the target word ending. When the word presented clashed with the most likely inference, the brain elicited a classical N400. At this time point, we observed no differences in amplitude, latency or distribution depending on whether the inference was causal or location-related in nature.

As expected, a post-N400 positivity did develop in the later latency range (500–750 ms) in response to inference incongruent sentence endings. When all incongruent endings were considered, its scalp distribution was posterior. However, further statistical tests focused on each type of inference, revealed that *causally* incongruent endings elicited this positivity over frontal sites. We regard this effect as the post-N400 frontal positivity (pN400FP) that has been observed for unexpected word items in highly constraining contexts (Federmeier et al., 2007). Several not mutually exclusive explanations have been proposed for the underlying cognitive mechanism of this effect. According to Federmeier et al. (2007) a need to suppress or inhibit a strong prediction for a different word or concept lies behind the effect. Thus, suppressing or inhibiting a causal inference such as "*lottery*" in the sentence: "*He bought a house and a new car. He had won the*…" incurs a cognitive effort or "cost" when the incongruent word ending "*guitar*" is unexpectedly presented to the reader. The later verbal item does not provide a causal link with the preceding sentence and therefore it incurs a higher processing cost. In line with Davenport and Coulson's (2011) suggestion, the unexpected word challenges the expectations earlier encoded in the comprehender's mental model.

Surprisingly, in the case of locative inferences, the late positivity for inference incongruent endings was, by contrast, only marginally significant at a left posterior region, indicative of a P600 effect instead. Thus encountering: "*swimming pool*", instead of "*farm*", after the sentence: "*There were hens, chickens, and rabbits. We were in a*…" did not incur the same brain processing costs. The implausibility of this type of incongruity most likely prevented the occurrence of a frontal pN400 effect (Federmeier et al., 2007; Van Petten and Luka, 2012). Late posterior effects in the language domain, typically regarded as the P600, have been linked to the need to repair or revise syntactically or semantically anomalous sentences (see Kuperberg (2007) for a review). Interestingly, P600 effects have also been claimed to occur only when a deeply implausible ending induces a strong conflict between the expected and unexpected event (van de Meerendonk et al., 2010). Thus, in our study, whereas *causal* incongruities incurred a need to inhibit a prediction, *locative* incongruities seem to evoke linguistic repair/revision processes to deeply implausible events. Our results, thus, reveal that different brain mechanisms are put forward for the violation of causal and locative inferences (see Van Petten and Luka (2012) for distinct scalp topographies of late positivities).

Finally, in the case of emotional sentences, no congruity effect emerged in the late time-window. It is important, however, to point out that, relative to causal and locative endings, emotional endings (both congruent and incongruent) elicited a large post-N400 at frontal sites. This enhanced amplitude can also be regarded as a pN400FP. Our result suggests that emotional outcomes, regardless of their congruity value, demand more domain-general processes of cognitive control and conflict monitoring (Kutas et al., 2011). It is remarkable that in our study, once the ERP session was over, there was a higher recognition of words in the emotional (83%) relative to the causal (59.5%) and the locative

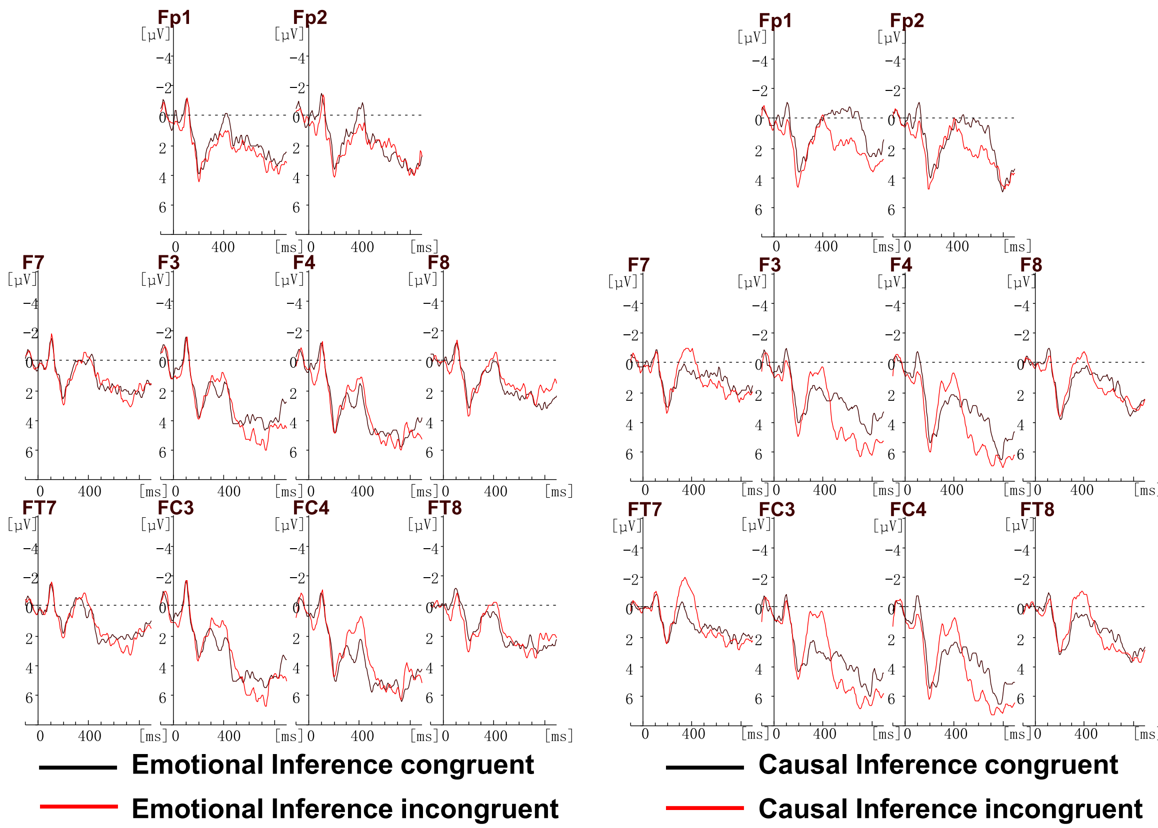

Fig. 4. Post N400 frontal-positivity in the 500–750 ms time-window. The right panel shows the congruity effect (larger positivity for incongruent relative to congruent endings) in the causal inference conditions. By contrast, the left panel shows a large positivity for both congruent and incongruent endings in the emotional condition. Left and right frontal electrode quadrants are shown.

(64.5%) conditions. The salience of emotional word items might have driven a higher recognition effect (McNeely et al., 2004). We have previously found that for sentences strongly biased towards an emotional outcome, a large postN400FP is elicited whenever an emotionally opposite outcome is encountered (Moreno and Rivera, 2014). More studies are needed to determine how sentence comprehension proceeds when emotionally charged contents come into play.

In conclusion, our participants' ERP responses indicated that, in reading for comprehension tasks, both causal and locative inferences can readily be generated before a critical word item comes in. The consequence of encountering a violation of these types of inferences is reflected by an N400 and a postN400 late positivity ERP effect. The later effect is frontally distributed for incongruent causal inferences (pN400FP) and tends to be posteriorly distributed for incongruent locations (P600). Emotional sentences were processed in a quite dissimilar way. The violation of an emotional inference only incurred an N400 effect once the cloze probability of the expected outcome was matched to that of causal and locative inferences. Thus, emotional state inferences were also made as long as contextual constraint allowed them. Furthermore, both congruent and incongruent emotional endings elicited a late pN400FP.

Together, these results suggest that all types of inferences were established and our participants were committed to generating them in advance when context allowed them. Interestingly, the differences between inference conditions arouse at the later portion (500–750 ms) of the ERP response, indicating that diverging processes are implicated in inference resolution. We need to point out that our study was not accompanied by any specific instruction to generate inferences while reading. According to the constructionist model, comprehension is to some extent directed and strategic partially based on a reader´s goals (Graesser et al., 2015). A basic automatic search for local and global coherence nicely fits our results. Regardless of being congruent or incongruent with previous contextual constraint, emotional endings seemed to engage domain-general mechanisms of control and conflict monitoring indexed by the late pN400FP.

The postulation of different types of inferences (Kendeou, 2015) finds a partial support in our study in the sense that not all inference eliciting sentences evoked a similar pattern of ERP responses. Nonetheless, the distinction between bridging (text-connecting) inferences versus elaborative (knowledge-based) inferences is unclear. Our inferences could generally be regarded as text-connecting inferences in the sense that a cause, emotion or locative word served to connect the second sentence to the previous one. However, general knowledge needed to be activated to predict or make a forward elaboration of a particular cause, emotion or location at each particular sentence. In our view, it becomes difficult to disentangle these two factors: prior text information *versus* general-knowledge contributions to the generation of inferences. Nevertheless, our study demonstrates that when inferences are made in advance, their unfulfillment provokes quite a specific pattern of brain response depending on the type of inference (causal, emotional, locative). An N400 reaction is common for causal and locative violated inferences, as well as for emotional state inferences when contextual constraint allows them. However, whereas causal inferences further elicited a frontally distributed pN400FP effect, locative inferences generated if anything a posterior positivity (P600) effect. By contrast, congruent and incongruent emotional endings generated a frontal positivity enhancement. Together, these results suggest: (1) that all inference types are readily made when contextual constraint allows them, (2) the violation of causal inferences drives an effort to inhibit the inference made whereas the violation of locative inferences appears to drive sentence repair/reanalysis processes instead; (3) emotional sentences, regardless of congruity, lead to more general monitoring processes. As far as we know, our study is the only one examining different types of inferences and their ERP correlates. A replication and elaboration of these results is necessary in order to provide a deeper understanding on how we infer different kinds of information when it is not yet explicit in a reading passage and how we make use of specific background knowledge.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.neuropsychologia.2016.04.032.

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Capítulo 6

Generación de inferencias válidas e inválidas a partir de premisas verdaderas y falsas

El tercer estudio nos permitió explorar qué ocurre a nivel neural cuando entran en competición las dos fuentes de información involucradas en la generación de inferencias: el texto y nuestro propio conocimiento del mundo. Cuando los participantes anticipaban una inferencia válida a partir de una premisa verdadera, la amplitud del N400 disminuyó. En cambio, la generación de una inferencia válida a partir de una premisa falsa propició un aumento de la amplitud del componente N400. Esto sugiere que los participantes otorgaron más peso a su propio conocimiento del mundo que a la información aportada por las premisas.

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REGULAR ARTICLE

When logical conclusions go against beliefs: an ERP study

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ABSTRACT

Reasoning is a fundamental human ability, vulnerable to error. According to behavioural measures, we are biased to consider valid the conclusion of an argument based on the veracity of the conclusion itself rather than on the formal logic of the argument. Nowadays, brain imaging techniques can be used to explore peoplés responses as they reason with linguistic materials. Using the Event-Related Potential technique in a categorical syllogism reading task, an N400 enhancement was found for the processing of invalid conclusions preceded by true premises (e.g. *All men are mortal*). By contrast, when initial premises consisted of socially prejudiced statements previously rated as false (e.g. *All blond girls are dumb*), valid rather than invalid conclusions enhanced the N400 response. Considering what the modulation of N400 indexes (i.e. word anticipation processes), our data suggests that people cannot follow the logic of an argument to anticipate upcoming words if they clash with veracity.

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Event-related potentials; language; categorical reasoning; N400

1. Introduction

Reasoning is a fundamental human ability and language is the instrument of thought. Initial statements (premises) guide our reasoning leading us to valid or invalid conclusions. Whenever it follows a correct reasoning form, an argument is said to be *valid*. Otherwise, it is an invalid argument. Additionally, to reach to a valid and also *sound* conclusion we need yet another basic ingredient: the conclusion must be drawn from *true* rather than false premises.

1.1. Erp studies on conditional reasoning

Nowadays, brain imaging techniques can be used to explore peoplés responses as they reason with linguistic materials. Remarkably, different types of arguments (e.g. categorical, propositional, transitive) have been shown to engage distinct brain networks (Prado, Chadha, & Booth, 2011). Among brain imaging techniques, Event-Related Potentials (ERPs) have an excellent time resolution of the order of milliseconds (ms). Experimental manipulations in the attentional, linguistic, or memory domain lead to amplitude increases/decreases of specific ERP components (e.g. P2, P3, N400), each of which is linked to distinctive cognitive processes. Thus, for example the N400 ERP component, peaking at around 400 milliseconds, has been linked to the ease of integration/prediction of upcoming words in discourse (Kutas & Federmeier, 2011). The smaller the amplitude of the component, the more expected the word ending of the sentence was.

To date only a few ERP studies have been conducted on deductive reasoning, mostly examining conditional reasoning. This form of reasoning involves arguments in the form of: If p then q, p, then q (Blanchette & El-Deredy, 2014; Bonnefond & Henst, 2013; Bonnefond, Kaliuzhna, Van der Henst, & De Neys, 2014; Bonnefond & Van der Henst, 2009; Qiu et al., 2007). In arguments such as: (1) If a figure is a square then it is red (2). The figure is a square (3). Therefore it is red/a square (inference vs. repetition conditions), increased negative amplitudes were elicited in the 500–700 time window and later between 1700 and 2000ms by both logically valid and invalid inferences relative to the repetition of the minor premise (Qiu et al., 2007). The earlier effect was related to the activation and the application of the inference rules, whereas the later was suggested to reflect cognitive effort to verify whether the deductive conclusions were correct. Thus, the making of an inference regardless of its validity has been linked to late ERP components. It is important, however, to point out that ERPs in this study were measured time-locked to the onset of the second minor premise and not to the processing of the conclusion itself.

Bonnefond et al. (2014) explored reasoning with more realistic semantic conditionals, such as: (1) If the butter

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warms then it melts (2). The butter warms (3). The butter melts. Their study considered that some conditions might prevent the consequent from occurring despite the presence of the antecedent, such as in: `If John studies hard, he would pass the test´. The reader can take into consideration some "disablers" for this argument: John might have a low IQ; the test could be very hard; John might not make it to the exam. Whether few or many disablers can be produced in a prior written task becomes critical. Responses to conditionals reveals a different ERP pattern at the point of the conclusion. In particular, an enhanced frontal N2 and a reduced parietal P3b effect were elicited in response to conditionals with many disablers relative to conditionals with fewer disablers, indicating that the many disablers condition made conditional conclusions harder to process. In particular, these effects were linked to the violation and satisfaction of expectations, respectively.

Finally, relative to the repetition of the premises, larger P3b and N400 effects were obtained for inference making conditions in the study by Blanchette and El-Deredy (2014). Conclusions were presented either with 2–5 words simultaneously in the screen (experiment 1) or in response to single words as follows: If dead, then morgue. Morgue. Dead. (experiment 2). According to their results, the authors concluded that inferences were drawn spontaneously before the conclusion was presented. However, in line with previous ERP studies that show an N400 reduction to words that could have been expected in previous context, a reduction rather than an increase should have been obtained for words potentially inferred from previous reading. The fact that the contrast was made in relation to the repetition of the minor premise may be crucial since word repetition has been associated with an N400 reduction (Petten, Kutas, Kluender, Mitchiner, & McIsaac, 1991).

Summarising, a limited set of studies has been conducted so far on reasoning using the ERP technique and it is difficult to integrate the existing work; every study addressed a slightly different question, examined different components, or investigated different types of reasoning, at different stages. Mostly, conditional reasoning is explored and the baseline condition is the repetition of the minor premise. Considering what the N400 ERP component indexes, we set out to explore online reasoning in the realm of categorical conclusions, where word anticipation processes are most likely to occur.

1.2. Categorical syllogisms

Categorical syllogisms are a form of deductive reasoning (Striker, 2009). They consist of three parts: a major premise, a minor premise, and a conclusion. According to philosophers, a *valid* conclusion is achieved if the syllogism *form* is correct. For example, assuming that all men are mortal (a general statement or major premise) and that Peter is a man (a particular statement or minor premise) one may validly conclude that Peter is mortal (conclusion). That conclusion does not come as a surprise and it might be anticipated by readers if the logical thread is followed. The previous example is a, so-called, affirmative "DARII" type of syllogism, since its major premise is a universal affirmative proposition (symbolised as A), while the minor premise and the conclusion are particular affirmative propositions (symbolised as I). DARII syllogisms are one of the 24 logically valid types of syllogisms, others being named: BARBARA, BOCARDO, FERIO, etc. The DARII example above, besides being a logically *valid* form of syllogism, is also a *sound* argument as both the major and minor premises happen to be true. Syllogisms, however, can be logically valid (the conclusion logically follows from the premises) but their premises may be uncertain or even false, in which case logically valid but *unsound* conclusions are attained (i.e. valid conclusions based on false premises). A critical question is whether our brains strictly follow the logic of arguments to predict upcoming words in discourse or are also influenced by the veracity of the premises during online reasoning tasks.

So far, behavioural research on categorical thinking has been committed to the understanding of the kind of errors people commit when reasoning with syllogisms. For example, the hypothesis of the *illicit conversion* of the premises (Chapman & Chapman, 1959) posits that people erroneously assume that "*All Ás are B´s*" is the same as "*All B´s are Ás*". Another source of error is called the *belief-bias effect*, according to which conclusions that seem likely are considered to be valid, irrespective of their logical validity (Evans, Barston, & Pollard, 1983). Two opposing theories were put forward: The rationality theory (Revlin, Leirer, Yopp, & Yopp, 1980) posed that people always follow logical rules and the errors they made arise at the wrong encoding of the premises. Thus, researchers claimed that we logically reason but we do so upon materials whose premises have been illicitly converted. In contrast, Evans et al. (1983) claimed that the believability in the conclusion effect still arises even in conditions in which the conversion of the premises is controlled for. According to this view, errors are still committed due to the strength of the veracity or falsity of the conclusions. Yet another theory, the mental model theory of reasoning (Johnson-Laird, 1975), posits than individuals grasp that an inference is no good if there is a counterexample to it (cited in Khemlani & Johnson-Laird, 2012). Based on the later theory, major premises might be crucial, i.e. especially when they are false universal premises (e.g. All Xs are Y). Nonetheless, a recent meta-analysis of the theories of syllogism concludes that none of them provides an adequate account of syllogistic reasoning errors (Khemlani & Johnson-Laird, 2012). A model based on formal rules of inference for human reasoning might be unable to account for recent evidence on how we process information. Human everyday reasoning, is best viewed as solving probabilistic, rather than logical, inference problems (Oaksford & Chater, 2009).

1.3. Our ERP study on categorical reasoning

When reasoning occurs with categorical syllogisms, the conclusion for a valid and a sound argument could most likely be anticipated before it appears on the screen (e.g. All men are mortal. Juan is a man. Therefore, Juan is *mortal*). Here, the response to the last word of the conclusion is critical. Since the N400 effect is an index of word anticipation processes at a semantic level (Federmeier, 2007), it is expected that the more anticipated the word, the smaller the N400 amplitude associated with it. Other language related ERP components (e.g. ELAN, LAN, P600) are, by contrast, related to expectations at a syntactic level or are indexing sentence reanalysis processes. Critically, we manipulated the value of truth (belief) assigned to the major premise (All men are mortal *versus* All blond girls are dumb) in an attempt to elucidate whether the logic of the argument was still followed even when the major premise was considered false and stereotyped.

In the ERP field, the seminal work by Kutas and Hillyard (1980) found that words that render statements senseless (e.g. He spread the warm bread with *socks*.) elicited a large negative-going voltage at the brain scalp at around 400 ms (i.e. the N400) from the onset of the critical word `*socks*´. Since then, the N400 proves to be sensitive (i.e. larger in amplitude) to words embedded in context that: (1) make untrue statements such as: "The Dutch trains are *white* and very crowded." when they are in fact yellow (Hagoort, Hald, Bastiaansen, & Petersson, 2004), and (2) make statements clash with our own beliefs, e.g. "I think the increasing emancipation of women is a *negative* development" Van Berkum, Holleman, Nieuwland, Otten, & Murre, 2009). Target words in previous examples are highlighted in italics. In recent years, the N400 is viewed as an index of a facilitatory process that takes place for words in context that are either anticipated or easier to semantically be integrated in their context (DeLong, Urbach, & Kutas, 2005; Federmeier, 2007; Kutas & Federmeier, 2011).

Our study explored the N400 phenomenon in the realm of categorical syllogisms. Valid and invalid syllogisms were presented following premises previously rated in veracity terms (as true or false major premises).

With regard to syllogisms with true premises, if participants are able to use the premises to anticipate a conclusion, we expect a smaller N400 to logically valid and sound conclusions (i.e. to the word `*mortal*´ in "Therefore, Juan is *mortal*" when preceded by "All men are mortal" and "Juan is a man") than to invalid conclusions (e.g. to the word `*man*´ in "Therefore, Juan is a *man*" after reading "All men are mortal" and "Juan is mortal"). However, if the hypothesis of the illicit conversion holds true, i.e. "All men are mortal" is erroneously taken as "All mortal are men", participants will have a difficulty to detect that the conclusion drawn in the second example is invalid, in which case they will not elicit an N400. On the contrary, if they are able to detect the misleading logic of the argument, they will elicit an N400 to invalid conclusions. However, as this is the first ERP study manipulating these variables, other ERP components might be altered at this point in the conclusion (e.g. a late positivity or P600).

With regard to syllogisms with false premises, a critical condition is the amplitude of the N400 elicited by valid-yet-*unsound* conclusions. If participants are able to follow the instruction to be solely guided by the logic of the argument, disregarding major premises veracity, they will anticipate the valid yet *unsound* conclusion (such as: Therefore, Raquel is *dumb*, after reading: All blond girls are dumb. Raquel is blond.) Anticipation would thus prevent the elicitation of an N400 response. In contrast, if the lack of veracity of the major premise is rapidly taken into consideration, as prior studies on the processing of false or morally unacceptable statements show (Hagoort et al., 2004; Van Berkum et al., 2009), participants will instead elicit an N400 to this perfectly valid yet *unsound* conclusion, thus indexing that despite the logical form of the argument, an anticipation was not carried out whenever the major premise was untrue.

2. Methods

2.1. Participants

A sample of twenty-nine native Spanish speakers (9 males, mean age = 22.5 years, range = 18–48 years) volunteered to participate in the study in exchange for course credits. All participants gave written informed consent. Twenty-seven participants reported being right handed. The average handedness score (Oldfield, 1971) was 60.8. All participants reported normal or corrected-to-normal vision and none had a history of neurological or psychiatric disorders. No participant data was excluded from analysis based on these exclusion criteria.

2.2. Materials

An initial set of experimental stimuli was created. It consisted of 280 major premises, all written in Spanish. Half of these major premises (140) began with the word "Todos" ("Todos" = All), and the other half began with the word "Ningún" ("Ningún" = No). The structure of the major premises was thus mixed in order to avoid automaticity in the responses from participants, which had to randomly alternate between affirmative (DARII) and negative (FERIO) types of syllogism. The major premises were elaborated with the aim that most people would tend to categorise them as true or false. They consisted of universal affirmative or negative propositions (e.g. All men are mortal; No obese is thin; All blond girls are dumb; No obese can be happy) (see supplemental data for a full list of major premises used as stimuli).

These major premises lead to two logically *valid* forms of syllogisms: DARII in the case of affirmative propositions and FERIO in the case of negative propositions, as follows (Table 1).

The examples in the first rows are valid and sound arguments because (1) they follow a correct form of syllogism; and (2) both premises are true. In contrast, the examples in the last row are logically valid (they follow a correct syllogism form) yet *unsound* arguments because their conclusion originates from false premises.

As a second step, in order to create similar but logically *invalid* syllogisms we used the *fallacy of the undistributed middle term* by switching the minor premise and the conclusion as follows (Table 2).

Deductive fallacies like the ones presented above, fail in the transition from general statements to specific instances. The fact that Juan is a mortal does not necessarily imply that Juan is a man. Based on the hypothesis of the illicit conversion (Chapman & Chapman, 1959), these invalid syllogisms rely on the common error of misinterpreting the major premise (that is, to take "All men are mortal" to be the same as "All mortals are men"). If that was the case, the invalid conclusion that "Juan is a man" would be taken as valid.

For major premise veracity rating purposes, all major premises were divided into four lists (70 major premises per list) and were subjected to subjective evaluation. A hundred subjects (25 per list) were asked to evaluate the major premises included in a list in terms of their veracity. Based on the idea that there are few propositions that people can hold as certainly true, or certainly false because of "most of our beliefs come in degrees" (Evans, Thompson, & Over, 2015), we used a five point rating scale. Participants chose between five different options, as follows: The statement is: 1, totally false; 2, partially false; 3, neither true nor false; 4, partially true; 5, totally true. According to the mean value of truth obtained using this procedure, all major premises were then divided into four different groups. The first group consisted of a priori "true" major premises beginning with "All" (range of value of truth = 1.48–5), the second group comprised "true" major premises starting with "No" (range of value of truth = 1.92–4.96), the third group consisted of "false" major premises beginning with "All" (range of value of truth = 1.24–3.72), and the fourth group comprised "false" major premises starting with "No" (range of value of truth = 1.04–4.6). Before the ERP experiment was setup, 30 major premises of each group were rejected based on their value of truth, not being considered highly true or highly false. The major premises with the higher value of truth were kept for groups one and two, and the major premises with the lower value of truth were kept for groups three and four, for a total of 40 sentences per group. The final values of truth for each group were as follows: group 1 (mean = 4.34; range = 3.6–5), group 2 (mean = 4.51; range = 4.12–4.96), group 3 (mean = 1.59; range = 1.24–1.92), group 4 (1.54; range = 1.04–1.84). This procedure was followed to ensure that the major premises within each group were considered as *true* or as *false* as possible.

Following a logical sequence, every major premise was continued with a minor premise and a conclusion. The major premise was always a general statement and the minor premise was a particular case related to this general statement. For example: All men are mortal (major premise); Juan is a man (minor premise); Therefore, Juan is mortal. Since we aimed to investigate brainwave responses to valid and invalid conclusions, in half of the syllogisms the order of the minor premise and

Table 1. Logically valid DARII and FERIO syllogisms with true and false premises.

Logically Valid		Affirmative (DARII)		Negative (FERIO)	
True Premises	Major premise	All men are mortal.	Universal Affirmative (A)	No obese is thin.	Universal Negative (E)
	Minor premise	Juan is a man.	Particular Affirmative (I)	Coral is obese.	Particular Affirmative (I)
	Conclusion	Therefore, Juan is a mortal.	Particular Affirmative (I)	Therefore, Coral is not thin.	Particular Negative (O)
False Premises	Major premise	All blond girls are dumb.	Universal Affirmative (A)	No obese can be happy.	Universal Negative (E)
	Minor premise	Raquel is blond.	Particular Affirmative (I)	Raúl is obese.	Particular Affirmative (I)
	Conclusion	Therefore, Raquel is dumb.	Particular Affirmative (I)	Therefore, Raúl cannot be happy.	Particular Negative (O)

Table 2. Logically invalid syllogisms (fallacies) with true and false premises.

Logically invalid		Affirmative		Negative	
True Premises	Major premise	All men are mortal.	Universal Affirmative (A)	No obese is thin.	Universal Negative (E)
	Minor premise	Juan is a mortal.	Particular Affirmative (I)	Coral is not thin.	Particular Negative OI)
	Conclusion	Therefore, Juan is a man.	Particular Affirmative (I)	Therefore, Coral is obese.	Particular Affirmative Negative (I)
False Premises	Major premise	All blond girls are dumb.	Universal Affirmative (A)	No obese can be happy.	Universal Negative (E)
	Minor premise	Raquel is dumb.	Particular Affirmative (I)	Raúl cannot be happy.	Particular Negative (OI)
	Conclusion	Therefore, Raquel is blond.	Particular Affirmative (I)	Therefore, Raúl is obese.	Particular Affirmative (OI)

the conclusion was swapped to obtain invalid conclusions. For example: All men are mortal (major premise); Juan is a mortal (minor premise); Therefore, Juan is a man (conclusion). The later would be an invalid conclusion, since the fact that "All mean are mortal" does not imply that "All mortals are men". In the previous example, Juan could be an unhuman mortal (e.g. an animal whose nickname is Juan). Thus, the conclusion that "Juan is a man" is not warranted.

Finally, syllogisms were divided into eight different groups, based on the veracity of the major premise (true or false), the type of syllogism (Starting with "All" or "No", corresponding to DARII and FERIO type of syllogisms, respectively), and the validity of the conclusion (logically valid or invalid). Table 3. exemplifies each of these group of syllogisms.

For presentation purposes, the materials were distributed in two experimental lists such that a syllogism with a logical order in the first list would have an illogical order in the second list, and vice versa. Nevertheless, the major premises were all the same for the two experimental lists. Participants were randomly assigned to experimental list 1 or 2 and the order in which syllogisms were presented within a list was randomised.

2.3. Experimental procedure

After signing informed consent, participants were fitted with encephalogram (EEG) electrodes while they filled out handedness, vision and health questionnaires. They were seated approximately 100 cm in front of a 19" computer monitor. The session began with a short set of practice stimuli to acclimate the participants to the silently reading and validity decision task. After they read the major premise, the minor premise, and the conclusion, they decided whether the conclusion was logically valid or not. We asked them to do this validity decision to ensure that they would pay attention to the conclusion of the argument. Both initial premises were presented in the screen as a full sentence. The conclusion instead appeared word by word in the centre of the screen in order to avoid eye movements and obtain a precise time-lock to the final word of the conclusion. All words in the conclusion were shown in a black 30-point lower-case Arial font on a white background. The major premise was presented in the screen for 3000 ms with an interval of 100 ms before the minor premise. The minor premise appeared in the screen for 2500 ms. Participants had to press the space bar to initiate the conclusion. Each word of the conclusion was presented for 300 ms with an inter-words interval of 300 ms. Once the conclusion was over, the participants encountered the question: "Do you think the conclusion is logically valid?". They were previously informed that conclusions might be true or false but their task was to decide whether the conclusion correctly followed from the premises. If they thought it was valid, the correct button response was A ("Yes"). If they thought

Table 3. Groups of syllogisms presented in the experiment in Spanish and their English translation (in italics).

Group	Major premise veracity	First word	Major premise	Minor premise	Conclusion	Valid/ invalid conclusion	Value of truth (mean)
1	True	Todos	Todos los hombres son mortales.	Juan es un hombre.	Por tanto, Juan es mortal.	Valid	4.34
1	*True*	*All*	*All men are mortal.*	*Juan is a man.*	*Therefore, Juan is a mortal.*	*Valid*	*4.34*
2	True	Todos	Todos los hombres son mortales.	Juan es mortal.	Por tanto, Juan es un hombre.	Invalid	4.34
2	*True*	*All*	*All men are mortal.*	*Juan is mortal.*	*Therefore, Juan is a man.*	*Invalid*	*4.34*
3	True	Ningún	Ningún obeso es delgado.	Coral es obesa.	Por tanto, Coral no es delgada.	Valid	4.51
3	*True*	*No*	*No obese is thin.*	*Coral is obese.*	*Therefore, Coral is not thin.*	*Valid*	*4.51*
4	True	Ningún	Ningún obeso es delgado.	Coral no es delgada.	Por tanto, Coral es obesa.	Invalid	4.51
4	*True*	*No*	*No obese is thin.*	*Coral is not thin.*	*Therefore, Coral is obese.*	*Invalid*	*4.51*
5	False	Todas	Todas las rubias son tontas.	Raquel es rubia.	Por tanto, Raquel es tonta.	Valid	1.59
5	*False*	*All*	*All blonde girls are dumb.*	*Raquel is blonde.*	*Therefore, Raquel is dumb.*	*Valid*	*1.59*
6	False	Todas	Todas las rubias son tontas.	Raquel es tonta.	Por tanto, Raquel es rubia.	Invalid	1.59
6	*False*	*All*	*All blonde girls are dumb.*	*Raquel is dumb.*	*Therefore, Raquel is blonde.*	*Invalid*	*1.59*
7	False	Ningún	Ningún obeso puede ser feliz.	Raúl es obeso.	Por tanto, Raúl no puede ser feliz.	Valid	1.54
7	*False*	*No*	*No obese can be happy.*	*Raúl is obese.*	*Therefore, Raúl cannot be happy.*	*Valid*	*1.54*
8	False	Ningún	Ningún obeso puede ser feliz.	Raúl no puede ser feliz.	Por tanto, Raúl es obeso.	Invalid	1.54
8	*False*	*No*	*No obese can be happy.*	*Raúl cannot be happy.*	*Therefore, Raúl is obese.*	*Invalid*	*1.54*

it was invalid, the correct button response was L ("No"). Participants read a total of 160 syllogisms, presented in random order and divided into 3 blocks, with a break between them. Break's duration was unlimited; participants decided when to start the next block. The whole session lasted about thirty-five minutes.

2.4. EEG recording and analyses

EEGs were recorded from 31 tin electrodes mounted in an electrode cap (Electro-Cap International, Eaton, Ohio, USA). Electrode impedances were kept below 5 KΩ. Electrodes were referenced online to the left mastoid, amplified with Brain Amps amplifiers (Brain Products, Munich, Germany) at a sampling rate of 250 Hz with a bandpass of 0.01–40 Hz (electrode sites included: Fp1/z/2, F7/3/z/4/8, FT7/8, FC3/z/4, T7/8, C3/z/4, TP7/8, CP3/z/4, P7/3/z/4/8, O1/z/2, and right mastoid). The electrooculographic activity (EOGs) was recorded using vertical (VEOG) and horizontal (HEOG) bipolar electrodes placed at supra-infra-orbital level of the left eye and on the outer canthus of both eyes, respectively. EEG data were analyzed with the Fieldtrip software package (http://www.ru.nl/fcdonders/fieldtrip/), a toolbox implemented in Matlab environment (The MathWorks, Natick, MA). Only trials with a correct response in the validity task were included in the analysis. The continuous sets of raw data were re-referenced to the averaged mastoids and segmented into −100 to 900 ms epochs. An *infomax* independent components analysis (Makeig, Jung, Bell, Ghahremani, & Sejnowski, 1997) was then performed to eliminate the blinks activity (Jung et al., 2000). Finally, epochs contaminated with gross artefacts were rejected following a z-value visual inspection criteria, a semiautomatic procedure implemented in Fieldtrip. The signal was down pass filtered with a low cut-off at 20 Hz and the activity in the −100 to 900-ms epochs was adjusted to the baseline activity (−100 ms). ERP responses were then assessed using a nonparametric cluster-based random permutation analysis approach (Maris & Oostenveld, 2007). A mass-univariate approach is computed at each spatial and temporal point (Oostenveld et al. 2011). While this approach overrides the problem of a priori choosing locations and/or components, it results in an extremely large number of statistical tests which increase the probability of obtaining false positive results (type 1 error rate). A variety of methods exist to deal with the type 1 error, such as the Bonferroni correction. However, in the context of ERP data, the Bonferroni method is excessively conservative. A popular method to control for the multiple comparison problem is non-parametric statistics. Here we use permutation tests (random shuffles of the data) to obtain the sampling distribution of the test statistic under the null hypothesis. Specifically, permutation tests were used to compute the sampling distribution of a cluster-based statistic. Cluster-based statistics consist in grouping together spatial and temporal adjacent variables (t or F values for instance) into clusters. The cluster statistic can be defined by its maximal value, extension or a combination of both (Maris & Oostenveld, 2007).Thus, the timing and topographic distributions of logical validity effects for conclusions preceded by true and false major premises was analyzed. The analytic steps were as follows. First, a simple dependent-samples t-test for each contrast (invalid vs. valid conclusions from true premises and invalid vs. valid conclusions from false premises) was performed at each time-electrode pair. *P*-values below 0.05 were used to form clusters of adjacent time points and electrodes. A minimum of two channels were used to form a cluster. Cluster-level test statistic was calculated by taking the sum of all the individual t-statistics within that cluster. Then, a null distribution was created by computing 1000 randomised cluster-level test statistics. Finally, the actually observed cluster-level test statistics were compared against the null distribution and only clusters falling in the highest or lowest 2.5th percentile were considered significant. This procedure allows for the identification of the spatial distribution of validity effects and could effectively handle the multiple-comparisons problem. For significant interactions, we tested our directed hypothesis with respect to a validity. effect (i.e. larger amplitudes for invalid compared to valid conclusions) using one tailed paired t-tests as planned comparisons.

3. Results

3.1. Behavioural Results

The behavioural data were analyzed using the statistical programme SPSS IBM 22 version (International Business Machines Corp., Armonk, New York, USA). To examine how the type of syllogism, the veracity of the major premise, and the validity of the conclusion influenced the accuracy in the validity task, the number of errors was analyzed for each participant with a mixed factorial design (repeated measures ANOVA) including three within-subject factors (two levels): SYLLOGISM (DARII VS. FERIO), VERACITY (true and false) and VALIDITY (valid and invalid). Whenever the sphericity was violated, we applied the Greenhouse and Geisser (1959) epsilon (ε) correction for degrees of freedom of the within-subject measures. Interaction effects were explored with planned pairwise comparisons. All post-hoc pairwise contrasts were performed and corrected for multiple comparisons by means of the Bonferroni procedure establishing a significance level of $\alpha = 0.05$.

Overall participants were highly accurate in the validity decision task for conclusions following both true (92.5%) and false (91.9%) major premises. The analysis of the number of errors (say logically valid when the syllogism was invalid or say logically invalid when the syllogism was valid) revealed a main effect of Validity [$F(1,28) = 6.86$, $p = 0.014$, $\eta_p^2 = 0.19$], with fewer errors for valid (0.8) than invalid syllogisms (2.2). There was also a main effect of Type of syllogism [$F(1,28) = 9.87$, $p = 0.004$, $\eta_p^2 = 0.26$], with a higher number of errors for negative FERIO (1.7) than affirmative DARII syllogisms (1.3). There was also a significant interaction between Veracity and Validity [$F(1,28) = 8.85$, $p = 0.006$, $\eta_p^2 = 0.24$]. Post-hoc comparisons revealed significantly more errors for true invalid (5.2) and false invalid (3.8) than for true valid (0.8) syllogisms ($t = -4.22$, $p < 0.001$ and $t = -3.16$, $p = 0.004$); and between true (5.2) and false (3.8) invalid syllogisms ($t = 3.97$, $p < 0.001$). Thus, when the syllogisms were invalid, true premises made them more acceptable as valid (more errors) relative to when they followed false premises (fewer errors). The ANOVA revealed as well a significant interaction between the Veracity of the major premise and the Type of syllogism [$F(1,28) = 9.83$, $p = 0.004$, $\eta_p^2 = 0.26$]. The comparison between true DARII (affirmative) syllogisms and true FERIO (negative) syllogisms revealed a significant difference ($t = -4.38$, $p < 0.001$) in the number of errors committed. Participants made more mistakes when encountering a true negative (FERIO) syllogisms (3.8) than when encountering a true affirmative (DARIO) syllogisms (2.1). There was also a significant triple interaction between the three factors (Veracity, Validity and Type of Syllogism) [$F(1,28) = 13.62$, $p = 0.001$, $\eta_p^2 = 0.32$]. The multiple comparisons showed that most errors were committed for FERIO invalid syllogisms that had followed true premises. They tended to be responded to as logically valid.

Given the high accuracy in the validity task, no participant's ERP data was rejected based on a poor performance. However, individual trials with an incorrect response were rejected for further ERP computations.

3.2. Event-Related Potentials Results

The cluster-based permutation test revealed that the main effect of Veracity was significant [$p = .001$]. This effect appeared between 350 and 480 ms and was distributed over fronto-central scalp electrodes. Specifically, conclusions derived from true premises had larger negative-going amplitudes than conclusions derived from false premises. The main effects of Validity and Type of syllogism were not significant [$p > .014$]. However, Validity showed a significant interaction with Veracity [$p < .05$] in the 380–512 ms time-window over centro-posterior electrodes. Planned comparisons showed that, after true premises, invalid conclusions elicited larger negative going responses than valid conclusions [$t = -3.3200$; $p = .0013$]. In contrast, after false premises, valid conclusions elicited a larger negativity than invalid conclusions [$t = 1.7316$; $p = .0469$] (Figure 1).

3.3. Moral acceptability ratings

Given that the false major premises in our study were often associated with stereotyped social prejudices (e.g. All blond girls are dumb, All Jewish are greedy, All men are sexist) post hoc measures were obtained on the "moral" acceptability of each conclusion. Forty five volunteers, who did not take part in the ERP study, used a 1 to 5-point scale to indicate subjectively whether the conclusion was morally unacceptable (1), morally acceptable (5), or anywhere in between. A 2 by 2 ANOVA revealed a main effect of Veracity [$F(1,79) = 11.26$, $p = 0.001$, $\eta_p^2 = 0.125$], with conclusions from true premises more morally acceptable (3.42) than the ones from false premises (3.29). Note that in both cases, conclusions were on average rated in the middle range of morality (3.5 in a 1 to 5-point scale), that is neither moral nor immoral. Critically and in contrast to ERP measurements, the interaction of Veracity and Validity for the judgment of the conclusiońs morality was not significant [$F(1,79) = 0.86$, $p = 0.356$, $\eta_p^2 = 0.48$].

4. Discussion

Our experiment examined the electrical brain activity linked to online syllogistic reasoning with semantic materials. The value of veracity assigned to major premises (true or false) and the logic of the argument (valid or invalid) were manipulated.

For invalid arguments based on true premises and for valid arguments based on false premises, visual inspection suggested that the brain response to the last word of the conclusion elicited a negative-going voltage deflection at around 400 ms (N400). According to cluster-based random permutation analysis, two independent clusters of electrodes became significant at roughly the similar time window (350–480 and 380–512 ms). The first was a fronto-central cluster showing larger negative amplitudes for conclusions after true versus false premises. Its distribution does not correspond to the classical N400 effect and therefore, we will not treat it as an N400 effect. A validity by veracity interaction effect was somewhat delayed (350–475 ms) with respect to common ERP studies of reading for comprehension tasks (Kutas & Federmeier, 2000).

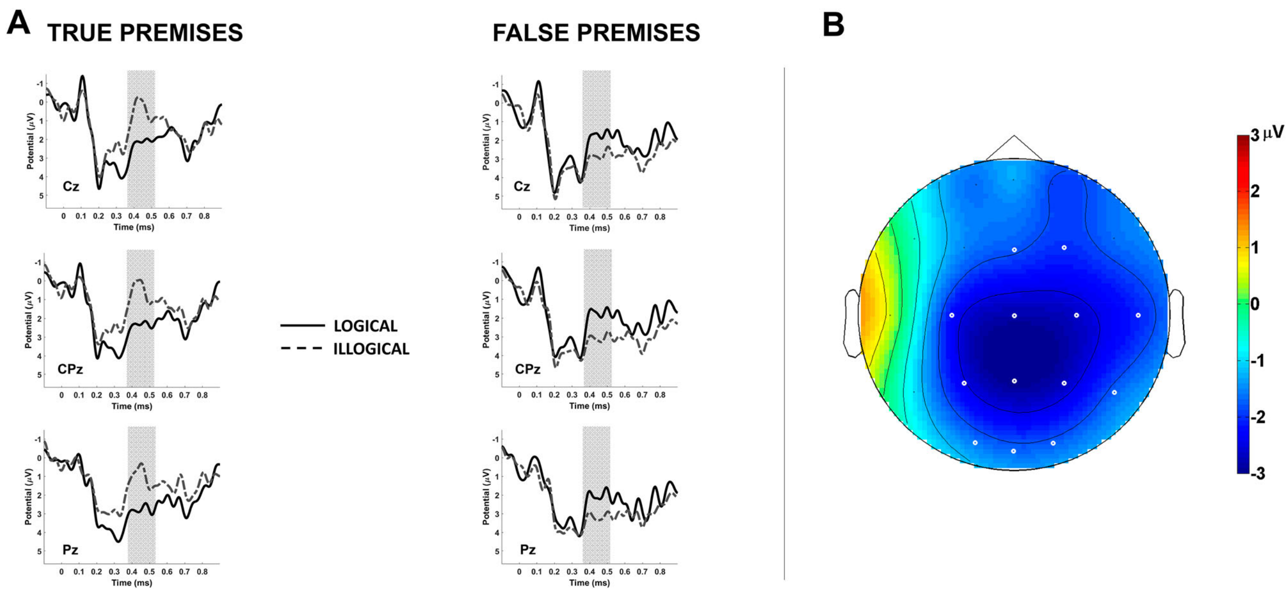

Figure 1. (A) Grand averaged ERP response to the final conclusion of syllogisms when true (left) or false (right) major premises preceded at three representative electrodes (Cz, CPz, Pz) Solid lines represent the response to logically valid conclusions. Dashed lines depict the response to logically invalid conclusions. According to cluster-based computation analysis, the shaded grey area indicates where conditions statistically differed, in the 380–512 ms time-window. (B) Topographical map of voltage. The ERP response to valid conclusions was subtracted from the one to invalid conclusions. The plot represents the difference between validity effects in true and false conditions. The set of electrodes included in the significant cluster are marked as white circles. A typical N400 centro-parietal distribution is observed.

Nonetheless, its topographical distribution followed the typical posterior, slightly skewed to the right, maximal amplitude (see Figure 1(B)). Interestingly, the direction of this effect varied depending on the interaction of Veracity and Validity (see Figure 1(A)).

As expected, when major initial premises were true (e.g. All men are mortal), a larger N400 was elicited for invalid (e.g. Therefore, Juan is a *man*) relative to valid conclusions (e.g. Therefore, Juan is *mortal*). According to recent views on what the N400 indexes (Kutas & Federmeier, 2011), for true premises, participants were able to anticipate the ending of the conclusion thereby reducing the N400 component to valid conclusions. In contrast, participants were troubled by the ending word in an invalid syllogism, eliciting a larger N400 response. Thus, we found a significant effect of validity for categorical syllogisms stemming from true premises, indicating that participants were able to follow the rules of logic to anticipate conclusions. This result was expected based on previous N400 literature. It, however, contrasts with the results obtained by Blanchette and El-Deredy (2014). These authors found increased N400s to any inference making conditions relative to baseline (i.e. the repetition of the minor premise). In addition, our results do not support the hypothesis of the illicit conversion of the premises (Chapman & Chapman, 1959). If conversion had occurred (If e.g. All men are mortal was taken as the same as All mortals are men), no N400 enhancement would have been present for the invalid conclusion.

Counterintuitively, when initial premises were previously assessed as false (e.g. All blond girls are dumb) a larger N400 was elicited for valid relative to invalid conclusions. Thus, the effect of validity for syllogisms with false premises went in the opposite direction (larger N400s for valid than invalid conclusions) relative to the syllogisms based on true premises. Despite we asked our participants to focus on the logic of the argument by responding whether the conclusion followed logically, their brains reacted with an N400 enhancement to logically valid conclusions drawn from false major premises as if they had not anticipated the "logical" conclusion. In line with one of our hypothesis, word anticipation processes seemed to not be followed whenever the major premise hold untrue. In one case, it was precisely the valid conclusions the ones enhancing the N400 response. In the other case, for invalid conclusions, no N400 was elicited. Therefore, valid yet based on false premises arguments resulted in a difficulty of semantic integration or were not previously anticipated by participants even though the reasoning form was a correct one. In this sense, the interference of beliefs in our logical thinking capacity is supported by our online electrophysiological measures. Previous behavioural studies examined this type of interference. However, they focused on the veracity of the conclusion itself (Evans et al., 1983; Revlin et al., 1980). Our study shows that the veracity of the major premise of an argument also influences the response to the processing of the conclusion. This result is difficult to reconcile with the rationality theory (Revlin et al., 1980) that holds that people always follow logical rules. According to this theory, the errors people commit arise by virtue of the wrong encoding of the premises (e.g. illicit conversion). However, when belief in the major premise is manipulated as in our study, beliefs make the processing of valid yet unsound conclusions difficult to process. Thus, logical reasoning is not independent of the veracity of the major premises and their value of truth.

As we mentioned in the introduction, the processing of false statements has previously shown to raise the amplitude of the N400 (ej. Hagoort et al., 2004). However, our study does not record the response to the word of a sentence that makes a statement untrue. Instead, it presents an initial true or false statement and allows people to keep on reading upstreaming minor premises and their logical/illogical conclusions. The question was whether the correct logic of the argument will make the response to the final conclusion be anticipated even if the initial premise was false (or prejudiced, as we will discuss later). Since the N400 indexes whether upcoming words in discourse could have been anticipated before they appeared on the screen, we were able to determine that logical yet based on false premises conclusions were not anticipated by our participants. The increased amplitude in the N400 time-window for valid versus invalid conclusions of false statements, indicated that they were not anticipated. Therefore, an N400 was still elicited by the highly plausible target word ending "dumb" despite the reasoning threat was a logically correct one. So to say, the inertia to anticipate upcoming words in discourse was overridden by a necessity to believe in the initial major premise. In this regard, our result extends previous results on the brain response to untrue statements themselves (Hagoort et al., 2004). A perfectly logical and a priori capable of being anticipated ending does however elicit an N400 response in so far as it is preceded by a false or prejudiced statement. On the other hand, when the conclusion was both invalid and based on false premises, an N400 was surprisingly not elicited. We speculate that after reading the second minor premise, participants might have realised that the syllogism did not follow logical rules and they stopped anticipating how it would finish. Future studies are needed to clarify this point.

Finally, it is important to consider that our design included true and false statements that not only differed in veracity rating terms. Some of the statements rated as false by our participants included socially prejudiced statements (e.g. All blond girls are dumb, All Jews are greedy, All men are sexist). This is due to the fact that making false universal categorical statements (i.e. starting with "All") often led to such socially prejudiced statements. Consequently, a limitation of our study is a potential confound with the conclusiońs morality. Under those conditions, participants could have elicited an N400 response to the logical conclusion not only grounded on the falsity of the initial premises but also on the "moral" unacceptability of the conclusion (see Van Berkum et al., 2009). However, post hoc analysis on the "moral" acceptability of the conclusions revealed that there was no interaction between veracity and validity. Conclusions from false statements, whether valid or invalid, were rated slightly more immoral than the ones from true statements. Note, however, that neither of them was considered to be high in immorality (i.e. which would have corresponded to scores closer to 1 in our morality scale). Moreover, if morality *per se* had an impact on ERP responses, the largest N400 would have been elicited for conclusions from false premises regardless of their validity. In contrast, the N400 results obtained showed no main effects of veracity. Only the interaction between these factors was significant. For true premises, the largest N400 was elicited by invalid syllogisms whereas for false premises, the largest N400 was elicited for valid syllogisms.

Our study suggests that among the theories of syllogistic reasoning (Khemlani & Johnson-Laird, 2012), the mental model theory of reasoning (Johnson-Laird, 1975) is the best to fit the ERP pattern of results. This theory posits than individuals grasp that an inference is no good if there is a counterexample to it (cited in Khemlani & Johnson-Laird, 2012). Participants in our study potentially found counterexamples to the false major premises (e.g. intelligent blond girls) and, as a consequence, they had difficulties to process a conclusion that despite being drawn on perfectly logical grounds disregarded veracity, relative to the condition in which the initial major premise was considered both valid and true.

With regard to the type of syllogism, behavioural errors in the validity judgment task significantly increased for FERIO relative to DARII syllogisms. However, whether affirmative or negative propositions were used (DARII and FERIO syllogisms, respectively) had no main effect, nor interactions with other factors in terms of ERP response.

In conclusion, human brains are rational: they do react to invalid conclusions drawn from true premises. However, in line with previous ERP studies (Hagoort et al., 2004; Van Berkum et al., 2009) human brains are also knowledge-biased during online categorical thinking: we cannot conceive of a valid argument if it clashes with our previous world knowledge and beliefs. The ERP technique is a useful tool to explore online reasoning with semantic materials. Our study reveals how prior beliefs, mostly related to socially unacceptable statements, override the anticipation of logical conclusions, in particular the processing of valid conclusions that are, however, grounded on false major premises.

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Capítulo 7

Influencia del estado de ánimo en la generación de inferencias

El cuarto y último estudio de la tesis doctoral pretende explorar cómo afectan aspectos extralingüísticos, tales como el estado de ánimo, en la generación de inferencias. Los participantes bajo un estado de ánimo negativo, en comparación con un estado de ánimo neutro, requerían de un esfuerzo cognitivo menor para anticipar inferencias válidas, evidenciado por la disminución de la amplitud del componente N400, frente a la anticipación de inferencias inválidas.

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Please be logical, I am in a bad mood: An electrophysiological study of mood effects on reasoning

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ABSTRACT

Several behavioral studies have reported a detrimental effect of emotion on reasoning tasks, either when the content of the reasoning and/or the mood state of the individual are emotionally loaded. However, the neural mechanisms involved in this phenomena remain largely unexplored. In an event-related potentials (ERPs) study, we examined the consequences of an induced mood over the electrophysiological signals obtained while processing logical and illogical categorical conclusions. Prior to performing a syllogism reading task, we aimed to induce, by using short film clips, high arousal negative and positive moods and neutral affective states to participants in three separate recording sessions. Our mood induction procedure was only successful at inducing a highly arousing negative state. Behaviorally, participants committed more errors overall while judging the invalidity versus the validity of illogical and logical conclusions, respectively, but no influences from mood state emerged at this logical validity task. Electrophysiologically and overall a negative going N400 deflection was larger for illogical relative to logical conclusions in a parietal region between 300 and 420 ms. However, further analysis revealed that the logical conclusions were only more expected (smaller N400 amplitudes) in the negative relative to the neutral and the positive sessions, providing support to theoretical views that posit that a more analytic reasoning style might be implemented under a negative mood state. These results provide further electrophysiological evidence of the influence of mood on other cognitive processes, particularly on the anticipation and processing of logical conclusions during online reasoning tasks.

1. Introduction

Reasoning is the psychological process through which individuals organize, structure, and draw inferences from information (Blanchette, 2014). The dual process model of reasoning postulates a distinction between heuristic (implicit, automatic, associative, and intuitive) and analytic processes (more effortful, explicit, rule-based, and slower) (Evans, 2003). Just like for other cognitive processes such as attention, perception, memory, and problem solving, reasoning has been found to be influenced by emotional content and emotional state (see review by Blanchette and Richards, 2010). Working memory load (i.e., requirement of additional cognitive resources to process emotional information) has been proposed as one of the potential mechanisms mediating this interference of emotion on logical reasoning tasks (Tremoliere et al., 2016, 2018).

Formal logical reasoning has been shown to be impaired (prompted to error) both when the content of the matter is emotional versus neutral (Blanchette and Richards, 2004; Lefford, 1946; Tremoliere et al., 2016) and also under negative and positive induced emotional states (e.g. Jung et al., 2014; Melton, 1995; Salovey, 1993).

Despite early studies on emotion and reasoning led to the simplified conclusion that "emotion leads to faulty reasoning", recent studies suggest that the interplay between emotion and reasoning is more nuanced and complex (Blanchette, 2014). For example, emotion can lead to better, not worse, logical reasoning as it may facilitate access to relevant information during reasoning (Gangemi et al., 2014). Moreover, rather than postulating whether reasoning is either right or wrong under emotional conditions, some authors posit that mood influences an overall individual's processing style. In their own words, 'being happy or sad influences the content and style of thought' (Clore and Huntsinger, 2007). The mood-influenced cognitive styles hypothesis (also called the affect-as-information hypothesis) suggests that, generally speaking, positive mood is associated with a more global and flexible processing mode that relies on heuristics (Ruder and Bless, 2003), whereas negative mood is thought to promote a relatively analytical, careful and effortful processing style (Clore and Huntsinger,

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2007). This view, has however been challenged by a recent review (Huntsinger and Clore, 2014) that posits that positive affect may also lead to detailed processing and a narrowed focus, and negative affect may lead to heuristic processing and broadened focus.

From an anatomical perspective, even in the absence of behavioral effects (a similar accuracy in logical decision tasks under different emotionally induced conditions) some functional Magnetic Resonance Imaging (fMRI) studies reveal the existence of mood-dependent differences with regard to the pattern of brain activations at the time of syllogistic reasoning (Smith et al., 2015, 2014). Other fMRI studies found a worse behavioral performance in syllogisms together with a lateral/dorsolateral prefrontal cortex (lat/dlPFc) increased activation under negative mood conditions (Brunetti et al., 2014). Thus, brain imaging studies point to a differential recruitment of brain areas for reasoning under the influence of a negative mood, but it is not clear yet when, if so, emotional state exerts its influence upon reasoning tasks.

In recent years, the Event-Related Potential (ERP) technique has been used to examine the online processing of both conditional (Blanchette and El-Deredy, 2014; Bonnefond and Henst, 2013; Bonnefond et al., 2014; Bonnefond and Van der Henst, 2009; Qiu et al., 2007) and categorical reasoning (Rodríguez-Gómez et al., 2018). Conditional reasoning uses arguments in the form: “If you water the plants, then they will grow; You water the plants; The plants grow.” (i.e., the “Modus Ponens” argument form), whereas categorical reasoning uses syllogisms such as: “All cats are mammals. All mammals have lungs. Therefore, all cats have lungs”. In both cases, reading the argument and following its logic allows the reader to most likely anticipate the last word of the conclusion (grow and lungs, in previous examples). The ERP technique, with a high temporal resolution, allows to examine the time course at which a variable such as emotion can exert its influence over an ongoing process, in our case, a reading for comprehension task.

The study by Blanchette and El-Deredy (2014) manipulated the emotionality of the verbal content upon which conditional reasoning was performed (e.g. If a country is at war, then people die; Britain is at war; British people have died). They found that emotional content had no influence on early ERP components, nor interaction with inference making ERP responses at middle time ranges (N400) and only marginal main effects at late latencies (800–1050 ms). The authors concluded that the effect of emotional content on conditional reasoning “might occur after actual inference making has taken place, maybe at the stage of conclusion maintenance, or response selection” (Blanchette and El-Deredy, 2014).

In contrast, the temporal dynamics of an individual's emotional state upon reasoning tasks with emotionally neutral materials remains unexplored. We carried out an adaptation of a previous ERP study on categorical reasoning (Rodríguez-Gómez et al., 2018). In the original study we were interested in the processing of syllogisms conclusions as a function of whether the major premises of the syllogism had previously been rated as true or false. In the condition in which the major premises had been rated as true, illogical conclusions lead to an increase of the N400 ERP component (between 380 and 512 ms) compared to logical ones. The N400 ERP component was first discovered as the response to words that render a sentence semantically incongruent (i.e. a nonsense word) (Kutas and Hillyard, 1980a, 1980b). Nowadays, a reduction of amplitude of the N400 is best viewed as an index of a facilitatory process for word items that could have been pre-activated or anticipated based on prior contextual constraints (Federmeier, 2007; Federmeier and Kutas, 1999).

Thus, according to N400 functional significance (Kutas and Federmeier, 2011), our result demonstrated that in the context of a reading task participants were most likely to anticipate logical rather than illogical conclusions as far as the major premises held true. Considering prior literature on how an emotional state might alter an individual's cognitive load, attentional resources and reasoning style, we replicated this part of the study manipulating current mood in three separate sessions. A large number of emotion-elicitation techniques have been used so far to induce emotional states: exposure to emotional slides (Bradley and Lang, 2000; Schaefer et al., 2009), autobiographical recollection (Schaefer and Philippot, 2005), mental imagery (Schaefer et al., 2003; Vrana et al., 1986), Velten mood-induction technique (Velten, 1968), facial feedback (Matsumoto, 1987), respiratory feedback (Philippot et al., 2002), and real-life techniques (Landis, 1924; Stemmler et al., 2001), but viewing emotional clips was chosen as it is one of the most commonly used and effective procedures to induce mood in participants (Gerrards-Hesse et al., 1994; Gross and Levenson, 1995; Schaefer et al., 2010; Westermann et al., 1996; Zhang et al., 2014).

Behaviorally, our results could either match those studies in which emotional states prompted to more errors in logical decision tasks (Jung et al., 2014) or those who failed to find such mood-related effects on logicality error rates (Smith et al., 2014).

Regarding brainwave responses, the study by Blanchette and El-Deredy (2014) only found a late marginal effect of emotional content during conditional reasoning. We aim to determine whether emotional state, in contrast, influences reasoning (i.e. categorical) and the time-course at which it might exert its influence, if any. Prior ERP work has shown that an induced positive mood facilitates the integration (smaller N400) of more distantly related semantic information during sentence comprehension (Federmeier et al., 2001; Pinheiro et al., 2013). However, influences of a negative mood have also been described (Chwilla et al., 2011), with a reduction of the N400 cloze probability effect (i.e. a reduction of the commonly larger N400 to low vs. high cloze probability target words embedded in sentences). Using ERP measurements, other linguistic phenomena have also been described to be mood-dependent, such as a better referential anticipation under a happy versus a sad mood (Van Berkum et al., 2013) or a better sensitivity to semantic reversals under a happy than a sad mood (Vissers et al., 2013). The results of these studies indicate that indeed mood is able to influence processes of language comprehension. The question is whether these mood effects also arise during the anticipation of conclusions for categorical syllogisms (reasoning), and whether the influence is early (at the stage of semantic integration) or late (at the stage of reanalysis processes). As we saw, the latter is the finding for conditional reasoning with emotional vs. neutral content (Blanchette and El-Deredy, 2014).

In summary, the goal of the current ERP study is to provide a direct test of the effects of mood state on categorical reasoning, particularly on whether the logical conclusion might have better be anticipated under the influence of a particular induced mood or alternatively whether the response to illogical conclusion is enhanced for a particular mood state. To achieve this purpose, we tried to induce positive, negative and neutral moods using short-duration videos in three different recording sessions. Subsequently, participants were engaged in a silent reading task of categorical syllogisms, while they were asked to decide whether the logical conclusion followed from prior premises.

Based on the results of the studies reviewed here and on theoretical accounts that posit that reasoning style is more analytic under a negative mood (Clore and Huntsinger, 2007), we expect to obtain a smaller N400 to logical conclusions under a negative mood, indicating that it facilitates anticipation of logically valid analytical conclusions. Likewise, if positive mood is associated with a more global and flexible processing mode that relies on heuristics (Ruder and Bless, 2003), the ERP response to illogical conclusions under a positive mood might show a reduced N400 response indicating that they became more acceptable. Alternatively, the influence of emotional state in online reasoning tasks might only be manifested in later ERP components in line with the study on conditional reasoning with emotional content that was conducted by Blanchette and El-Deredy (2014).

2. Materials and methods

2.1. Participants

Thirty native Spanish speakers (27 females, mean age = 19.6 years, range = 18–29 years) volunteered to participate in the study in exchange for course credits. All participants gave written informed consent. All except for one reported being right handed. The average handedness score (Oldfield, 1971) was + 78.8 (range, + 100 to − 44.4). All participants reported normal or corrected-to-normal vision and none had a history of neurological or psychiatric disorders.

2.2. Stimuli

Twelve clips of about 40'' each were selected and divided into three groups according to the emotion they elicit: positive, negative and neutral clips. Positive clips were collected from the database by Carvalho et al. (2012) and consisted of different heterosexual couples engaged in sexual intercourse (with no genitalia exposure). We decided to include this videos in our experimental design because they are assessed as the most arousing and pleasant ones (Lang et al., 1990, 1998, 1997). The negative clips were 4 films excerpts from commercial movies: *Saving Private Ryan*, *Schindler's List*, *The Piano* and *The Rest Stop* (collected from both Carvalho et al., 2012; Megías et al., 2011). These negative clips were rated as highly arousing as well. In contrast, neutral clips were included to distract participants from any emotional bias and to better define the relationship between positive and negative moods and their interaction with reasoning (Egidi and Nusbaum, 2012; Mitchell and Phillips, 2007). Neutral videos included people riding their bicycle or silently riding the tube, and an old woman knitting. Mean valence and arousal ratings are reported in Table 1. Positive and negative videos ratings differed both in valence and arousal levels from neutral ones. The order of presentation of the four films within a particular mood induction session was random across participants.

In a previous study by Rodríguez-Gómez et al. (2018), a set of syllogisms containing true and false major premises was used to study the effect of the premises veracity upon reasoning. For the present study, we selected only those syllogisms including true major premises. Thus, we had an initial set of 240 logical syllogisms. Following a logical sequence, every major premise was continued with a minor premise and a conclusion. Major premises were universal statements. Minor premises consisted of a particular case related to these general statements. For example: *All men are mortal* (major premise); *Juan is a man* (minor premise); *Therefore, Juan is mortal* (conclusion). This type of syllogism is called DARII and its conclusion is valid, since it combines the information of both premises following a logical sequence. To create illogical syllogisms, we swapped the order of the minor premise and the conclusion. For example: *All men are mortal* (major premise); *Juan is mortal* (minor premise); *Therefore, Juan is a man* (conclusion). This type of syllogism is a fallacy and its conclusion is invalid because the fact that "*All men are mortal*" does not imply that "*All mortals are men*" (i.e., illicit conversion of the major premise). Therefore, the conclusion that "*Juan is a man*" is not warranted and logically invalid. Thus, the experimental set consisted of 240 logical and 240 illogical syllogisms. Table 2 contains some examples of the different stimuli conditions. The frequency of use (Sebastián-Gallés et al., 2000) of the last word of the conclusions was contrasted via one-way analysis of variance (ANOVA). There was no difference between logical and illogical conclusions F (1478) = 0.004; $p < 0.951$.

In addition, 120 fillers were added to the stimuli set. Eighty of these fillers consisted of different types of syllogisms: BARBARA, DATISI and DISAMIS syllogistic forms, and the resultant conclusion could be valid or invalid as well (80 logical fillers and 80 illogical fillers). The rest of fillers (40) were non-sense syllogisms. In half of these fillers the minor premise was not related to the major premise, so it was not linked to the conclusion either. In the other half, the conclusion was unrelated to the major and minor premise. The inclusion of these fillers was done to avoid the participants' automatization of responses when solving the validity of the conclusions decision task.

Finally, we created two experimental lists, containing each: 120 logical syllogisms, 120 illogical syllogisms and 120 fillers (fillers were the same for both lists). A syllogism with a logical structure in the first list would have an illogical structure in the second list, and vice versa. Nevertheless, the major premises were all the same for the two experimental lists. The 120 logical and the 120 illogical syllogisms were then divided into three sets (40 + 40 each) for each mood session, such that participants never saw the same syllogisms across sessions. Participants were randomly assigned to one of these lists in each of the three sessions.

Table 1
Characteristics of the stimuli used in the present study. Means and standard deviations (in parentheses) of Valence (1, very negative, to 9, very positive), and Arousal (1, very calming, to 9, very arousing), according to Carvallo (2012) and Megías et al. (2011) databases. ** $p < 0.01$. ^ANOVAs were followed up by Bonferroni-corrected post hoc pairwise comparisons ($p < 0.05$).

	Positive clips	Negative clips	Neutral clips	One-way ANOVA on each factor	Post-hoc comparisons^
Valence	6.48 (0.09)	2 (0.29)	3.41 (0.35)	$F_{(2,9)}$ = 348.275**	Pos > Neu Neg < Neu
Arousal	6.06 (0.043)	6.06 (0.29)	1.57 (0.33)	$F_{(2,9)}$ = 243.428**	Pos > Neu Neg > Neu

2.3. Experimental procedure

Participants were tested in three separate recording sessions (with a one week interval, +/− one day), in which a different mood was induced to them. We performed a within-subject design with the factor EMOTION (positive, negative and neutral) to take advantage of the statistical efficiency of these designs (Greenwald, 1976). The order of mood induction, as well as the assignment to an experimental list was counterbalanced across participants. Moreover, the order of presentation of syllogisms within a given list was randomized for each participant.

Upon arrival at the laboratory, and after signing informed consent, participants filled out a questionnaire rating their current emotional state. The questionnaire consisted of a scoresheet including scales of valence (from − 5, extremely negative, to + 5, extremely positive), and arousal (from − 5, extremely calmed, to + 5, extremely activated) dimensions. This is a short method to use in comparison with other widely used mood-assessment scales such as the PANAs (Egidi and Nusbaum, 2012; Kross et al., 2011; Sereno et al., 2015; Verhees et al., 2015). Participants were then fitted with encephalogram (EEG) electrodes while they filled out additional handedness, vision and health questionnaires. They were seated approximately 100 cm in front of 19" computer monitor. The session began with a short set of practice syllogisms to acclimate the participants to the silently reading and the logical decision tasks.

The experiment was divided into four blocks with the same structure: display of a clip, current-mood questionnaire and reasoning task (Fig. 1). In each of these blocks, the clip was displayed. After that, participants were asked to rate the current state of their mood using the same questionnaire they filled out upon arrival. Thus, participants fulfilled the questionnaire a total of six times: when they arrived at the laboratory, after each clip, and at the end of the experimental session. Once the questionnaire was fulfilled, the presentation of the syllogisms began. After they read the major premise, the minor premise, and the conclusion, they decided whether the conclusion was logically valid or not. They were informed that their task was to decide whether the conclusion correctly followed from the premises. We asked them to do

Table 2
Examples of syllogisms presented in the experiment in Spanish and their English translation (in italics).

Major premise	Minor premise	Conclusion	Validity of the conclusion
Todos los hombres son mortales.	Juan es un hombre.	Juan es mortal.	Valid
All men are mortal.	*Juan is a man.*	*Juan is mortal.*	*Valid*
Todos los hombres son mortales.	Juan es mortal.	Juan es un hombre.	Invalid
All men are mortal.	*Juan is mortal.*	*Juan is a man.*	*Invalid*
Todos los adultos fueron niños.	Mario es un adulto.	Mario fue un niño.	Valid
All adults were kids.	*Mario is an adult.*	*Mario was a kid.*	*Valid*
Todos los adultos fueron niños.	Mario fue un niño.	Mario es un adulto.	Invalid
All adults were kids.	*Mario was a kid.*	*Mario is an adult.*	*Invalid*
Todos los rascacielos son altos.	Este edificio es un rascacielos.	Este edificio es alto.	Valid
All skyscrapers are tall.	*This building is a skyscraper.*	*This building is tall.*	*Valid*
Todos los rascacielos son altos.	Este edificio es alto.	Este edificio es un rascacielos.	Invalid
All skyscrapers are tall.	*This building is tall.*	*This building is a skyscraper.*	*Invalid*
Todos los gorriones son pájaros.	Este animal es un gorrión.	Este animal es un pájaro.	Valid
All sparrows are birds.	*This animal is a sparrow.*	*This animal is a bird.*	*Valid*
Todos los gorriones son pájaros.	Este animal es un pájaro.	Este animal es un gorrión.	Invalid
All sparrows are birds.	*This animal is a bird.*	*This animal is a sparrow.*	*Invalid.*

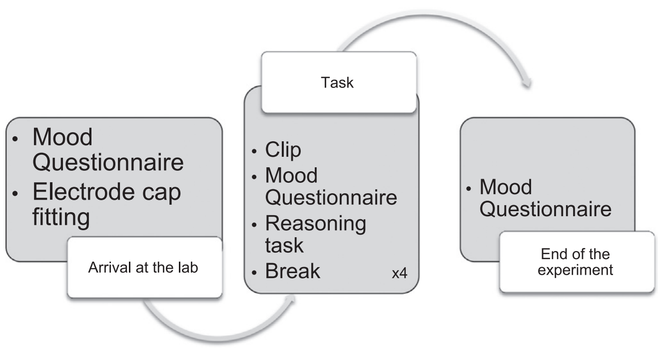

Fig. 1. Schedule of each experimental session (three sessions per participant).

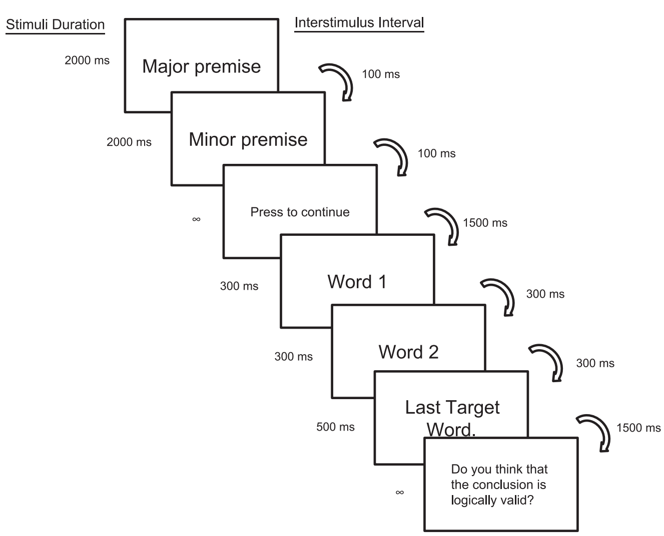

Fig. 2. Sequence of events during the experiment.

this validity decision to ensure they would pay attention to the conclusion of the argument. Both initial premises were presented in the screen as a full sentence. The conclusion appeared word by word in the center of the screen in order to avoid eye movements and obtain a precise time-lock to the final word of the conclusion. All words in premises and in the conclusion were shown in a black 30-point lowercase Arial font on a white background. The major premise was presented in the screen for 2000 ms with an interval of 100 ms before the minor premise. The minor premise appeared in the screen for 2000 ms. Once the minor premise disappeared, there was an interval of 100 ms and a fixation point was shown in the center of the screen. Participants had to press the space bar to initiate the conclusion. Each word of the conclusion was presented for 300 ms with an inter-word interval of 300 ms, except for the last word of the conclusion that lasted 500 ms. This approach was taken to avoid overlap of the response to the disappearance of the word from screen with ongoing EEG activity. Once the conclusion was over, the participants encountered the question: “Do you think that the conclusion is logically valid?”. They could press two different buttons: one for “Yes” and one for “No” (Fig. 2). These buttons were counterbalanced across participants. Participants read a total of 90 syllogisms per block (30 logical syllogisms, 30 illogical syllogisms and 30 fillers). Each block's duration was approximately 7–8 mins. There was a break between blocks. Break's duration was unlimited; participants decided when to start next block. The whole session lasted about 40–45 min.

2.4. EEG data recording and preprocessing

EEG data were recorded from 64 Ag/AgCl electrodes distributed according to the 10–20 international system (“American Electroencephalographic Society guidelines for standard electrode position nomenclature”, 1991). These electrodes were mounted in an electrode cap (Electro-Cap International) and their impedances were kept below 5 kΩ. Electrodes were referenced online to the left mastoid and amplified with a Brain Amps amplifier at a sampling rate of 1000 Hz. The signal was filtered through a 0.1–100 Hz online band-pass filter. The electrooculographic activity was recorded using vertical and horizontal bipolar electrodes placed at a supra-infraorbital level of the right eye and on the outer canthus of both eyes, respectively.

Data was processed using BrainVision Analyzer software (Brain Products, Munich), re-referenced off-line to the mastoid average. For artifact rejection purposes, the following thresholds were set: maximal allowed voltage step, 50 µV; minimal and maximal allowed amplitude, ± 100 µV; lowest allowed activity (max-min), 5 µV for a 1500 ms interval length. Once any threshold was met in the continuous EEG file, data recorded at that point were marked and discarded, together with data recorded during the 200 ms before and after the detection. This was performed to avoid including any residual artifacts in subsequent computations of ERP averages. EEG raw data from all subjects were scanned and marked using the same criteria. Four participants with less than 15 artifact-free trials in at least one condition were excluded from analysis. Trials for which subjects responded erroneously were eliminated from further analyses. Moreover, 6 participants were excluded as well due to their high number of errors (more than 50% of trials). For the 20 remaining participants, 18.9% of trials were discarded and an average of 32.4 trials remained per experimental condition. A Butterworth zero phase filter was applied to the EEG data (low cutoff at 0.1 Hz, time constant = 1.6 s, 24 db/oct; high cutoff at 20 Hz, 24 dB/oct). Thus, we used a widely used offline high pass filter setting in most ERP studies of language comprehension (see e.g., Rommers and Federmeier, 2018, for a recent report) while following the recommendations of Tanner et al. (2015) for an optimal trade-off between statistical power and artifactual effects. The continuous EEG was segmented into 1000 ms epochs starting 100 ms before the onset of the target word item. Artifact-free average waveforms were then computed for each condition separately, after subtraction of the pre-stimulus baseline.

2.5. Data analysis

2.5.1. Behavioral analysis

Accuracy was measured by computing the mean number of errors committed by each participant and was analyzed with a mixed factorial design (repeated measures ANOVA) including two within-subject factors: EMOTION (positive, negative and neutral) and VALIDITY (logical, illogical). Reaction times were not analyzed because the participant's responses were delayed to avoid overlap of overt responses on ongoing EEG activity.

2.5.2. Scalp ERP analysis

ERP responses were assessed using a nonparametric cluster-based random permutation analysis approach (Maris and Oostenveld, 2007). The advantage of this approach in the ERP field is that it avoids an a priori selection of locations and/or components. In order to control for the multiple comparison problem (i.e., increase of type 1 error rate) the following procedure is implemented. First, a simple dependent-samples t-test for each contrast (e.g. valid vs. invalid conclusions) was performed at each time-electrode pair. P values below 0.05 were used to form clusters of adjacent time points and electrodes. Adjacency for electrodes was defined using a triangulation method. This triangulation algorithm tries to build triangles between nearby nodes, thereby being independent of distance of sensors. Even in a network with different clusters of nodes, the algorithm tries to build as many triangles until the whole area filled up by the nodes is covered. A minimum of two channels were used to form a cluster. Cluster-level test statistic was calculated by taking the sum of all the individual t-statistics within that cluster. Then, a null distribution was created by computing 1000 randomized cluster-level test statistics. Finally, the actually observed cluster-level statistics were compared against the null distribution and only clusters falling in the highest or lowest 2.5th percentile were considered significant. EEG data were analyzed with the Fieldtrip software package (http://www.ru.nl/fcdonders/fieldtrip/), a toolbox implemented in Matlab environment (The MathWorks, Natick, MA). As a first step, the most common latency range of 250–450 ms for N400 effects was selected and all channels were included in the analysis. Then, based on the scalp distribution of the N400 effect across mood sessions, the later 450–570 ms time-window was also selected at a region of interest including the following electrodes: FC1, FCZ, FC2, C1, CZ and C2.

3. Results

3.1. Mood induction manipulation

Participants rated the valence and arousal values of their current mood six times throughout the experiment. Mean ratings across these sessions are shown in Figs. 3 and 4. They illustrate the changes in valence (Fig. 3) and arousal (Fig. 4) at different moments throughout the experiment.

The results of a one-factor ANOVA showed no significant differences in valence or arousal across sessions when participants arrived at the laboratory.

Differences in valence ($F(2,38) = 9.815$; $p < 0.000$) and arousal ($F(2,38) = 4.209$; $p < 0.020$) emerged after watching the first clip. Post-hoc analyses revealed that participants in the negative mood condition showed a significant decrease in valence compared to those in the neutral and positive mood conditions. In addition, participants reported higher arousal scores, compared to the neutral condition.

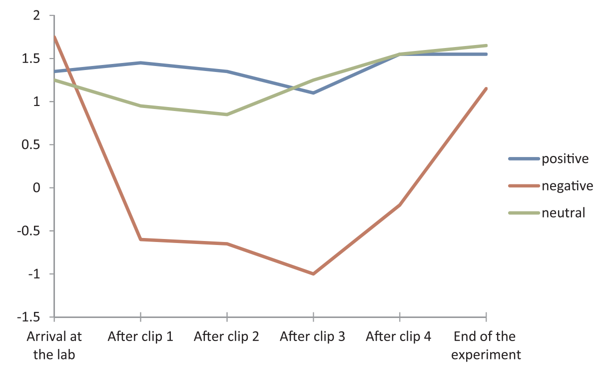

Fig. 3. Mean changes in valence throughout the experiment.

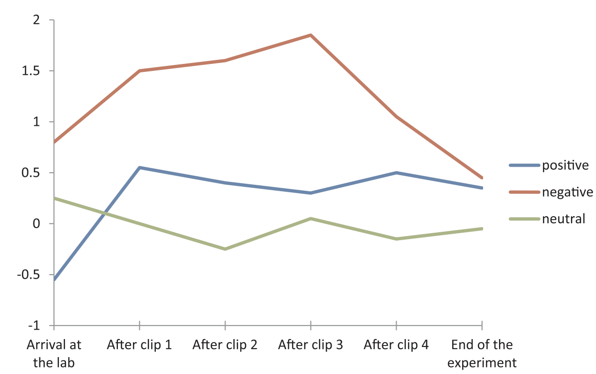

Fig. 4. Mean changes in the level of arousal across the experiment.

Similar results were found after watching the second clip. Differences in valence ($F(2,38) = 6.874$; $p < 0.002$) and arousal ($F(2,38) = 5.599$; $p < 0.006$) were noticeable. As in the previous questionnaire, viewing negative clips elicited a reduction in valence scores compared to those elicited by neutral and positive clips. Again, negative clips provoked a higher arousal state in participants compared to the neutral condition.

Following the tendency, effects in valence ($F(2,38) = 10.161$; $p < 0.000$) and arousal ($F(2,38) = 5.321$, $p < 0.008$) were also significant after watching the third clip. Participants in the negative condition presented lower levels of valence compared to those in the positive and neutral condition. Moreover, higher arousal levels were reported after watching negative clips when compared with both neutral and positive conditions.

Only differences in valence ($F(2,38) = 9.014$; $p < 0.000$) emerged after viewing the last clip of the experiment. Again, valence scores were significantly lower for the negative clips when compared with the positive and neutral clips.

At the end of the experiment, no differences in valence or arousal were found.

Overall, these results show that the mood induction procedure was only successful for the negative clips. Viewing these clips elicited lower emotional state valence ratings relative to the positive and neutral clips. In addition, all except for the last clip elicited higher arousal scores than neutral videos. In contrast, viewing positive clips did not significantly increase valence or arousal levels.

3.2. Behavioral data

A repeated-measures ANOVA with the number of errors for each

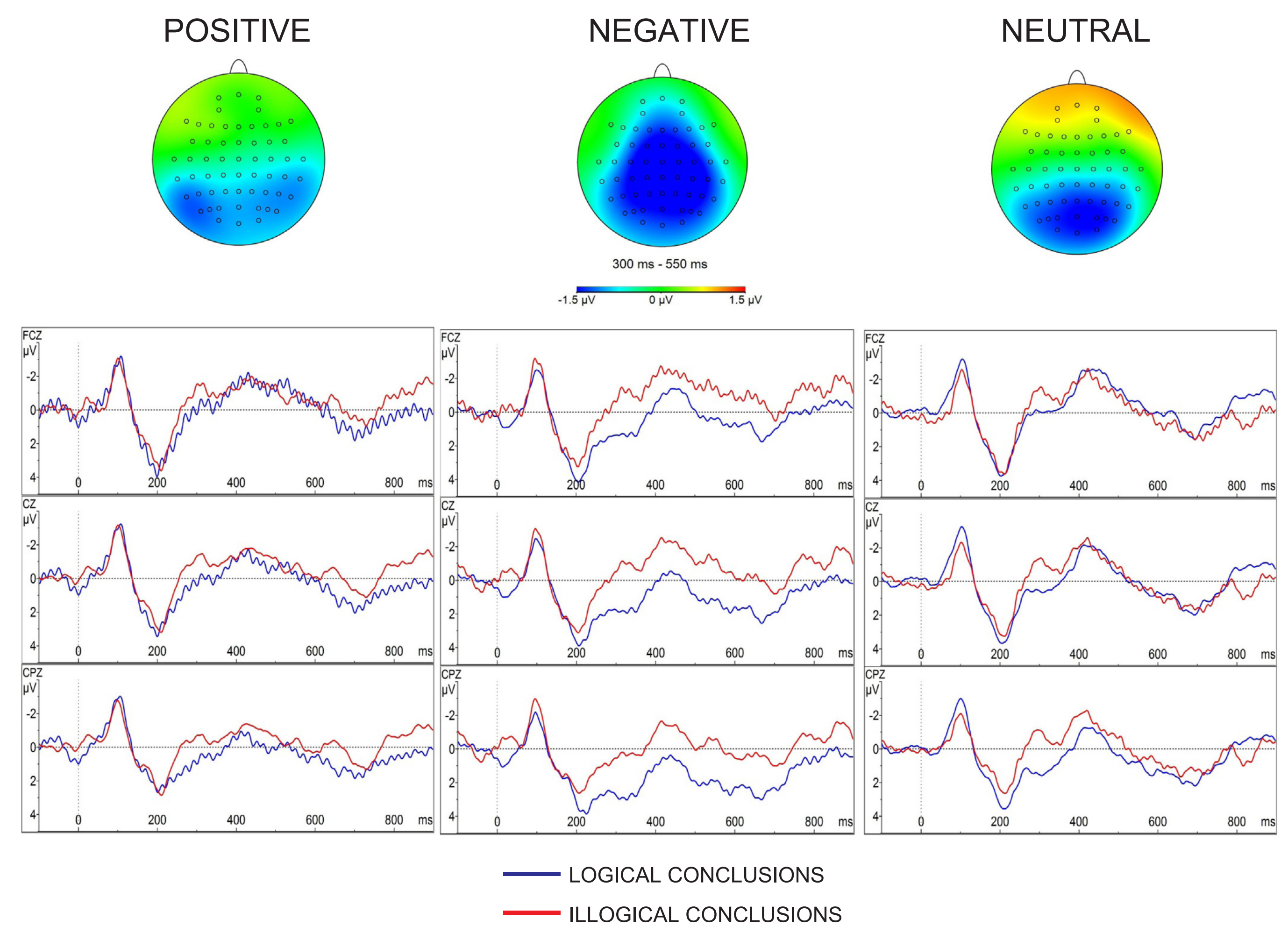

Fig. 5. ERP responses elicited by logical conclusions (black lines) and illogical conclusions (red lines) in the three inducted moods (positive, negative and neutral). Responses are plotted at a selection of 3 midline electrodes front to back (FCz, Cz and CPz). Negative voltage is plotted up. Voltage maps are also plotted at the top of the figure for each comparison. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

participant was computed including the following factors: EMOTION (positive, negative and neutral) and VALIDITY (logical and illogical). A main effect of VALIDITY was found ($F(1,19) = 8.355$; $p < 0.009$). A higher number of errors was committed for illogical syllogisms (2.519) compared to logical syllogisms (1.00), representing a 6.3% and a 2.5% of errors, respectively. This result suggests that participants experienced more difficulties when solving illogical syllogisms. However, no main effects of EMOTION ($F(2,38) = 0.505$; $p = 0.607$) or interaction EMOTION by VALIDITY ($F(2,38) = 0.355$; $p = 0.704$) were found in behavioral error rates.

3.3. Electrophysiological data

Grand-averages comparing the processing of the last word of the conclusion for logical and illogical syllogisms within moods are shown at a selection of 3 midline electrodes (front to back). (Fig. 5).

According to visual inspection, the ERP response to illogical conclusions showed an enhanced negativity compared to logical conclusions in the N400 time-window across all three sessions (positive, negative and neutral). However, the size of this effect was most prominent and longer sustained under the negative mood state, while was minimal under both positive and neutral mood states.

The cluster-based permutation test revealed a main effect of VALIDITY ($p = 0.033$). This effect appeared between 300 and 420 ms and was distributed over centro-parietal electrode sites. Of critical interest for the present study was whether logical and illogical conclusions would significantly differ as a function of the EMOTION session in which they were presented. Thus, cluster-based permutation analyses were also conducted in a selection of 6 fronto-central electrodes (FC1, FCZ, FC2, C1, CZ and C2), where the N400 seemed to vanish for the neutral and positive sessions and remain active in the negative mood session. The analysis revealed a significant interaction between VALIDITY and EMOTION in the 470–550 ms time window ($p = 0.037$). Further analyses in this region of interest (ROI), revealed that the difference between logical and illogical conclusions was only significant in the negative mood session ($p = 0.0125$).

To further characterize the nature of the effect, additional analyses were conducted to contrast all the responses to logical conclusions and all the responses to illogical conclusions (regardless of mood session). This approach was taken since an N400 effect consists of a difference wave (e.g. congruent versus incongruent, high cloze versus low cloze) (Kutas and Hillyard, 1980c). Thus, our effect might potentially be driven by either an increase in the response to illogical or a decrease in the response to logical conclusions. The analysis revealed that while no significant cluster of electrodes showed significant effects for the responses to the illogical conclusions, the analyses of the response to the logical ones differed as a function of mood ($p = 0.048$). Specifically, the response to logical conclusions in the negative mood session was less negative-going than the one in the positive ($p = 0.03$) and the neutral ($p = 0.08$) sessions in the frontal cluster. In contrast, mean amplitude responses for logical conclusions in positive and neutral mood sessions were not statistically significant ($p = 0.74$). Fig. 6 illustrates this

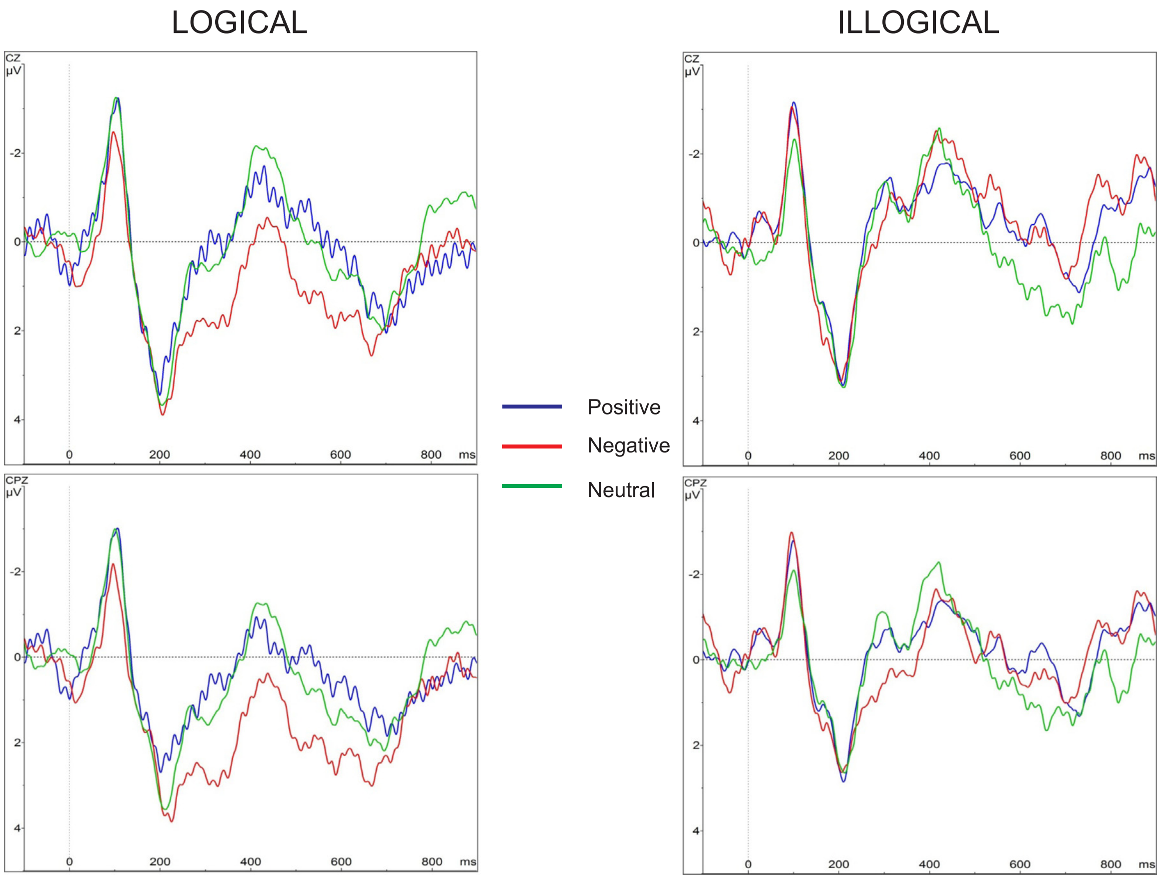

Fig. 6. ERP responses elicited by logical conclusions (left) and illogical conclusions (right) in the three inducted moods (positive, negative and neutral). Responses are plotted at two electrode sites (Cz and CPz). Negative voltage is plotted up. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

contrast at a two midline electrode sites.

4. Discussion

The current study aimed to examine the time course of potential influences of mood state on reasoning processes. In particular, we explored whether mood altered the online processing of syllogisms whose conclusions were either logically valid or invalid. First, our results confirmed previous findings with regard to an overall enhancement of the N400 ERP in response to illogical versus logical conclusions for categorical syllogisms whose initial major premise had been rated as true (Rodríguez-Gómez et al., 2018). This result indicated that participants overall anticipated the logical conclusions to a better extent than the illogical ones, according to the functional interpretation of classical posteriorly distributed N400 effects (Federmeier, 2007). It is a noticeable finding considering that by the time of the reading of the second premise of the syllogism, readers could potentially predict in advance whether the conclusion was going to be logical or illogical. Thus, the anticipation of logical conclusions (as indexed by the smaller N400 to the last word of the conclusion) is a rather pervasive phenomena during online reading of reasoning arguments.

It is important to bear in mind that our analysis of mood scores indicated that the method used for mood induction (video films) was only successful in eliciting a negative mood while it failed to elicit a positive mood. We attribute the failure to elicit a positive mood to the nature of the content of the positive films. Our initial purpose was to increment arousal levels both in negative and positive emotional states. Thus, we selected both negative/violent and positive/erotic videos, respectively. However, the ratings of mood after watching erotic videos did not result in an increase in positive valence nor arousal levels in our sample. Participants only reported a negative mood increase after watching clips with violent negative content. In addition, differences between negative and neutral moods were also found with regard to the level of arousal induced by the films (higher arousal for the former than the later). This contributes to a potential confound between negative valence and high arousal levels, which might together account for the current findings as we will discuss later.

Behavioral performance on the conclusion validity task, was slightly worse for illogical than for logical conclusions. Participants overall committed more errors when judging the invalidity of illogical conclusions relative to when judging the validity of logical ones. However, in line with previous studies (Smith et al., 2014) and in contrast with others (Jung et al., 2014), our results indicate that performance on this task was insensitive to the mood manipulation. In regard to the presence of absence of mood effects on task performance, we speculate that the method used to induce changes in emotional state, might be critical. The mood induction procedure that was used in the study that found effects of induced emotion on reasoning performance (Jung et al., 2014) consisted of giving feedback to participants on an excellent, poor or on average performance in a previous manipulated intelligence test.

Critically, even in the absence of mood influences on behavioral performance in our study, emotional state effects arouse when examining the time-course of electrophysiological responses. In the later portion of the N400 time-window (470–550 ms), the ERP validity effect (larger N400 for illogical than logical conclusions) only was significant under the influence of a negative compared to a neutral or positive mood. The latency of this effect falls within the period of semantic integration processes and, thus, it is in contrast with the results from the study by Blanchette and El-Deredy (2014), which found only later influences of the emotional content on conditional reasoning

(800–1050 ms). Our results therefore support an earlier influence of mood state (relative to the one obtained when the emotional content of the reasoning was manipulated) on how conclusions were anticipated, which goes in line with other studies showing earlier mood influences in other language comprehension processes (Chwilla et al., 2011; Federmeier et al., 2001; Pinheiro et al., 2013; Van Berkum et al., 2013).

Since the positive mood induction failed in our study, current results are unable to determine whether it might influence categorical reasoning. Thus, the hypothesis of a more flexible, heuristic-based processing style under a positive mood (Ruder and Bless, 2003), deserves future investigation in the context of reasoning tasks. With regard to a negative mood, in contrast, we found evidence to support a more analytical, rule-based cognitive style (Clore and Huntsinger, 2007), as indexed by the reduced N400 response to logical conclusions under this emotional state. We must, however, acknowledge that modulations of arousal were also present after watching video clips 1, 2 and 3, with higher arousal levels for negative relative to neutral and positive mood induction sessions. Thus, the stronger anticipation of logical conclusions occurring during this session may be driven by a negative valence increase, a higher arousal state, or a combination of both factors.

Regarding theoretical accounts on the mechanisms by virtue of which emotion might exert and influence in other cognitive tasks, an alternative interpretation of our results is that a negative mood consumed cognitive resources (Tremoliere et al., 2016, 2018) which interfered with the main reasoning task. Impaired task performance in prior studies manipulating mood has been thought to reflect a decrease in the processing capacity because cognitive resources were committed to the processing of people's own mood (Ellis, 1988; Schmeichel, 2007), or to concentration in mood regulation processes to re-establish positive mood (Mitchell and Phillips, 2007). In our view, our results do not fit well with the cognitive load hypothesis. The lack of behavioral mood effects and the fact that the larger N400 effect seemed to be driven by a specific reduction of N400 amplitude to logical conclusions under a negative mood, do not fit well with an overall memory capacity overload under emotional states.

From a slightly different view, our results could also be explained in terms of general attentional mechanisms. Negative affective states have been associated with a narrowing of attention (Derryberry, 1994; Forster et al., 2006). Under this view, drawing attentional resources away from the demands placed by the task, in conjunction with a narrowing of attention, might have led to the results. Again, the lack of behavioral mood effects and the specific reduction of N400 amplitude for logical conclusions under a negative mood, do not seem to support the hypothesis of an overall disruption of mood by a narrowing of attention.

Although attentional and cognitive capacity overload explanations are not mutually exclusive, our electrophysiological data seem to support the hypothesis that an emotional state leads to a rather specific change in cognitive style by virtue of which only the logical conclusions were more readily available in semantic memory. In the study by Federmeier et al. (2001) a positive mood had the opposite effect, a broadening for the prediction of more distantly related semantical items. Our electrophysiological findings suggest that a more remarkable anticipation of logical conclusions was triggered under a negative mood influence, as indexed by the specific reduction in N400 in response to them. Thus, in line with the postulated association between mood and cognitive styles, a more analytical (e.g. logically valid) style seems to be prompted under the influence of a negative mood (Clore and Huntsinger, 2007). In contrast to our results, Chwilla et al. (2011), found a less spread N400 effect under negative mood condition when high and low cloze probability items were processed within sentences. It is unclear, however, whether the later effect was driven by the differential response to the high or the low cloze probability items. Our electrophysiological data suggests a specific rather than a broad effect of mood state on language processing.

With regard to the discrepancies between the results of the current study and the ones obtained by Blanchette and El-Deredy (2014), our study differs from theirs in at least two main respects. First, our syllogism reading task includes categorical rather than conditional reasoning. In fact, rather than an N400 reduction to logical versus illogical conclusions (Rodríguez-Gómez et al., 2018), they found a larger N400 in the inference making condition relative to a baseline condition (which in their study consisted on the repetition of premises). Second, they manipulated the nature of the contents of the reasoning task (either negative or neutral) whereas we induced emotional states prior to reasoning with emotionally neutral materials. These methodological differences might explain the observation of a late ERP effects (800–1050 ms) of emotional content versus an earlier influence (N400 time-window) of emotional state in reasoning with categorical syllogisms. Noteworthy, a recent study by Bago et al. (Bago et al., 2018) also reveals early effects (N2 and P300) when there is a conflict between heuristic and logic conclusions in problem solving.

Despite methodological discrepancies across ERP studies, our current findings add to the proliferating body of research that shows electrophysiological evidence on how non-linguistic aspects like emotional state exert an influence in online language comprehension tasks (Chwilla et al., 2011; Federmeier et al., 2001; Pinheiro et al., 2013; Van Berkum et al., 2013; Verhees et al., 2015; Vissers et al., 2013). From an anatomical point of view, language comprehension is suggested to involve different brain networks depending on people's mood (Egidi and Caramazza, 2014). Thus, our results fit well with reports from recent brain imaging studies that point to the recruitment of differential mood-dependent neural networks during reasoning with semantic material (Brunetti et al., 2014; Smith et al., 2015, 2014).

In sum, the current study investigated the influence of an individuals' mood in reasoning with categorical syllogisms, using electrophysiological measures. Our results reveal that a negative mood state results in a higher capacity or an inclination to anticipate logical conclusions. In a broad sense, the results of the present study contribute to the accumulating body of evidence that highlights the importance of considering emotion as a source of modulation of other cognitive processes.

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Capítulo 8

Discusión general

El conjunto de los experimentos que engloba esta tesis doctoral evidencia la adecuación de la técnica de los ERPs para el estudio de la generación de inferencias online. En la totalidad de las tareas, y bajo diferentes condiciones experimentales, los participantes han sido capaces de utilizar la información del contexto previo y de su conocimiento del mundo para inferir el significado de pseudopalabras, generar inferencias de causalidad, emocionales o de lugar y realizar inferencias deductivas a partir de unas premisas de manera lógica, aunque modulada por creencias personales. Los resultados de nuestros estudios muestran que la variación en la amplitud y/o morfología del componente N400 constituyen marcadores particularmente sensibles de los procesos involucrados en la generación de inferencias. Además, nos permiten relacionar esta onda con diferentes procesos y modelos teóricos de la generación de inferencias. De manera general, hemos encontrado una menor amplitud de este componente en respuesta a palabras precedidas por una pseudopalabra como referente cuando el contexto favorece la generación de inferencias (Capítulo 4), respuestas cerebrales específicas para distintos tipos de inferencias (Capítulo 5), una influencia del conocimiento del mundo y de las creencias en la generación de inferencias deductivas (Capítulo 6) y un efecto del estado de ánimo en la generación de inferencias deductivas (Capítulo 7). En los dos primeros estudios (Capítulos 4 y 5), además del N400, encontramos efectos en positividades más tardías en función de las distintas manipulaciones experimentales (P600 y pN400FP).

En el primer bloque del diseño experimental del primer estudio (Capítulo 4), las respuestas cerebrales registradas a la última palabra de las frases revelaron una mayor negatividad cuando el referente previo era una pseudopalabra frente a cuando éste era una palabra. Esta negatividad presentó la distribución centroparietal típica del N400, mostrando mayores amplitudes en el hemisferio derecho. Sin embargo la duración del efecto fue inusualmente larga, con un inicio en torno a los 250 msegs que finalizaba alrededor de los 900 msegs. Este tipo de N400 de larga duración se han observado en estudios previos como el de

Kotchoubey y El-Khoury (2014), donde se utilizaron frases que terminaban con palabras ambiguas. Después de la frase presentaban el significado dominante o el subordinado de la palabra final, que podía ser congruente o incongruente. El efecto duradero de la N400 se encontró cuando aparecían significados dominantes de las palabras ambiguas en contextos que favorecían el significado subordinado, lo que se interpretó como el coste necesario para inhibir su activación. En nuestro estudio, todo parece indicar que esta negatividad sostenida refleja el esfuerzo persistente que podrían haber llevado a cabo los participantes para integrar la palabra final de la frase con su referente (la pseudopalabra) y su incapacidad para hacerlo en condiciones en las que no es posible el proceso de acceso al léxico (no existe huella en el almacén de memoria léxica para el referente). Por tanto, se postula que el hecho de tener que integrar esta palabra final en un contexto en la que el referente era una pseudopalabra, de la que se carece de huella de memoria, es lo que provoca esta N400 de duración atípica. En el bloque 2 del mismo experimento, las frases del bloque 1 fueron precedidas esta vez de una frase que invitaba a generar una inferencia deductiva sobre el significado de la pseudopalabra. En este caso, la diferencia entre la respuesta al final de oración target fue también dependiente de que le precediera una palabra o una pseudopalabra y fue solo significativa entre 250 y 350 msegs. La búsqueda de coherencia, el sondeo de los posibles significados de la pseudopalabra y la incertidumbre de no saber con certeza cuál atribuir al referente pueden estar relacionados con el hecho de que la negatividad que era sostenida en el primer bloque se limite a 250-350 msegs en el bloque 2. Esto parece indicar con cierta probabilidad que la inferencia sobre el significado de la pseudopalabra se ha realizado online, bajo las condiciones adecuadas. Si las *sias* vuelan (invitación a una inferencia deductiva), lo más probable es que se trate de algún tipo de ave o algún modelo de avión, y por tanto la N400 se interrumpe y tiene una duración más breve para la palabra final “vuelan”. Así pues, nuestro estudio revela que el cerebro realiza un esfuerzo sostenido por establecer coherencia intra-frase, aún sin instrucciones precisas para ello.

Además, el hecho de que este esfuerzo se reduzca cuando la inferencia es posible, parece confirmar el carácter automático de las inferencias y la necesidad de establecer coherencia intra-frases (Kuperberg, Paczynski, & Ditman, 2011; St George, Mannes, & Hoffman, 1997; Yang, Perfetti, & Schmalhofer, 2007). Por tanto, el mecanismo de generación de inferencias es automático y eficiente, y parece reflejar procesos que estarían en la base del aprendizaje de palabras nuevas, es decir, en el proceso de adquisición léxica durante la comprensión lectora.

Por otro lado, se realizaron análisis adicionales de la respuesta al referente previo (pseudopalabra/palabra) en cada una de sus tres presentaciones a lo largo del experimento. La segunda repetición de pseudopalabras en el segundo bloque experimental generó una positividad tardía similar al P600 en comparación con las palabras reales. Bermudez-Margaretto et al. (2015) encuentran también una positividad tardía con la repetición de pseudopalabras a lo largo de la tarea experimental, lo que atribuyen a la formación de huellas de memoria. Por lo tanto, en nuestro estudio, el P600 podría también reflejar la creación y el fortalecimiento de huellas de memoria para pseudopalabras. Esta formación de huellas de memoria podría llevarse a cabo mediante los procesos de revisión y monitorización reflejados por el P600 (Kolk & Chwilla, 2007; van de Meerendonk, Kolk, Vissers, & Chwilla, 2010; Vissers, Chwilla, & Kolk, 2006, 2007; Vissers, Kolk, van de Meerendonk, & Chwilla, 2008) que servirían para establecer asociaciones semánticas. Estas huellas de memoria podrían servir, además, para actualizar el modelo situacional propuesto por el modelo construccionista de Graesser et al. (1994).

Los resultados relativos al N400 del segundo estudio (Capítulo 5) estuvieron inicialmente marcados por la baja probabilidad de cierre para las inferencias de emoción (52.07%) con respecto a las de causalidad (78.9%) y lugar (78.73%). El motivo de esta diferencia puede explicarse por dos motivos. Por un lado, las palabras emocionales presentan un alto índice de dispersión de candidatos léxicos (vecinos semánticos o sinónimos) (ej. triste, decaído, apenado, destrozado). En el estudio normativo de probabilidad de cierre de la frase, los individuos usaron de manera dispersa uno u otro término, reduciendo así la probabilidad de cierre de la palabra que usamos finalmente como target en el estudio de ERPs. Este porcentaje de probabilidad de cierre relativamente más bajo en comparación con los otros tipos de inferencias indica la dificultad de generación de inferencias emocionales a partir de un contexto social como mencionamos en la introducción: al leer que alguien ha roto la relación con su pareja, la tendencia general es pensar que esa persona tiene que estar en un estado emocional negativo (ej. destrozada); sin embargo, también cabe la posibilidad de que se encuentre en un estado de ánimo positivo (aliviada), ya que puede que estuviera inmersa en una relación tóxica. Es decir, las inferencias emocionales pueden estar más sujetas a CIs. Estos dos factores pueden haber influido en la estimación de la probabilidad de cierre en el estudio normativo y, por lo tanto, a la manera en la que interpretamos la amplitud del N400. En concreto, esto podría explicar la ausencia inicial de diferencias entre los finales de oración congruentes e incongruentes en la condición de inferencia emocional. Por el contrario, los finales de frase para las inferencias de causalidad y de lugar eran más constreñidos: si queremos cortar carne para preparar un guiso, lo más probable es que necesitemos un cuchillo; si estamos ayudando a nuestro sobrino a hacer un castillo de arena, lo más probable es que estemos en la playa. Así lo demuestran los valores de probabilidad de cierre de nuestro estudio normativo. Una vez igualada la probabilidad de cierre entre los distintos tipos de inferencias (eliminando los ítems con una probabilidad de cierre menor de 33.3% en el grupo de inferencias emocionales), el efecto de congruencia/incongruencia también fue significativo para las inferencias de emoción. Por tanto, cuando un contexto constreñido lo permite (artificialmente quedándonos con los ensayos de más alta probabilididad de cierre), se demuestra que las inferencias emocionales también se realizan de manera online. En conclusión, no existen diferencias en la N400 ante la violación de los diferentes tipos de inferencias: la amplitud de este componente crece ante palabras inesperadas que presentan dificultad de integración en relación al contexto en el que se encuentran.

En los componentes tardíos posteriores a la ventana temporal del efecto N400 encontramos diferencias de procesamiento en función del tipo de inferencia. Para las violaciones de inferencias causales, encontramos una positividad frontal post N400 (pN400FP) en la ventana de tiempo 500-750 msegs. Este efecto se ha encontrado en otros estudios para el procesamiento de palabras inesperadas en contextos muy constreñidos (Moreno, Federmeier, & Kutas, 2002; Moreno & Vazquez, 2011). Este efecto parece reflejar procesos de inhibición de una fuerte expectativa generada por el contexto oracional previo. Es decir, el pN400FP estaría relacionado con el coste de procesamiento asociado a situaciones en las que una predicción fuerte se ve incumplida. Por otro lado, tanto los finales congruentes como incongruentes en las inferencias emocionales generaron esta positividad frontal. Nuestros resultados parecen indicar que las inferencias emocionales, independientemente de su congruencia, demandan más procesos de control cognitivo y monitorización del conflicto (Kolk & Chwilla, 2007; van de Meerendonk et al., 2010; Vissers et al., 2006, 2007; Vissers et al., 2008), probablemente debido a las CIs que existen para ellas. Sorprendentemente, para las violaciones de inferencias de lugar, una positividad marginalmente significativa apareció en regiones más posteriores en la ventana de tiempo 500-750 msegs. Esta positividad, por su distribución y latencia, se podría considerar una P600. La poca plausibilidad de los finales incongruentes (Había gallinas, pollos y conejos. Estábamos en la *piscina*) sería la responsable de este efecto, en comparación con la pN400FP encontrada para las violaciones de inferencias causales. La P600, como mencionamos en la introducción, se ha relacionado con la necesidad de reparar o revisar la estructura de las frases tanto sintáctica como semánticamente (Kuperberg, 2007). Así pues, las violaciones de inferencias causales en nuestro estudio provocarían la inhibición de una predicción, mientras que las violaciones de inferencias de lugar estarían relacionadas con procesos de revisión de finales muy poco plausibles. Algunos ejemplos de los estímulos presentados podrían ayudarnos a esclarecer esta cuestión. Para las violaciones de causalidad, presentamos algunas de estas frases: ese día la panadería no pudo cocer el pan, no funcionaba el *micrófono*; el teléfono no se encendía, se le había agotado la *cuchara*; el campo estaba lleno de flores, había llegado la *fiebre*. Se trata de violaciones semánticas. Por el contrario, algunos ejemplos para las violaciones de lugar son las siguientes: después de pasar por recepción nos ayudaron a subir las maletas, estábamos en un *museo*; pedimos una caña y unas aceitunas de tapa, estábamos en un *cine*; al llegar le hicieron las pruebas sanguíneas, estaba en la *montaña*. Como se puede observar, las inferencias de causalidad son muy constreñidas e invitan a realizar una predicción muy fuerte que no se ve cumplida. Los finales de frase podían pertenecer a categorías semánticas diferentes (como por ejemplo, la palabra *fiebre* en el ejemplo anterior). Por tanto, una ruptura tan brusca de nuestra predicción pondría en marcha un mecanismo que implicaría mayores costes de procesamiento para el sistema (Foucart, Martin, Moreno, & Costa, 2014). Las diferencias con las inferencias de lugar son sutiles. La violación de las expectativas en estas últimas, pese a que también invita a realizar una predicción muy fuerte, sigue refiriéndose a otros "lugares". Es decir, la categoría semántica se mantiene, aunque la palabra encontrada no es la que se había anticipado. Este hecho propiciaría los procesos de revisión relacionados con la P600. Por tanto, la distinción que la literatura de ERPs y lenguaje hace entre componentes tardíos de distribución frontal (pN400FP) y de distribución parietal (P600) se ve reforzada por los datos de este estudio (Van Petten & Luka, 2012). Los procesos cognitivos que reflejan cada uno de estos tipos de componentes tardíos no son los mismos. Los primeros estarían relacionados con procesos de inhibición de predicciones fuertes, mientras que los segundos estarían relacionados con procesos de revisión y de reparación de la estructura de la oración al aparecer un elemento léxico que no encaja con el contexto previo.

El tercer estudio de la presente tesis doctoral (Capítulo 6) nos permite estudiar si en el proceso de generación de inferencias deductivas, existe o no una primacía de la conclusión lógica por encima de las creencias personales sobre hechos que podrían ser veraces o falsos (p.ej. Todos los seres vivos mueren vs. Todas las rubias son tontas). Para ello, empleamos silogismos categóricos y analizamos la amplitud del componente N400 en respuesta a la última palabra de la conclusión del silogismo. Concretamente, nos servimos de la sensibilidad del componente N400 al grado de facilidad/dificultad de anticipación de una palabra en un contexto. Las palabras más fáciles de anticipar dado un contexto oracional determinado (aquellas en las que hay un amplio consenso según un estudio normativo previo de probabilidad de cierre) generan un N400 de menor amplitud con respecto a las menos esperadas obtenidas. En base a los resultados de nuestro estudio, las conclusiones lógicas derivadas de premisas verdaderas se integraron más fácilmente (menor N400) que las conclusiones ilógicas derivadas de premisas verdaderas. Por tanto, en este estudio el incremento relativo en el N400 para conclusiones ilógicas refleja una mayor dificultad para combinar la información contenida en las premisas verdaderas y elaborar a partir de ellas una inferencia. Sin embargo, nos encontramos con el patrón inverso cuando las conclusiones se derivan de premisas falsas: en este caso la amplitud del componente N400 es mayor para conclusiones lógicas que para conclusiones ilógicas. Este resultado evidencia la interferencia que provocan nuestras creencias y conocimiento del mundo sobre el procesamiento de la información que se nos presenta en forma de silogismos categóricos. Las instrucciones que ofrecimos a los participantes eran claras: tenían que dejar a un lado cualquier valoración sobre la veracidad de las premisas y centrarse únicamente en si las conclusiones se alcanzaban de manera lógica o ilógica, según lo que habían leído. Esto parece indicar que, a pesar de que se ofrezca la posibilidad de hacer una inferencia deductiva lógica, los participantes otorgaron más peso a sus propias creencias que a la anticipación directa de unas conclusiones que contrastan con ellas. Este hecho pone de manifiesto y corrobora estudios previos sobre la influencia del conocimiento del mundo en procesos de lectura comprensiva (Hagoort, Hald, Bastiaansen, & Petersson, 2004; Van Berkum, Holleman, Nieuwland, Otten, & Murre, 2009; Van Berkum, van den Brink, Tesink, Kos, & Hagoort, 2008). La teoría del modelo mental del razonamiento (Johnson-Laird, 1975) es la que mejor encaja con los resultados de este estudio. Esta teoría sostiene que tendemos a considerar que una inferencia no es buena si podemos encontrar un contra ejemplo para ella (Khemlani & Johnson-Laird, 2012). Por lo tanto, ante la premisa “Todas las rubias son tontas” al poder hallar un contra-ejemplo (p.ej. conocer a una rubia inteligente), los participantes podrían incurrir en un proceso de desconexión de la anticipación de la conclusión, lo que explicaría la mayor amplitud del componente N400 para las conclusiones lógicas derivadas de premisas falsas en comparación con las conclusiones ilógicas.

Los resultados del último estudio (Capítulo 7), refuerzan igualmente la teoría de Hagoort et al. (2004), que defiende que la amplitud del N400 indica el nivel de integración de un estímulo lingüístico en una red neural multimodal. Esta red depende de nuestra experiencia a corto y largo plazo teniendo en cuenta aspectos tales como el conocimiento del mundo, los estados atencionales o el estado de ánimo. En concreto, en el último estudio nos centramos en uno de estos aspectos al examinar el papel desempeñado por el estado de ánimo sobre los procesos implicados en la comprensión lectora. Existen numerosos estudios que han intentado abarcar esta cuestión (Chwilla, Virgillito, & Vissers, 2011; Federmeier, Kirson, Moreno, & Kutas, 2001; Pinheiro et al., 2013; Van Berkum, De Goede, Van Alphen, Mulder, & Kerstholt, 2013; Verhees, Chwilla, Tromp, & Vissers, 2015; Vissers, Chwilla, Egger, & Chwilla, 2013). Los resultados de Federmeier et al. (2001) sugieren que un estado de ánimo positivo expande los límites de las categorías semánticas, haciendo más aceptable un final alejado semánticamente. En este cuarto estudio de la presente tesis doctoral, los participantes fueron capaces de anticipar más fácilmente las conclusiones lógicas, en comparación con un estado de ánimo neutro, bajo un estado de ánimo negativo. Estos resultados sugieren que nuestro estado emocional conduce a cambios en nuestro estilo de procesamiento, de manera que las conclusiones lógicas están disponibles antes en nuestra memoria semántica bajo un estado de ánimo negativo que bajo un estado de ánimo neutro. En línea con la asociación que existe en la literatura entre estado de ánimo y estilo de procesamiento (Clore & Huntsinger, 2007), los resultados de nuestro estudio sugieren que, bajo un estado de ánimo negativo, nuestro estilo de procesamiento tiende a ser más analítico, de tal manera que nos supone un menor esfuerzo cognitivo operar de manera lógica. Por tanto, estos resultados complementan los hallazgos de Federmeier et al. (2001). Si se pretende sacar una conclusión lógica, parece que un estado de ánimo negativo puede facilitar este proceso.

En conclusión, la presente tesis profundiza en los diferentes mecanismos neurales implicados en la generación de inferencias gracias especialmente a los componentes N400 y P600. Ambos componentes nos ayudan a comprender mejor el curso temporal de la generación de inferencias y su relación con los diferentes procesos involucrados. El N400, en primer lugar, pone de manifiesto la capacidad de la información que se nos presenta para generar una inferencia. Si ésta es insuficiente y/o resulta difícil de combinar se reflejará en un incremento de la amplitud de este componente. Una vez generada la inferencia, si su integración con el contexto precedente y el conocimiento del mundo es fácil, se producirá una disminución de la amplitud del N400. Por tanto, el N400 es un marcador sensible a los procesos de activación e integración de inferencias que proponen los modelos psicolingüísticos mencionados en la introducción. En caso de que la inferencia aporte información nueva, es posible que tenga lugar la formación de una huella de memoria, proceso que se ve reflejado en un incremento de la amplitud del P600. Por otro lado, si la integración de la inferencia no puede completarse con éxito, aparecerán distintas positividades en función del tipo de violación: si se incurre en procesos de revisión, tiene lugar un aumento de la amplitud del P600; por el contrario, si es necesario inhibir una fuerte predicción, la distribución tiende a ser frontal, en lo que se conoce como pN400FP (Federmeier, Wlotko, De Ochoa-Dewald, & Kutas, 2007). En la Figura 3 se presentan de manera gráfica estas diferentes posibilidades.

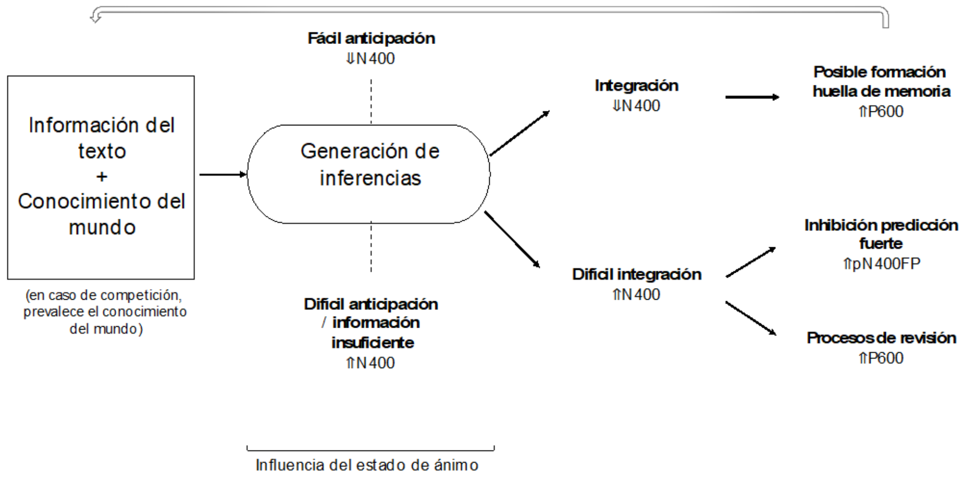

Figura 3. Esquema de los elementos que intervienen en la generación de los inferencias, así como de la relación de los procesos involucrados con la amplitud del N400, P600 y PN400FP.

Como se ha mencionado en la introducción, no existe un consenso a la hora de clasificar inferencias: la disparidad de teorías y modelos deja en evidencia la complejidad de esta cuestión. Los resultados del segundo estudio (Capítulo 5) tienen implicaciones directas sobre la taxonomía y clasificación de las inferencias. En contra del argumento de Gerrig y O'Brien (2005), que sostienen que la clasificación de inferencias posee un valor limitado ya que todas coinciden en procesos comunes de activación, hemos mostrado diferencias en los mecanismos neurales que tienen lugar en función del tipo de inferencia. Nosotros proponemos clasificarlas en función del tipo de conocimiento del mundo que se está activando para cada una de ellas, al haber encontrado que existen diferencias a nivel neural en este sentido.

Los resultados de la presente tesis tienen además implicaciones teóricas para algunos de los modelos sobre generación de inferencias y la importancia de las mismas en la comprensión lectora. Como se mencionó en la introducción, los modelos más importantes en este sentido son la hipótesis minimalista de MacKoon y Ratcliff (1992) y el modelo construccionista de Graesser et al. (1994). Frente al modelo minimalista, que establece que las únicas inferencias que se llevan a cabo durante la lectura sirven para dotar de coherencia local al texto, el modelo construccionista defiende un papel activo del lector, que continuamente realiza inferencias estratégicas en busca de significado. Los resultados de nuestros estudios, especialmente los del tercer (Capítulo 6) y cuarto estudio (Capítulo 7), parecen apoyar los argumentos de este último modelo. En el tercer estudio (Capítulo 6), la búsqueda de contraejemplos de premisas mayores falsas (*"Todas las rubias son tontas"*) supone un proceso controlado y estratégico que conlleva un esfuerzo cognitivo y requiere de nuestro conocimiento del mundo, premisas defendidas por el modelo construccionista. En el caso de conclusiones lógicas derivadas de estas premisas mayores falsas, se alcanza coherencia a nivel local, puesto que las conclusiones se obtienen de manera lógica. Sin embargo, los participantes no las toman por válidas, tal y como evidencia el incremento de la amplitud del N400 en esta condición. Por tanto, estos resultados contrastan con los presupuestos de la hipótesis minimalista, que otorga mucha más importancia a la información contenida en el texto y a sus relaciones de causalidad que a la información previa que tenemos almacenada en nuestra memoria. Los resultados del cuarto estudio (Capítulo 7), además de constituir un apoyo para la teoría construccionista de Graesser et al. (1994) al considerar aspectos extra-lingüísticos en la comprensión lectora (como la intencionalidad del lector), aporta nuevos aspectos a tener en cuenta en la comprensión lectora. Este modelo no considera la influencia del estado de ánimo sobre los procesos de comprensión lectora. Nuestros datos sugieren que es necesario tener en cuenta este aspecto, ya que nuestro estado de ánimo puede influir en el tipo de información a la que se accede más fácilmente (Blanchette, 2013). Además, la información de tipo emocional generalmente atrae más atención y se recupera de manera preferente de la memoria a largo plazo que la información de tipo neutro (Kensinger, 2009). Estos factores, por tanto, modularían los procesos de comprensión lectora en sí misma, así como los procesos de generación de inferencias online durante la comprensión lectora.

La presente tesis doctoral profundiza en los mecanismos neurales implicados en la generación de inferencias. Durante la lectura, continuamente elaboramos inferencias en aras de crear un modelo situacional, defendido por el modelo construccionista (Graesser et al., 1994). La información contenida en el texto, así como nuestra propia experiencia y conocimiento del mundo, determina el nivel de anticipación de estas inferencias, así como su posterior integración. Nuestros resultados también revelan que, en caso de competición entre el conocimiento del mundo y la información del texto a la hora de generar una inferencia inter-frase, el lector se apoya más en su propio conocimiento del mundo, por lo que el peso de ambas fuentes de información difiere a la hora de contribuir a la generación de una inferencia. Si esta inferencia contiene información que puede ser recuperada posteriormente, es posible la creación de una huella de memoria. Por último, aspectos extralingüísticos como el estado de ánimo también influyen en algunos procesos involucrados en la generación de inferencias.

Las limitaciones de la tesis doctoral sugieren direcciones futuras en la investigación y caracterización de las inferencias. Hemos comprobado experimentalmente que existen diferencias a nivel neural en el procesamiento de violaciones de inferencias en función del tipo de información que se activa para cada una de ellas. A la hora de clasificar las inferencias aún no se ha alcanzado una unanimidad, y nosotros proponemos una nueva taxonomía de las inferencias que las clasifique en función de la información que se activa para su elaboración, en base a los resultados obtenidos en el segundo estudio (capítulo 5).

Además, algunos subprocesos implicados en la generación de inferencias pueden ser explorados en mayor profundidad. Los resultados del conjunto de estudios apoyan el modelo construccionista de Graesser et al. (1994), que, entra otras cosas, propone la creación de un modelo situacional por parte del lector. La repetición de pseudopalabras a lo largo de los bloques del primer estudio (capítulo 4) generó un aumento de la amplitud del P600, que atribuimos a la posible creación de huellas de memoria del significado de las pseudopalabras que ayude a la elaboración de este modelo situacional. Para poderlo afirmar con seguridad, se requiere de otros paradigmas con repetición de pseudopalabras que consoliden y reproduzcan estos resultados, similar al que utilizaron Mestres-Misse et al. (2007).

Además, en el último estudio (capítulo 7) no se indujo con éxito un estado de ánimo positivo. Por tanto, inducir un estado de ánimo positivo y ver su efecto sobre la generación de inferencias queda como una cuestión por resolver.

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Capítulo 9

Conclusions Conclusiones

CONCLUSIONS

- We are constantly looking for inner coherence within texts and the fitting with our own world knowledge, experience and beliefs.
- There are not big differences in terms of neural activity between recently learnt words and old words. This phenomenon takes place after the presentation of a single sentence that facilitates the generation of an inference.
- Different neural mechanisms are engaged depending on the type of inference that is being generated. Violations of causal inferences cause very strong predictions to be inhibited, whereas violations of location elicit revision processes.
- The N400 component is mainly related to the activation and integration processes involving inferences, whereas the P600 component indexes revision processes when the integration of the inference is not successful. If the integration takes place, this component may be related to the strengthening of memory traces.
- Our own world knowledge and beliefs are preferred over the information included in texts in case of competition. When a statement is logically predictable, but it is derived from a false premise, it is harder to process.
- Extra linguistic aspects, such as reader's mood, exert an influence on our processing style, and consequently, on comprehension. Concretely, negative mood facilitates the processing of logic information.
- None of the models (constructionist, minimalist) takes into the account the influence of mood on comprehension.
- The constructionist model (Graesser et al., 1994) fits best our results, since it defends the creation of a situation model and the constant search for meaning.

CONCLUSIONES

- Buscamos de manera constante e inevitable la coherencia interna en los textos que leemos y la coherencia externa con respecto a nuestro conocimiento previo del mundo (incluyendo su adecuación a nuestras creencias previas).
- Las palabras de nueva adquisición se comportan a nivel cerebral de manera muy similar al resto de palabras, y este fenómeno ocurre tan solo con una única exposición a una frase previa que invite a realizar dicha inferencia.
- Diferentes tipos de inferencia entrañan diferencias de procesamiento a nivel neural. Concretamente, las violaciones de inferencias de tipo causal provocan una inhibición de una predicción muy fuerte mientras que las violaciones de inferencias de lugar incurren en procesos de revisión.
- El N400 se relaciona de manera general con los procesos de activación e integración de una inferencia, mientras que el P600 indica procesos de revisión cuando no se produce la integración. En caso de que se produzca esta integración, el P600 podría estar relacionado con la creación de huellas de memoria.
- Nuestras creencias previas priman sobre la información contenida en un texto. Cuando un final de oración es predecible en base a la lógica de un argumento pero parte de una premisa mayor falsa (a juicio del lector), genera una dificultad de procesamiento a nivel neural.
- Aspectos extra-lingüísticos, como el estado de ánimo, influyen sobre nuestro estilo de procesamiento y por consiguiente sobre la comprensión lectora. Concretamente, un estado de ánimo negativo provoca una facilitación del acceso a información de tipo lógico.
- Ninguno de los modelos de comprensión lectora propuestos incluye la influencia del estado de ánimo en la comprensión lectora.
- El modelo construccionista de Graesser et al. (1994), es el que mejor se adapta a nuestros resultados, ya que defiende la creación de un modelo situacional y la constante búsqueda de significado en la que incurren los lectores, otorgando más peso al conocimiento del mundo.